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Generic Cost Estimates for the Disposal of Radioactive Wastes

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Prepared for
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Commission

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ABSTRACT

NRC regulatory impact analyses address the costs and benefits associated with proposed regulatory requirements. Many of these requirements will result in physical modifications to existing structures and systems at nuclear power plants.

This report provides a methodology and data needed to estimate the generic costs of disposing of radioactive wastes that may be generated as a result of NRC regulations requiring modifications or repairs to nuclear facilities. Also presented are descriptions of typical low-level radioactive wastes generated at nuclear power plants and the various processes used to treat the wastes in preparation for shipment and burial. The waste disposal cost estimates included in this report cover all the major elements that contribute to the overall costs. The key factors that influence the costs are discussed. Pertinent ranges of values for the key variables are explored and important sensitivities identified. The cost implications of the burial surcharges authorized by the Low-Level Radioactive Waste Policy Amendments Act of 1985 are covered. Occupational radiation exposure associated with in-plant handling of the wastes is also discussed.

This report updates and revises information presented in NUREG/CR-4555.

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PREFACE

In early 1986, Congress passed and the President signed into law legislation changing the requirements imposed on the disposal of low-level radioactive wastes. This new legislation supports the formation of regional compacts of waste-producer states and encourages the development of regional waste disposal sites. While the law permits access to the three existing burial sites in Nevada, South Carolina, and Washington until 1993, it also allows for a system of disposal cost surcharges for those generators in compacts or states which do not have a licensed disposal facility. These surcharges, discussed in Section 5.2.4.2 of this report, add significantly to the total disposal costs of low-level radioactive waste.

SEA had previously performed a study[1] for the U.S. Nuclear Regulatory Commission to estimate the generic costs of disposing of low-level wastes. In the past two years, the various cost elements of the generic cost model have increased dramatically. Therefore, the NRC asked SEA to revisit the generic cost model, update the model, and, in particular, assess the impact of the new burial surcharges. The result is this revision to the original report.

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[1]NUREG/CR-4555, Generic Cost Estimates for the Disposal of Radioactive Wastes, March 1986.

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Appreciation is also due to Mrs. Rose Flores for her courageous efforts in preparing the text and graphics for this report.

NOMENCLATURE

BWR	Boiling Water Reactor
CONCLIQ	Concentrated Liquids
COTRASH	Compactible Trash
DAW	Dry Active Waste
FSLUDGE	Filter Sludge
HTGR	High Temperature Gas-Cooled Reactor
IXRESIN	Ion-Exchange Resin
LSA	Low Specific Activity
NCTRASH	Noncompactible Trash
PVC	Polyvinyl Chloride
PWR	Pressurized Water Reactor
RWP	Radiation Work Permit
VRF	Volume Reduction Factor

1.0 EXECUTIVE SUMMARY

Many pending and proposed Nuclear Regulatory Commission (NRC) regulations may require operating nuclear facilities to undergo hardware or material related modifications. The repairs and/or modifications to such materials or equipment in these facilities will likely generate radioactive wastes as a byproduct of these efforts. The costs of disposing of these radioactive wastes should be included in the value-impact assessments of these pending NRC requirements.

The NRC's Regulation Development Branch, Office of Nuclear Regulatory Research,[1] sponsored this study. Its purpose is to provide an analyst with estimates of the generic costs of disposing of radioactive wastes that may be generated as a result of NRC regulations requiring modifications or repairs to nuclear facilities. This report also presents descriptions of typical low-level radwastes generated at nuclear power plants. The various processes used to treat the wastes in preparation for shipment and burial are also described.

In order to estimate the costs of disposing of radioactive waste associated with a particular repair or modification, one must first estimate the type and quantity of waste generated. Procedures are outlined herein to carry out this aspect of the estimation effort.

The waste disposal cost estimates included in this report cover all of the major elements that contribute to the overall costs. The key factors that influence the costs are discussed. Pertinent ranges of values for the key variables have been explored and important sensitivities identified.

Table 1.1 presents the representative or most typical total estimated disposal costs (with and without surcharges) for each type of waste likely to be generated as a result of repairs or modifications at nuclear plants. The estimates are per 1000 ft^3 of as-generated waste and represent conditions consistent with typical or prevalent waste treatment processes and waste characteristics. Table 1.1 gives the user a feel for the approximate level of the waste disposal costs and for the difference in the costs among the different waste types. The estimated disposal costs can vary significantly, depending on the specific characteristics of the waste. The more information the NRC user has, the more refined the analyst can make the estimates by using the data and sensitivities presented in this report. The costs presented in Table 1.1 assume that the transport distance from the plant to the waste disposal site is 1000 miles.

Section 1.1, which follows, discusses the various types of low-level radwastes which may be produced as a consequence of NRC requirements. It also introduces the various volume reduction processes used to treat the different wastes. Section 1.2 briefly outlines an approach for estimating the volume of waste generated. Section 1.3 then discusses waste disposal costs. An algorithm for estimating occupational radiation exposure incurred in handling radioactive waste is presented in Section 1.4. Finally, suggested procedures for using the cost and personnel radiation exposure information provided herein are outlined in Section 1.5.

1.1 RADIOACTIVE WASTE TYPES AND VOLUME REDUCTION PROCESSES

1.1.1 Waste Types

There are several different types of wastes which could be generated as a result of NRC-required modifications or repairs to nuclear power plants. The different types of wastes

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[1] Formerly the Cost Analysis Group, Office of Resource Management.

Table 1.1

Summary of Total Cost Estimates for the Disposal of Low Level Radioactive Wastes (1988 dollars)

Cost per 1000 cubic feet of As-Generated Waste (rounded to the nearest $100)

	Total Cost Assuming Typical Waste Activity Level and Most Prevalent Volume Reduction Processes**	Total Cost (Including $\$20/ft^3$ Surcharges) Assuming Typical Waste Activity Level and Most Prevalent Volume Reduction Processes**
<u>WET WASTES</u>		
Noncompactible Trash		
BWR	$257,800 *	$332,800*
PWR	$255,700 *	$330,700*
Compactible Trash		
BWR	$15,000 *	$19,400*
PWR	$15,000 *	$19,400*
<u>WET WASTES</u>		
Ion Exchange Resins		
BWR	$162,700 *	$187,300*
PWR	$143,700 *	$168,300*
Concentrated Liquids		
BWR	$182,600	$210,800
PWR	$98,900	$127,100
Filter Sludge		
BWR	$232,400	$268,100
PWR	$193,000	$228,700

* Cost Estimate is an average cost based on the two most prevalent volume reduction (waste treatment) processes available for this waste stream

** Based on a transport distance from the plant to the waste disposal site o[illegible]00 miles.

are generally referred to as waste streams. Each stream is relatively distinct in terms of its form (wet or dry, compactible or noncompactible), its chemical makeup, and its radionuclide content and concentration. For the purposes of this study, the following waste streams have been pursued:

Waste Types	Symbol
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-NCTRASH
PWR Ion-Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
BWR Ion-Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE

Compactible and noncompactible trash are normally referred to as dry active wastes (DAW). These waste streams are those most likely to be generated as a result of NRC-mandated modifications or repairs to the plants. The other wastes may also be generated as a result of activities such as system drainage to accomplish the modifications, system flushing and decontamination, area washdown, and laundering.

Noncompactible trash is the waste stream of primary interest to this study. This is because the noncompactible trash is made up of the hardware and components which are most commonly the subject of the repair or modification efforts. Other wastes such as compactible trash are normally generated as a by-product of the repair, removal, replacement, or modification efforts. Noncompactible trash typically consists of materials such as conduit, piping, valves, wood, hardware equipment, tools, concrete, dirt and glass. This waste is not amenable to extensive volume reduction.

The other waste stream expected to be produced from repairs and modifications to nuclear plants is compactible trash. Large quantities of this waste are typically generated at most plants. Compactible trash is made up of the following types of materials: plastic, paper, absorbent materials, polyvinyl chloride, cloth, rubber and wood shavings.[1] This waste stream is amenable to considerable volume reduction.

Ion-exchange resins, concentrated liquids, and filter sludges are classified as wet wastes. They are generated as a result of filtering and purification efforts for radioactive liquids. Ion-exchange resins are small porous beads used to process various liquid waste streams through a combination of absorption and/or adsorption of soluble ionic material (both chemical and radiochemical), and through the filtration of insoluble material. Resins used for cleanup of liquid radwaste streams are generally disposed of as waste once they have lost their filtering and demineralizing qualities.

Many nuclear plants have employed evaporator systems to reduce the volume of liquid radwastes. Concentrated liquid wastes are a combination of the liquid stream and accumulations of solids and solutes carried in the stream. Concentrators (evaporators) are used in processing laundry waste water, decontamination solutions, liquids from floor drains, and other such sources.

Filter sludges refer to powdered ion-exchange resin generally used as a precoat material on filter demineralizers, and flocculating agents (filter aids) used to extend the

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[1] Solid wood pieces are sometimes disposed as compactible trash.

processing life of the filter. Most plants use powdered resin not only for filtration of insoluble material but also for its ion-exchange properties. Sludge from precoat filters can be a combination of the original precoat material, insolubles such as dirt removed from the liquid stream being processed, corrosion particles, and other suspended solids and flocculating agents used in the system.

An important characteristic of each radwaste stream is its radionuclide content. The following tabulation indicates the typical activity concentration for each waste type in its as- generated state, i.e., prior to any compaction or other processing (Ref. 1).

Typical Activity Concentration, Ci/ft^3

Stream	BWRs	PWRs
Noncompactible Trash	0.00133	0.00267
Compactible Trash	0.00011	0.000185
Ion-Exchange Resins	0.176	0.11
Concentrated Liquids	0.17	0.01
Filter Sludges	0.23	0.07

This tabulation indicates that the activity concentrations from one waste type to another can be different by several orders of magnitude.

1.1.2 Volume Reduction Processes

Radioactive waste volume reduction processes have always been employed at nuclear power plants. Volume reduction is attractive from practical as well as economic standpoints. In recent years, the costs of disposing of low-level radioactive wastes have risen dramatically. This is particularly true of burial costs (Ref. 2). Since burial costs are generally assessed on a per-unit-volume basis (i.e., $\$/ft^3$), in general, the lower the volume of waste from a given plant requiring burial the lower the disposal costs to that plant. Thus there is an incentive for nuclear utilities to improve their effectiveness in reducing the volume of radioactive wastes which must ultimately be disposed.

Enhanced volume reduction efforts have occurred on two fronts. First, the problem of waste generation is getting renewed attention at nuclear plants. Utilities are changing their procedures and administrative controls to help reduce the amount of low-level wastes generated. Second, once waste has been generated it is generally subjected to some type of volume change process. For compactible trash, the as-shipped volume is less than the as-generated volume. For wet wastes, the processing may either increase or decrease the final volume. For example, solidification of spent resin in cement increases the volume to be disposed, while incineration processes can substantially decrease the final volume.

Table 1.2 summarizes the various waste processing systems and associated volume reduction or increase factors for each waste stream. This table emphasizes the fact that a given volume reduction factor for a given waste stream applies to a specific waste processing system. In some cases different systems employing the same basic technique, e.g., evaporation, will reduce the volume of a given waste stream to different extents. An example of this is shown for the concentrated liquid waste stream (CONCLIQ). Three different evaporation systems are noted, each resulting in a different final volume for the processed waste. Also, with this particular waste stream the extent of volume reduction achieved by a given system is dependent on whether the waste stream was generated in a BWR or a PWR.

Table 1.2 Waste Processing Techniques and Associated Volume Reduction Factors

Waste Stream	Volume Reduction Factor *	Processing Technique
COTRASH	2.3	Standard Compactor
	3.8	Standard Compactor, complete filling of waste containers
	5.7	Improved Compactor
	8.7	Supercompactor
	113.4	Incinerator, solidification of ash
NCTRASH	0.2	Hand packing
	0.4	Careful hand packing
	0.6	Cutting plus careful hand packing
	0.8	Cutting, careful hand packing, and supercompactor
IXRESIN	0.7	Solidification in Cement
	0.95	Dewatered, placed in high integrity containers
	1.4	Mobile evaporator, solidification in binder
	2.0	Evaporation of water, grinding of resins, mixing with binder
	4.0	Incineration, mising ash with binder
CONCLIQ	BWR/PWR	
	0.7/0.7	Solidification in cement
	1.9/3.7	Evaporator/crystallizer process, solidification in binder
	2.4/5.4	Mobile evaporator, solidification in binder
	3.8/6.6	Evaporator, grinding of residue, solidification in binder
	4.5/10.4	Dryer/incinerator, solidification in binder
FSLUDGE	0.56	Solidification in cement
	2.0	Evaporator, solidification in binder
	4.0	Incinerator, solidification in binder

$$\text{* Volume Reduction Factor (VRF)} = \frac{\text{Untreated (As-generated) Waste Volume}}{\text{Packaged (As-shipped) Waste Volume}}$$

3.2 ESTIMATION OF WASTE VOLUME GENERATION

The foregoing discussions indicated that in order to develop estimates of the cost of disposing of radioactive waste, it is necessary to know the volume of waste generated. In the case of NRC-initiated plant modifications, this capability to predict waste volume generation will be required for a very wide range of specific tasks. Moreover, since the cost of waste disposal depends upon the type of waste handled, it will be necessary to predict the waste types generated as well as the volumes. Predicting waste volume generation by specific task is difficult because very few of the operating nuclear stations track waste volume generation by source within the plant.

Based upon visits to two nuclear stations that do track waste volume generation by source within the plant, supplemented by discussions with waste handling equipment vendors and information in the open literature, some simple notions relating to the estimation of waste volume generation have been outlined.

In general, the primary waste stream for a plant modification is noncompactible dry active waste (P- or B- NCTRASH). The first step in the estimation of the volume of this primary waste stream is to evaluate the actual physical volume of the identifiable plant components and materials that will be removed/replaced and thus become waste. The next step is to determine the packing fraction of the constituents in the shipping containers. To estimate packing fraction, the optimum configuration of the constituents in the box is estimated. The packing fraction is the ratio of the volume of the constituents to the volume of the box. Typical packing fractions for noncompactible trash are estimated to be on the order of 0.75.

The volume of compactible DAW (P- or B-COTRASH) generated in the course of a specific task is difficult to estimate. This is because this waste stream is composed mostly of paper and plastic (including PVC). The quantities of disposable paper and plastic generated in the course of a task is a function of general housekeeping considerations at any particular plant, and cannot be derived from first principles.

Reference 1 presents data obtained from a significant portion of the industry in 1981 on as-shipped volumes of compactible and noncompactible wastes generated. From these data, the following ratios can be derived:

$$\text{At PWRs:} \quad \frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} \approx 0.9$$

$$\text{At BWRs:} \quad \frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} \approx 2.1$$

Given the estimated volume of noncompactible DAW generated, these ratios can be used to estimate the associated volume of compactible DAW generated. The volumes used in deriving the above ratios are those for the as-shipped (i.e., after processing) condition.

To provide analogous estimates for the as-generated condition, the as-shipped volumes should be adjusted according to the appropriate volume reduction factors. For example, for both BWRs and PWRs typical volume reduction factors for non- compactible trash are about 0.2 to 0.4, while those for compactible trash are about 3.8 to 5.7. The ratio of the as-generated compactible trash volume to the volume of non- compactible trash generated at each type of plant can be approximated as follows:

At PWRs:

$$\frac{\text{As-Generated Volume Compactible DAW}}{\text{As-Generated Volume Noncompactible DAW}} \approx \frac{0.9 \times (3.8 + 5.7)}{(0.2 + 0.4)} = 14.3$$

At BWRs:

$$\frac{\text{As-Generated Volume Compactible DAW}}{\text{As-Generated Volume Noncompactible DAW}} \approx \frac{2.1 \times (3.8 + 5.7)}{(0.2 + 0.4)} = 133.3$$

The volumes of wet wastes generated as a result of repairs or modifications can vary widely from one job to the next. Since wet wastes are not the primary focus of the present effort, discussions of volume estimation for these wastes are reserved for Section 4.0.

Table 1.3 summarizes several of the considerations and guidelines which should be taken into account in estimating waste volumes.

1.3 WASTE DISPOSAL COSTS

1.3.1 Major Cost Elements

There are four primary cost elements that contribute to the costs of disposing of low-level radioactive wastes generated at nuclear power plants. These elements are those associated with processing, interim-storage, transportation, and burial of the wastes. Processing encompasses all activities and costs associated with converting and/or packaging raw wastes (as- generated) into states or conditions wherein they are suitable for storage, transportation, and burial. Processing usually occurs at the plant site.

The uncertainty in the availability of permanent burial sites for low level radioactive wastes has caused many nuclear utilities to plan for interim on-site storage of these wastes. The present cost assessment includes costs associated with such storage. These are capital costs of the structures needed to safely store the wastes until permanent burial is accomplished.

Transportation costs encompass all activities necessary to transport radioactive waste from the nuclear plant to the burial site. They include shipping charges and fees associated with shielded van or cask rental if such items are needed.

The final cost element is that associated with burial of the wastes. Burial costs include the fees charged for cask handling, waste handling, burial of the radioactive materials, and fees such as those set up to provide perpetual care of the burial sites. The Low-Level Waste Policy Amendments Act of 1985 (Ref. 7) has also added a system of surcharges to compensate the states with waste disposal sites in order to permit access to these facilities until new regional burial sites are in operation. Other fees and taxes are also assessed by some of the states with commercial low-level radioactive waste burial sites.

1.3.2 Costs and Basis

The quantitative cost estimates generated during this study are summarized in this section. Prior to reviewing the costs, however, it is important to discuss the bases, key assumptions, and key parameters used in generating the costs.

There are four primary variables or key factors that have prominent influences on waste disposal costs. These key factors are:

TABLE 1.3 Summary Approach to Waste Volume Estimating *

WASTE STREAM	COMPONENTS	APPROACH	QUANTITATIVE GUIDANCE
Noncompactible DAW (P- or B-NCTRASH)	Piping, conduit, insulation valves, pumps, cable trays, concrete, dirt, etc.	1. Estimate physical volume of plant components.	Use geometry.
		2. Estimate approximate VRF (packing fraction) in waste containers.	Range of 0.2 to 1.2 in ~100 ft^3 boxes. (Typical values are 0.2 to 0.4)
		3. Might be able to decontaminate and recycle at a lower cost.	Overall, estimated cost of recycle ≈ 80-85% cost of disposal
Compactible DAW (P- or B-COTRASH)	Largely paper and plastic.	Correlation based on 1981 data for industry-wide, as-shipped volumes of compactible and noncompactible DAW	BWRs: $\frac{\text{Vol Comp DAW}}{\text{Vol Noncomp DAW}} \approx 2.1$
			PWRs: $\frac{\text{Vol Comp DAW}}{\text{Vol Noncomp DAW}} \approx 0.9$
Ion Exchange Resin (P- or B-IXRESIN)	From cleanup of primary system, fuel pool water, or plant drain water.	Depletion of resin is a function of concentration of dissolved solids in liquid stream.	For ~2 µmho conductivity: ~1.5 ft^3 of waste/10^5 gal.
			For ~150 µmho conductivity: ~1.5 ft^3 of waste/10^3-10^4 gal.
	From cleanup of decontamination solution.	Depletion of resin is a function of volume and condition of system being decontaminated, and the decon solution used.	For LOMI decon solution: ~0.1 ft^3 of waste/gal. decon soln.
Filters	From decontamination of personnel respirators.	Use actual data.	~$1x10^{-3}$ ft^3 of waste/respirator deconned (~1/2 comp. & ~1/2 non-comp.)
	From laundering protective clothing.	Use actual data.	~$2x10^{-3}$ ft^3 of waste/dressout (all compactible)

* Volumes and ratios are given on as-shipped basis. To estimate on as-generated basis, use following relationship with appropriate volume reduction factors (VRF): As-Generated Volume = As-Shipped Volume x VRF

- Reactor type (BWR and PWR)
- Waste type (NCTRASH, COTRASH, IXRESIN, CONCLIQ and FSLUDGE)
- Activity level (Low, Typical, High and Very High)
- Extent of volume reduction (3 to 5 different volume reduction factors for each waste type).

Each of these factors was essentially treated as an independent variable. Costs were calculated for all applicable combinations of these parameters. In addition, for each case transportation distance was treated as an independent variable and costs were calculated for several distinct one-way distances from the nuclear plant to the burial site.

All costs presented in this section represent the costs to dispose of 1000 cubic feet of as-generated waste for each waste stream. This is the volume of the waste in its as-generated condition, i.e., prior to any type of processing to reduce its volume, solidify it, or otherwise treat it. The selection of the 1000 ft^3 reference volume is arbitrary, but reasonable. Costs for volumes other than this can be estimated using linear scaling.

Tables 1.4 and 1.5 summarize the waste disposal costs for each waste stream. BWR wastes are treated in Table 1.4 and PWR wastes in Table 1.5. Each table shows costs for each waste stream, for low, typical, high and very high activity levels, and for each applicable volume reduction factor. Costs for processing, transport, storage, and burial, as well as the total costs, are displayed. In these tables the transportation distance has been set at 1,000 miles.

The following bases were used in generating the cost estimates shown in Tables 1.4 and 1.5.

- The costs are for the disposal of 1000 ft^3 of as-generated wastes; i.e., given 1000 ft^3 of waste prior to processing, the table shows estimates of the costs to process (including volume reduction), store, transport, and bury the wastes, as well as the total costs.

- The typical activity of each waste stream is as discussed in Section 1.1.1. The low activity cases are a factor of 10 less than the typical, the high activity cases are a factor of 10 greater than the typical, and the very high are a factor of 100 greater than for the typical waste conditions.

- All costs shown in Tables 1.4 and 1.5 are based on an assumed one-way transport distance from the plant to the disposal site of 1000 miles. Cost adjustments for distances other than 1000 miles can be made using the information provided in Appendix B.

- The use of 7.5-ft^3 disposal containers is assumed throughout. For certain of the waste streams larger containers are typically used. However, the specific container size used is believed to play a minor role in the overall costs.

- Burial costs are based on average costs for the three commercial low-level waste disposal sites available in the United States. Site-specific burial costs are presented in Appendix C.

- Even though the costs of facilities for interim on-site storage are included in the tables, all costs are treated as if they are present day costs. Therefore, transportation and burial costs, even though they might in reality occur several months or years after the waste is processed, are assumed to occur immediately and are not discounted.

Table 1.4 Estimated Cost for the Disposal of Low Level Radioactive Wastes (BWRs) 7/88

B-NCTRASH WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.2	$106,908	$14,591	$50,862	$162,951	$335,311
	0.4	$64,250	$8,992	$25,469	$81,597	$180,309
	0.6	$50,087	$8,672	$17,005	$100,721	$176,485
	0.8	$43,908	$8,596	$12,735	$75,428	$140,667
TYPICAL	0.2 *	$106,908	$14,591	$50,862	$162,951	$335,311
	0.4 *	$64,250	$8,992	$25,469	$81,597	$180,309
	0.6	$50,087	$8,672	$17,005	$100,721	$176,485
	0.8	$43,908	$8,596	$12,735	$75,428	$140,667
HIGH	0.2	$106,908	$14,591	$56,049	$162,951	$340,498
	0.4	$64,250	$8,992	$28,066	$81,597	$182,906
	0.6	$50,087	$8,672	$18,739	$100,721	$178,219
	0.8	$43,908	$8,596	$14,033	$75,428	$141,965
VERY HIGH	0.2	$106,908	$131,653	$56,049	$234,718	$529,328
	0.4	$64,250	$65,925	$28,066	$120,141	$278,382
	0.6	$50,087	$44,016	$18,739	$126,455	$239,297
	0.8	$43,908	$32,963	$14,033	$98,486	$189,390

Cost per 1000 cubic feet of As-Generated Waste

* Typical Conditions

** Based on 1000 mile distance

Table 1.4 Estimated Cost for the Disposal of Low Level Radioactive Wastes (BWRs) (cont.) 7/88

B-COTRASH WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	2.27	$9,159	$1,291	$4,499	$14,414	$29,362
	3.78	$5,555	$788	$2,745	$8,795	$17,882
	5.67	$3,911	$525	$1,830	$5,863	$12,129
	8.69	$3,355	$364	$1,220	$3,909	$8,848
	113.4	$2,880	$58	$153	$489	$3,580
TYPICAL	2.27	$9,159	$1,291	$4,499	$14,414	$29,362
	3.78 *	$5,555	$788	$2,745	$8,795	$17,882
	5.67 *	$3,911	$525	$1,830	$5,863	$12,129
	8.69	$3,355	$364	$1,220	$3,909	$8,848
	113.4	$2,880	$58	$168	$489	$3,595
HIGH	2.27	$9,159	$2,769	$4,958	$15,669	$32,554
	3.78	$5,555	$1,690	$3,025	$9,561	$19,830
	5.67	$3,911	$1,280	$2,017	$6,430	$13,637
	8.69	$3,355	$1,252	$1,344	$4,431	$10,382
	113.4	$2,880	$395	$168	$719	$4,162
VERY HIGH	2.27	$9,159	$11,645	$4,958	$21,000	$46,762
	3.78	$5,555	$7,106	$3,025	$13,094	$28,780
	5.67	$3,911	$4,737	$2,017	$8,730	$19,394
	8.69	$3,355	$4,880	$1,344	$6,670	$16,249
	113.4	$2,880	$789	$168	$1,382	$5,219

Cost per 1000 cubic feet of As-Generated Waste

* Typical Conditions

** Based on 1000 mile distance

Table 1.4 Estimated Cost for the Disposal of Low Level Radioactive Wastes (BWRs) (cont.)

B-I-SLUDGE WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.56	$39,784	$24,744	$20,083	$68,390	$153,001
	2	$26,030	$13,225	$5,630	$24,100	$68,985
	4	$28,943	$10,370	$2,857	$14,173	$56,343
TYPICAL	0.56 *	$39,784	$72,895	$20,083	$99,627	$232,390
	2	$26,030	$26,417	$5,630	$37,231	$95,308
	4	$28,943	$13,466	$2,857	$24,285	$69,491
HIGH	0.56	$39,784	$94,234	$20,083	$200,268	$354,370
	2	$26,030	$56,699	$5,630	$115,075	$203,434
	4	$28,943	$28,773	$2,857	$66,564	$127,137
VERY HIGH	0.56	$39,784	$202,254	$20,083	$468,616	$730,737
	2	$26,030	$56,699	$5,630	$165,241	$253,599
	4	$28,943	$28,773	$2,857	$85,025	$145,597

Cost per 1000 cubic feet of As-Generated Waste
* Typical Conditions
** Based on 1000 mile distance

B-CONCLIQ WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.71	$31,100	$18,907	$15,798	$53,594	$119,400
	1.9	$36,569	$14,014	$5,966	$24,965	$81,535
	2.4	$17,476	$11,053	$4,706	$20,143	$53,378
	3.8	$23,527	$7,106	$3,025	$12,949	$46,607
	4.5	$28,875	$5,921	$2,521	$10,912	$48,229
TYPICAL	0.71 *	$31,100	$57,340	$15,798	$78,368	$182,606
	1.9	$36,569	$21,655	$5,966	$39,454	$103,645
	2.4	$17,476	$17,080	$4,706	$31,119	$70,380
	3.8	$23,527	$14,194	$3,025	$21,651	$62,397
	4.5	$28,875	$11,829	$2,521	$21,428	$64,652
HIGH	0.71	$31,100	$74,126	$15,798	$157,519	$278,543
	1.9	$36,569	$60,084	$5,966	$104,599	$207,218
	2.4	$17,476	$47,390	$4,706	$82,537	$152,109
	3.8	$23,527	$30,465	$3,025	$61,877	$118,894
	4.5	$28,875	$25,388	$2,521	$51,593	$108,376
VERY HIGH	0.71	$31,100	$159,095	$15,798	$368,480	$574,473
	1.9	$36,569	$60,084	$5,966	$174,318	$276,937
	2.4	$17,476	$47,390	$4,706	$137,856	$207,428
	3.8	$23,527	$30,465	$3,025	$89,241	$146,258
	4.5	$28,875	$25,388	$2,521	$74,656	$131,439

Cost per 1000 cubic feet of As-Generated Waste
* Typical Conditions
** Based on 1000 mile distance

Table 1.4 Estimated Cost for the Disposal of Low Level Radioactive Wastes (BWRs) (cont.)

B IXRESIN WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.71	$31,553	$20,063	$15,798	$55,578	$122,982
	0.95	$21,912	$13,787	$11,848	$41,129	$88,676
	1.4	$25,733	$18,949	$8,067	$33,306	$86,055
	2	$42,179	$13,225	$5,630	$24,100	$85,134
	4	$29,093	$6,711	$2,857	$12,230	$50,891
TYPICAL	0.71 *	$31,553	$57,340	$15,798	$78,368	$183,059
	0.95 *	$21,912	$43,005	$11,848	$65,620	$142,385
	1.4	$25,733	$29,280	$8,067	$51,348	$114,429
	2	$42,179	$20,435	$5,630	$37,231	$105,475
	4	$29,093	$13,406	$2,857	$20,448	$65,804
HIGH	0.71	$31,553	$74,126	$15,798	$157,527	$279,004
	0.95	$21,912	$55,594	$11,848	$137,785	$227,139
	1.4	$25,733	$81,240	$8,067	$118,029	$233,069
	2	$42,179	$56,699	$5,630	$98,723	$203,231
	4	$29,093	$28,773	$2,857	$58,456	$119,178
VERY HIGH	0.71	$31,553	$159,095	$15,798	$368,552	$574,998
	0.95	$21,912	$119,321	$11,848	$276,865	$429,946
	1.4	$25,733	$81,240	$8,067	$235,159	$350,200
	2	$42,179	$56,699	$5,630	$164,667	$269,174
	4	$29,093	$28,773	$2,857	$84,451	$145,173

Cost per 1000 cubic feet of As-Generated Waste
* Typical Conditions
** Based on 1000 mile distance

Table 1.5 Estimated Cost for the Disposal of Low Level Radioactive Wastes (PWRs)

P-NCTRASH WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.2	$103,578	$14,591	$50,862	$162,951	$331,981
	0.4	$62,584	$9,742	$25,469	$81,597	$179,393
	0.6	$48,977	$9,518	$17,005	$100,721	$176,221
	0.8	$42,206	$9,427	$12,735	$75,428	$139,796
TYPICAL	0.2 *	$103,578	$14,591	$50,862	$162,951	$331,981
	0.4 *	$62,584	$9,742	$25,469	$81,597	$179,393
	0.6	$48,977	$9,518	$17,005	$100,721	$176,221
	0.8	$42,206	$9,427	$12,735	$75,428	$139,796
HIGH	0.2	$103,578	$36,685	$56,049	$180,800	$377,111
	0.4	$62,584	$33,591	$28,066	$96,779	$221,020
	0.6	$48,977	$32,707	$18,739	$115,073	$215,496
	0.8	$42,206	$32,658	$14,033	$89,525	$178,422
VERY HIGH	0.2	$103,578	$203,435	$56,049	$311,826	$674,888
	0.4	$62,584	$101,870	$28,066	$167,507	$360,028
	0.6	$48,977	$68,015	$18,739	$173,575	$309,306
	0.8	$42,206	$50,935	$14,033	$129,987	$237,161

Cost per 1000 cubic feet of As-Generated Waste

* Typical Conditions

** Based on 1000 mile distance

P-COTRASH WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	3.78	$5,555	$788	$2,745	$8,795	$17,882
	5.67	$3,911	$525	$1,830	$5,863	$12,129
	8.69	$3,355	$364	$1,220	$3,909	$8,848
	113.4	$2,880	$58	$153	$489	$3,580
TYPICAL	3.78 *	$5,555	$788	$2,745	$8,795	$17,882
	5.67 *	$3,911	$525	$1,830	$5,863	$12,129
	8.69	$3,355	$364	$1,220	$3,909	$8,848
	113.4	$2,880	$201	$168	$570	$3,819
HIGH	3.78	$5,555	$1,690	$3,025	$9,561	$19,830
	5.67	$3,911	$1,280	$2,017	$6,489	$13,697
	8.69	$3,355	$1,252	$1,344	$4,489	$10,441
	113.4	$2,880	$610	$168	$834	$4,492
VERY HIGH	3.78	$5,555	$10,980	$3,025	$15,530	$35,089
	5.67	$3,911	$7,320	$2,017	$10,353	$23,601
	8.69	$3,355	$4,880	$1,344	$7,446	$17,026
	113.4	$2,880	$789	$168	$1,676	$5,513

Cost per 1000 cubic feet of As-Generated Waste

* Typical Conditions

** Based on 1000 mile distance

Table 1.5 Estimated Cost for the Disposal of Low Level Radioactive Wastes (PWRs) (cont.)

P-IXRESIN WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.71	$31,553	$5,875	$15,798	$45,929	$99,155
	0.95	$21,912	$13,787	$11,848	$40,052	$87,599
	1.4	$25,733	$7,509	$8,067	$26,937	$68,246
	2	$42,179	$5,615	$5,630	$18,953	$72,377
	4	$29,093	$6,711	$2,857	$12,230	$50,891
TYPICAL	0.71 *	$31,327	$37,108	$15,798	$67,624	$151,856
	0.95 *	$21,912	$43,005	$11,848	$58,776	$135,541
	1.4	$25,382	$29,280	$8,067	$43,283	$106,012
	2	$41,786	$20,435	$5,630	$31,181	$99,032
	4	$29,093	$10,370	$2,857	$18,893	$61,214
HIGH	0.71	$31,553	$74,126	$15,798	$129,909	$251,386
	0.95	$21,912	$55,594	$11,848	$118,122	$207,477
	1.4	$25,733	$37,851	$8,067	$93,801	$165,453
	2	$42,179	$56,699	$5,630	$82,361	$186,869
	4	$29,093	$28,773	$2,857	$58,388	$119,111
VERY HIGH	0.71	$31,553	$159,095	$15,798	$323,357	$529,803
	0.95	$21,912	$119,321	$11,848	$276,188	$429,270
	1.4	$25,733	$81,240	$8,067	$188,403	$303,443
	2	$42,179	$56,699	$5,630	$163,990	$268,498
	4	$29,093	$28,773	$2,857	$83,774	$144,497

Cost per 1000 cubic feet of As-Generated Waste

* Typical Conditions

** Based on 1000 mile distance

P-CONCLIQ WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.71	$31,553	$5,576	$14,336	$45,929	$97,395
	3.7	$19,182	$820	$3,109	$9,039	$32,150
	5.4	$9,210	$1,630	$2,101	$6,805	$19,746
	6.6	$15,107	$583	$1,765	$5,130	$22,585
	10.4	$14,075	$1,307	$1,092	$3,706	$20,181
TYPICAL	0.71 *	$31,553	$5,576	$15,798	$45,929	$98,857
	3.7	$19,182	$7,303	$3,109	$13,309	$42,904
	5.4	$9,210	$4,935	$2,101	$9,093	$25,339
	6.6	$15,107	$4,145	$1,765	$7,554	$28,570
	10.4	$14,075	$2,566	$1,092	$5,023	$22,757
HIGH	0.71	$31,553	$37,108	$15,798	$67,624	$152,083
	3.7	$19,182	$11,285	$3,109	$20,561	$54,137
	5.4	$9,210	$9,857	$2,101	$15,616	$36,784
	6.6	$15,107	$8,280	$1,765	$12,629	$37,781
	10.4	$14,075	$5,126	$1,092	$10,891	$31,184
VERY HIGH	0.71	$31,553	$74,126	$15,798	$129,909	$251,386
	3.7	$19,182	$31,311	$3,109	$54,523	$108,126
	5.4	$9,210	$21,156	$2,101	$42,954	$75,421
	6.6	$15,107	$17,771	$1,765	$36,098	$70,740
	10.4	$14,075	$11,001	$1,092	$25,464	$51,633

Cost per 1000 cubic feet of As-Generated Waste

* Typical Conditions

** Based on 1000 mile distance

Table 1.5 Estimated Cost for the Disposal of Low Level Radioactive Wastes (PWRs) (cont.) 7/88

P-FSLUDGE WASTE STREAM COSTS (1988 dollars)

ACTIVITY LEVEL	VRFs	PROCESSING COSTS	TRANSPORTATION ** COSTS	STORAGE COSTS	BURIAL COSTS	TOTAL COSTS
LOW	0.56	$39,784	$7,211	$20,083	$58,389	$125,467
	2	$26,025	$5,241	$5,630	$18,556	$55,452
	4	$28,943	$6,711	$2,857	$11,965	$50,476
TYPICAL	0.56 *	$39,784	$47,174	$20,083	$85,969	$193,011
	2	$26,025	$20,435	$5,630	$28,903	$80,993
	4	$28,943	$10,570	$2,857	$18,893	$61,064
HIGH	0.56	$39,784	$72,895	$20,083	$132,810	$265,573
	2	$26,025	$56,699	$5,630	$67,862	$156,217
	4	$28,943	$28,773	$2,857	$50,079	$110,651
VERY HIGH	0.56	$39,784	$202,254	$20,083	$352,238	$614,359
	2	$26,025	$56,699	$5,630	$131,423	$219,777
	4	$28,943	$28,773	$2,857	$83,367	$143,939

Cost per 1000 cubic feet of As-Generated Waste
* Typical Conditions
** Based on 1000 mile distance

Tables 1.4 and 1.5 show costs for a range of volume reduction factors (VRFs) for each waste stream. The cases or VRFs which are believed to be most representative of current conditions and practices at light water reactors are indicated by an asterisk (*) following the pertinent VRF. For example, the cases with VRF=0.2 and VRF=0.4 are believed to be most representative of the way noncompactible trash is handled and disposed.

The trend over the past several years has been for nuclear utilities to improve their processing to increase volume reduction for most waste types. If this trend continues, the higher volume reduction factor cases shown in Tables 1.4 and 1.5 should become more prevalent in future years.

The tables indicate that waste disposal costs for noncompactible trash should be in the range of $140,000 to $675,000 per 1000 ft^3 of waste (for a transport distance of 1000 miles). The tables also indicate that these costs are quite similar between BWRs and PWRs, and that there are relatively modest differences in costs over the factor of 100 range from low to high activity levels. However, the disposal costs increase by about a factor of 2 if the waste activity is much higher than that for typical noncompactible wastes (~100 x typical).

The costs per 1000 ft^3 of disposing of compactible trash are estimated to be very much less than those for noncompactible trash. This is primarily due to the fact that the as-shipped volume of waste, given the same initial 1000 ft^3, is generally much less for this waste than for the noncompactibles. Also, its weight and activity levels are relatively low.

The wet waste categories (ion-exchange resins, concentrated liquids, and filter sludges) show fairly high disposal costs, especially when the high and very high activity cases are considered.

As noted above, the burial costs presented in Tables 1.4 and 1.5 are based on averages of the costs for burial at specific disposal sites. The burial costs can vary significantly from one site to another. Appendix C presents site-specific burial cost estimates.

The user of this document is cautioned that burial costs have escalated dramatically in the last several years. The average annual escalation rate has been on the order of 10 to 20%. Therefore, the cost analyst should consult with current burial rate schedules to determine changes in burial pricing compared to the pricing used herein.

Nuclear power plants in unsited states or regional compacts are also subject to significant surcharges in accordance with the Low Level Radioactive Waste Policy Amendments Act of 1985. For example, in 1988, a plant in a state or compact in compliance with federally mandated milestones for the development of regional disposal sites will pay a $20/ft^3$ surcharge. A plant in a state or compact not in compliance with the milestones pays a $80/ft^3$ surcharge. Meanwhile, a plant in a sited compact currently pays no surcharge. Because of the scattered nature of the sited and unsited states and compacts, these surcharges have not been incorporated into the generic estimating model. Section 5.2.4.2 provides a discussion of the milestones, surcharge rates, formula for including surcharges, and the status of states and compacts toward meeting the requirements of the new national policy.

Section 6.0 of this report presents a more complete discussion of the generic disposal costs for each waste stream. Cost sensitivities for each waste are also discussed.

1.4 OCCUPATIONAL RADIATION EXPOSURE

Any comprehensive evaluation of the costs incurred in handling the wastes generated as a result of regulatory requirements should include an estimate of the radiation exposures received by workers. Unfortunately, the data were not available to estimate exposures broken down by waste stream. However, using data submitted by licensees to the NRC, the following correlation has been derived (see Section 8.0 and Appendix A) to estimate the overall in-plant occupational radiation exposure associated with handling and processing wastes:

$$E = 1.2 \times V$$

where:

E = Occupational radiation exposure in person-rem
V = As-Shipped Volume of waste in thousands of cubic feet.

This correlation does not capture exposures incurred outside of the nuclear power plant, such as those associated with transportation or waste burial. Moreover, because it was derived from the overall exposure to all wastes handled during an annual period, it should be used with caution when it is necessary to consider the exposure associated with handling and processing wet waste streams.

1.5 SUGGESTED ESTIMATING PROCEDURES

The following listing briefly outlines the major steps which should be taken to effectively use the cost and radiation exposure information contained in this report. To estimate costs:

1. Define the type of wastes to be generated as a result of particular NRC requirements. This may require reviews of plant systems and components affected. If possible, determine the activity levels anticipated for each type of waste.

2. Estimate the quantities of each waste type expected. This is best ascertained by discussions with plant personnel of the plants impacted. Use the guidelines presented in Section 4.0 if estimates are not available. If the Section 4.0 guidelines are used, the quantities must be converted to the as-generated values in order to use the cost estimates presented herein. This requires the use of appropriate volume reduction factors.

3. Based on the plant waste type and activity level, determine the costs from Tables 1.4 and 1.5. If the degree of volume reduction achieved at the effected plants for each waste type is known, select the costs based on that volume reduction factor. If the specific VRF is not known, use the "average" values indicated in Tables 1.4 and 1.5.

4. Refinements, based on additional knowledge, are available to the analyst. For example:

   - If it is known that interim storage is not to be used, subtract the storage costs from the total costs.

   - If the specific burial site to be used is known, adjust the costs from Tables 1.4 and 1.5 to reflect site-specific burial costs. Appendix C presents the site-specific burial cost information for each waste stream.

- If the impacted nuclear plants and the specific burial sites are known, adjust the total costs obtained from Tables 1.4 and 1.5 to reflect actual transport distances anticipated. Determine the amount of the cost correction from Appendix B. Also, average distances from the five NRC regions to the three existing commercial low-level radwaste burial sites are discussed in Section 5.2.2.

- Surcharge costs have to be included for waste produced in all unsited states and regional compacts. These surcharges are \$20/ft^3 during 1988 and 1989, and \$40/ft^3 during and after 1990. A penalty surcharge of \$80/ft^3 for the second six-month period of 1988 will be assessed to all plants in states not in compliance with the 1986 legislation milestones. Appendix D includes a list of surcharge costs for each state by regional compact or present compliance status. Section 5.2.4.2 presents surcharge costs by VRFs for all waste streams. If a surcharge is applicable to the generic estimate being calculated, the following formula should be used:

$$\frac{\text{Surcharge}}{1000\ \text{ft}^3\ \text{Unproc. Waste}}\ [\$] =$$

$$\frac{1000\ \text{ft}^3\ \text{Unproc. Waste}}{\text{VRF}} \quad \times \quad \text{Surcharge Rate}\ [\$/\text{ft}^3]$$

5. After the foregoing refinements have been made, adjust the totals for each waste stream according to the expected waste volume. That is, multiply the costs per 1000 ft^3 by the ratio of:

$$\frac{\text{Actual Waste Volume (As-Generated)}[\text{ft}^3]}{1000\ \text{ft}^3}$$

To estimate occupational radiation exposure:

1. Estimate the total volume of as-shipped waste for each waste stream. The as-shipped volume is the as-generate waste volume divided by the applicable volume reduction factor for that stream:

$$\text{As-Shipped Volume} = \frac{\text{As-Generated Volume}}{\text{VRF}}$$

2. Determine the total volume of waste in the as-shipped condition by summing the volumes from (1) above over all applicable waste streams.

3. Multiply the total as-shipped waste volume generated as a result of the repair or modification of interest by the factor 1.2×10^{-3} person-rem/ft^3 For example,

Exposure [Person-rem] =

$$1.2 \times 10^{-3}\ \frac{\text{Person-rem}}{\text{ft}^3} \qquad \text{Total Volume (As-Shipped)}\ [\text{ft}^3]$$

2.0 INTRODUCTION

Many pending and proposed NRC regulations may require operating nuclear facilities to undergo hardware or material related repairs and modifications. These modifications to plant hardware and materials will likely generate low-level radioactive wastes. The costs of disposing of these wastes may need to be considered in value-impact assessments of the proposed regulations.

2.1 OBJECTIVES

The Regulation Development Branch within the USNRC's Office of Nuclear Regulatory Research authorized Science and Engineering Associates, Inc. (SEA) and its subcontractor, S. Cohen and Associates, Inc. (SC&A), to perform an assessment of the generic costs of disposing of low level radioactive wastes. The results of this assessment are presented in this report.

The specific objectives of this effort were as follows.

- Identify the types of waste likely to be generated as a result of NRC regulations on nuclear facilities.
- Determine the principal methods of disposal available to NRC licensees.
- Determine the most prevalent processing and disposal methods for each type of waste.
- Establish estimates of the costs of disposing of the different types of radioactive wastes.
- Determine the key factors which influence disposal costs.
- Present the resulting cost estimates in a readily understandable and easily used format.

The investigations aimed at satisfying the foregoing objectives pointed to yet another aspect of estimating the waste disposal costs. For a given NRC regulation, an estimate is needed of the quantity of each waste type likely to be generated. Investigators pursued this problem and established notions about how these waste quantities could be estimated. Given the waste types and the waste quantities, the disposal costs could then be assessed.

2.2 APPROACH

The basic approach used in this study was:

1. Perform a literature search. From this literature search, the various types of wastes generated at light water reactors were determined. This search also provided information as to waste compositions, typical radioactivity characteristics, and other important features of the wastes.

   The literature search provided information on the various processes used at nuclear plants and the effectiveness of each process in reducing the waste volume. Newer, more advanced processing methods were also identified.

Finally, the literature obtained identified the key cost elements that must be accounted for in estimating disposal costs.

2. Perform a survey of nuclear plant operators to establish current waste handling practice and future trends. This survey identified typical handling methods for each waste stream. It also helped identify the steps plants are taking to reduce the costs of low-level radwaste disposal.

3. Contact vendors and equipment and service suppliers to obtain present-day costs for the various materials and services needed to dispose of radioactive wastes.

4. Conduct nuclear plant visits to identify means for estimating waste quantities and the relationship, if any, between the generation of one type of waste and the generation of other waste types.

The foregoing sources and processes provided a means for establishing a cost estimating calculational model. They also identified the key variables and aspects which should be treated in order to produce comprehensive and meaningful cost estimates. This calculational model was constructed and exercised to produce estimates of disposal costs for each waste stream over a range of possible conditions.

For Revision 1 of this report, each of these basic steps was revisited with the objective of identifying significant changes, if any, that have taken place since the compilation of the original information. Changes have been made to the the original text to update the information to 1988 conditions. These changes are identified with a vertical bar in the right-hand margin. Tables and figures have also been updated with the current date shown in the upper right-hand corner for a complete revision or a vertical bar in the right-hand margin for changes or additions.

2.3 REPORT ORGANIZATION

Section 1.0 of this report is the Executive Summary. It presents, in an abbreviated fashion, the overall results accomplished in this study. The means for estimating the volume and type of wastes likely to be generated as a consequence of NRC requirements are discussed. It briefly describes the various waste types, the waste characteristics, and the processing methods applicable to each waste stream. Generic estimates of disposal costs for each waste are then presented in Section 1.0, along with a brief outline of a procedure for applying these estimates to a specific case.

Section 3.0 presents a description of the various types of low-level radioactive wastes. Characteristics such as composition, radionuclide content, and activity levels are discussed. The various processes used to treat each type of waste to prepare it for storage, transport, and burial are reviewed. A brief discussion of current trends and practices is also presented.

An approach and methodology for estimating waste volume generation is presented in Section 4.0. That section also discusses the general relationship between the quantity of one type of waste generated and the quantities of other wastes generated.

Section 5.0 discusses each of the various elements making up the total waste disposal costs. Each cost element is described, together with the basis and cost methodology. Section 5.2.4.2 contains an extensive discussion of the effects of the Low Level Radioactive Waste Policy Act of 1985 on the costs of radioactive waste disposal.

Section 6.0 presents a detailed assessment of the costs of disposing of each different type of waste. Costs are presented to cover a wide range of conditions. This section also identifies the key factors and sensitivities influencing the disposal costs for each waste type.

As a check on the usefulness and accuracy of the cost data present in this report, Section 7.0 presents a number of example cases where actual waste disposal costs reported by utilities are compared against the generic estimates. These cases also present useful examples of deriving disposal cost estimates to fit specific situations.

Section 8.0 discusses personnel radiation exposure associated with handling low-level radioactive wastes in light water reactor nuclear plants.

Finally, the report includes four appendices. Appendix A discusses personnel radiation exposure associated with handling low-level radioactive wastes in light water reactor nuclear plants. Appendix B presents data for adjusting costs based on transport distance from the nuclear plant to the burial site. Appendix C presents burial costs as a function of the specific sites presently available for burial of low-level radioactive wastes. Appendix D contains a list of nuclear power plants in each of the low-level radioactive waste regional compacts and independent states.

3.0 LOW-LEVEL RADWASTE CHARACTERISTICS AND VOLUME REDUCTION TECHNOLOGY

This section discusses the physical and radiological characteristics of the various waste streams that might be generated as a result of repair or modification activities at nuclear power plants. It also briefly reviews the volume reduction technologies available for treating the wastes. Both waste volume generation and volume reduction techniques are being carefully evaluated throughout the nuclear industry. Both can be considered to be in a state of flux at the present time. This section also discusses projected trends in both waste generation and volume reduction technologies.

3.1 WASTE CHARACTERIZATION

There are several different types of wastes which could be generated as a result of NRC-required modifications or repairs to nuclear power plants. The different types of wastes are generally referred to as waste streams. Each stream is relatively distinct in terms of its form (wet or dry, compactible or noncompactible), its chemical makeup, and its radionuclide content and concentration. For the purposes of this study, the following waste streams have been pursued:

Process Wastes & Trash	Symbol
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-NCTRASH
PWR Ion-Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
BWR Ion-Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE

Dry active wastes (DAW), compactible and noncompactible trash, are likely to be generated as a result of NRC-mandated modifications or repairs to the plants. The other wastes may also be generated as a result of activities such as system drainage to accomplish the modifications, system flushing and decontamination, area washdown, and laundering. The physical and chemical makeup of each waste stream was taken to be as defined in EPRI NP-3370 (Ref. 1).

EPRI NP-3370 presents the results of a survey taken in 1981 and 1982. The survey included two-thirds of the U.S. nuclear plants in operation as of December 1981. Waste volumes, waste characteristics, and waste processing system characteristics prevalent at that time were detailed for both BWRs and PWRs. This report gives general information on wastes generated during both periods of plant operation and plant shutdown. It does not specifically characterize wastes generated as part of NRC mandated repairs or modifications to nuclear plants.

Estimates of the radionuclide concentrations in each of the waste streams was based on information presented in Reference 2 and discussions with utility and radwaste support vendors. Tables 3.1 and 3.2 show these radionuclide concentrations and also give the total activity for each waste stream. In actual use of this data, the concentrations were adjusted to reflect the nominal (total) stream activity as reported in Reference 1.

TABLE 3.1

AS-GENERATED (UNTREATED) ISOTOPIC CONCENTRATIONS -- PWR

(Ci/m^3)

ISOTOPE	P-IXRESIN	P-CONCLIQ	P-FSLUDGE	P-COTRASH	P-NCTRASH
H-3	2.66E-03	2.86E-03	2.59E-03	3.04E-04	6.99E-03
C-14	9.74E-05	1.05E-04	9.55E-05	1.12E-05	2.57E-04
Cr-51*	7.66E-06	6.17E-05	1.01E-03	1.94E-05	4.48E-04
Mn-54*	3.45E-04	2.78E-03	4.57E-02	8.76E-04	2.02E-02
Fe-55	2.34E-03	1.88E-02	3.10E-01	5.97E-03	1.37E-01
Co-58*	2.23E-03	1.80E-02	2.95E-01	5.66E-03	1.30E-01
Ni-59	2.79E-06	2.25E-05	3.71E-04	7.11E-06	1.64E-04
Co-60	4.53E-03	3.65E-02	6.00E-01	1.15E-02	2.65E-01
Ni-63	8.61E-04	6.94E-03	1.14E-01	2.19E-03	5.05E-02
Nb-94	8.84E-08	7.12E-07	1.17E-05	2.25E-07	5.18E-06
Sr-90	1.94E-04	2.09E-04	1.89E-04	2.22E-05	5.11E-04
Tc-99	8.23E-07	8.88E-07	8.03E-07	9.42E-08	2.17E-06
Ru-106*	2.19E-05	2.37E-05	2.14E-05	2.51E-06	5.78E-05
Sb-125*	3.62E-05	2.92E-04	4.80E-03	9.20E-05	2.12E-03
I-129	2.44E-06	2.62E-06	2.37E-06	2.78E-07	6.41E-06
Cs-134*	2.1[illegible]E-02	2.37E-02	2.14E-02	2.51E-03	5.78E-02
Cs-135	8.23E-07	8.88E-08	8.03E-07	9.42E-08	2.17E-06
Cs-137	2.19E-02	2.37E-02	2.14E-02	2.51E-03	5.78E-02
Ce-144*	5.26E-05	5.68E-05	5.14E-05	6.02E-06	1.39E-04
Eu-154*	3.62E-06	2.92E-05	4.80E-04	9.20E-06	2.12E-04
Ra-226*	0	0	0	0	0
U-234*	9.77E-06	1.06E-05	3.05E-05	1.64E-06	3.78E-05
U-235	4.71E-08	5.10E-08	1.46E-07	7.89E-09	1.82E-07
U-238	3.71E-07	4.02E-07	1.15E-06	6.22E-08	1.43E-06
Np-237	9.06E-12	9.79E-12	2.81E-11	1.52E-12	3.49E-11
Pu-238	2.60E-05	4.25E-05	4.76E-05	5.97E-06	1.38E-04
Pu-239/240	1.82E-05	2.75E-05	1.55E-04	5.53E-06	1.27E-04
Pu-241	7.94E-04	1.20E-03	6.75E-03	2.41E-04	5.55E-03
Pu-242	3.99E-08	6.02E-08	3.39E-07	1.21E-08	2.79E-07
Am-241	1.87E-05	2.48E-05	2.64E-04	3.96E-06	9.12E-05
Am-243	1.26E-06	1.68E-06	1.78E-05	2.67E-07	6.15E-06
Cm-243	9.92E-09	9.71E-09	3.10E-07	2.74E-09	6.30E-08
Cm-244	1.38E-05	1.59E-05	1.77E-04	2.61E-06	6.00E-05
TOTAL	5.82E-01	1.35E-01	2.48E+00	3.20E-02	7.36E-01

* Not included in NRC source terms

TABLE 3.2

AS-GENERATED (UNTREATED) ISOTOPIC CONCENTRATIONS -- BWR

(Ci/m^3)

ISOTOPE	B-IXRESIN	B-CONCLIQ	B-FSLUDGE	B-COTRASH	B-NCTRASH
H-3	1.92E-03	4.78E-04	1.26E-02	6.75E-05	1.09E-02
C-14	1.19E-03	2.98E-05	7.78E-04	4.17E-06	6.73E-04
Cr-51*	2.69E-03	1.65E-04	4.07E-03	1.71E-05	2.74E-03
Mn-54*	1.21E-01	7.42E-03	1.84E-01	7.70E-04	1.23E-01
Fe-55	9.48E-01	5.82E-02	1.44E+00	6.01E-03	9.69E-01
Co-58*	7.82E-01	4.79E-02	1.19E+00	4.97E-03	7.97E-04
Ni-59	9.80E-04	6.02E-05	1.49E-03	6.21E-06	1.00E-03
Co-60	1.59E+00	9.73E-02	2.41E+00	1.01E-02	1.62E+00
Ni-63	2.15E-02	1.32E-0[illegible]	3.25E-02	1.36E-04	2.19E-02
Nb-94	3.09E-05	1.90E-06	4.70E-05	1.96E-07	3.16E-05
Sr-90	3.64E-03	9.04E-05	2.37E-03	1.27E-05	2.05E-03
Tc-99	7.65E-07	1.92E-06	5.00E-05	2.68E-07	4.33E-05
Ru-106*	2.04E-03	5.10E-05	1.33E-03	7.14E-06	1.15E-03
Sb-125*	1.27E-02	7.82E-04	1.93E-02	8.08E-05	1.30E-02
I-129	2.04E-04	5.10E-06	1.33E-04	7.14E-07	1.15E+00
Cs-134*	2.04E+00	5.10E-02	1.33E+00	7.14E-03	1.15E+00
Cs-135	7.65E-05	1.92E-06	5.00E-05	2.68E-07	4.33E-05
Cs-137	2.04E+00	5.10E-02	1.33E+00	7.14E-03	1.15E+00
Ce-144*	4.90E-03	[illegible].23E-04	3.19E-03	1.71E-05	2.76E-03
Eu-154*	1.27E-03	7.82E-05	1.93E-03	8.08E-06	1.30E-03
Ra-226*	0	0	0	0	0
U-234*	1.11E-05	5.47E-06	6.89E-05	2.53E-07	4.09E-05
U-235	5.33E-08	2.64E-08	3.32E-07	1.22E-09	1.97E-07
U-238	4.20E-07	2.08E-07	2.61E-06	9.60E-09	1.55E-06
Np-237	1.02E-11	5.07E-12	6.38E-11	2.35E-13	3.78E-11
Pu-238	8.34E-05	1.52E-04	4.66E-04	2.30E-06	3.71E-04
Pu-239/240	5.34E-05	7.23E-05	2.36E-04	1.16E-06	1.86E-04
Pu-241	2.60E-03	3.52E-03	1.15E-02	5.63E-05	9.08E-03
Pu-242	1.17E-07	1.58E-07	5.18E-08	2.53E-09	4.08E-07
Am-241	2.32E-05	9.2[illegible]E-05	1.56E-04	9.67E-07	1.56E-04
Am-243	1.57E-06	6.21E-06	1.05E-05	6.52E-08	1.05E-05
Cm-243	2.70E-08	1.98E-07	2.97E-07	1.93E-09	3.12E-07
Cm-244	1.82E-05	1.57E-0[illegible]	2.24E-04	1.49E-06	2.41E-04
TOTAL	7.60E+00	3.20E-01	7.97E+00	3.65E-02	5.08E+00

* Not included in NRC source terms

3.1.1 Dry Active Waste Characteristics

3.1.1.1 Noncompactible Trash (NCTRASH)

Noncompactible trash is the waste stream of primary interest to this study. This is because the noncompactible trash is made up of the hardware and components which are the subject of the repair or modification efforts. Other wastes such as compactible trash are normally generated as a byproduct of the repair, removal, replacement, or modification efforts. Noncompactible trash typically consists of the following materials as reported by plants surveyed in the 1981 EPRI study (Ref. 1):

- Wood includes construction lumber, plywood, packing etc.
- Conduit includes tubing, cable, wire, electrical fittings, etc.
- Pipe/Valves includes pipe, tubing, valves, pipe fittings, etc.
- Filters include cartridge type, filter canister, etc.
- Compactible Material includes those items that are either inadvertently or intentionally packed with noncompactible waste. This can be . . . material that is considered compactible.
- Filter Frames are the wooden or metal frames that surround HEPA filters.
- Concrete can be the debris from scarifying and demolishing concrete structures and supports, or large concrete pieces.
- Tools generally consist of hand tools although some power driven tools can be included.
- Dirt includes dust, floor sweepings, and similar small particulates or large quantities of contaminated dirt/sand.
- Glass includes bottles, laboratory glassware, instrument tubing, face plates, view ports, etc.
- Lead is generally shielding material in any configuration.
- Miscellaneous is a category to include anything that has not been classified in the previous 11 types.

According to Reference 1, the composition breakdown for noncompactible trash was roughly as follows. Values are shown separately for BWRs and PWRs.

Fractional Composition of Noncompactible Trash

	BWR	PWR
Wood	0.29	0.24
Piping/Valves	0.21	0.13
Filters	0.07	0.13
Conduit	0.05	0.13
Compactible Materials.	0.04	0.06
Filter Frames	0.05	0.05
Dirt	-0-	0.03
Glass	0.04	-0-
Concrete	0.03	0.03
Tools	0.03	0.03
Miscellaneous	0.17	0.15
Other	0.02	0.02

The average specific activity of the noncompactible wastes was reported to be 0.4 mCi/ft^3 (14.1 mCi/m^3) for PWRs. This average excluded several plants reporting over a factor of 10 greater than this value. The specific activity for BWR noncompactible waste was 0.20 mCi/ft^3 (7.1 mCi/m^3), half that reported for PWRs. These activity levels represent the as-shipped conditions for the waste. As-generated activity concentrations for this and the other waste streams were noted in Sec. 1.1.1.

The data presented in the 1981 EPRI utility survey (Ref. 1) indicated that the average density of the packaged noncompactible trash was about 19 lb/ft^3. Based on the typical composition for this waste, the maximum theoretical density should be about 212 lb/ft^3 for BWRs and 233 lb/ft^3 for PWRs. Thus, the density of the packaged material was typically only about 10% of the maximum possible density. This indicates that significant void spaces were unfilled in the boxes and drums used to package this waste. This is at least partially due to the fact that the shapes and rigidity of noncompactible trash do not lend themselves to high packing efficiencies.

For the purposes of this study, a VRF of 1.0 for noncompactible trash is taken to be waste packaged to its theoretical density. Obviously a VRF of 1.0 is unattainable for this waste stream. The data from Ref. 1 suggest that typical VRFs for this waste were on the order of 0.1 to 0.15 in the early 1980s. Some improvements have been made in recent years but the packing efficiency is still relatively low.

As noted above, the average activity concentration for the as-shipped noncompactible trash was 0.4 mCi/ft^3 for PWRs and 0.2 mCi/ft^3 for BWRs. Since the as-shipped waste density was not more than 15% of the theoretical density, one can infer that the as-generated activity of the waste was about 2.67×10^{-3} mCi/ft^3 for PWRs and 1.33×10^{-3} mCi/ft^3 for BWRs. This is the as-generated activity concentration based on the actual waste value, exclusive of any voids.

3.1.1.2 Compactible Trash (COTRASH)

Substantial amounts of compactible wastes are generated at nuclear power plants. In many cases it represents one of the largest quantities of any of the waste streams generated over a fixed period of time.

Compactible trash, as reported in Reference 1, is made up of the following materials:

- Plastic consists of nonhalogenated plastics which can be coveralls, protective suits, lab coats, boots, gloves, sponges, hats, raincoats, sheets, bags, containers, bottles, etc.
- Paper includes coveralls, lab coats, absorbent paper, wrappings, cartons, etc.
- Absorbent Materials are hygroscopic materials used to absorb fluids.
- Insulation includes most nonrigid types of insulation.
- Polyvinyl Chloride (PVC) consists of halogenated plastics which can be protective suits, coveralls, lab coats, boots, gloves, hoses, containers, bottles, etc.
- Cloth includes coveralls, lab coats, rags, mops, gloves, etc.
- Rubber includes boots, hoses, gloves, sheets, etc.
- Wood includes construction lumber, plywood, packing, etc.
- Noncompactible includes those items that inadvertently are packed with compactible waste. It can include small tools, hardware (nuts, bolts, screws), or any other noncompactible material.
- Metal consists of metallic items that can be compacted such as aerosol cans, paint cans, etc.
- Filters include high efficiency particulate air (HEPA) filters, respirator canisters, etc.
- Glass includes bottles, laboratory glassware, instrument tubing, face plates, view ports, etc.
- Miscellaneous is a category to include anything that cannot be classified in the previous 11 types.

The following table gives the fractional composition which typifies this type of waste.

Fractional Composition of Compactible Trash

	BWR	PWR
Plastic	0.30	0.29
PVC	0.10	0.19
Paper	0.25	0.16
Cloth	0.17	0.10
Rubber	0.04	0.08
Wood	0.03	0.03
Miscellaneous	0.07	0.06
Other	0.04	0.04
Absorbent Materials	-0-	0.05

The average specific activity of PWR compactible trash was reported to be 0.7 mCi/ft^3 (24.7 mCi/m^3), while for the BWRs the corresponding value was 0.25 mCi/ft^3 (8.8 mCi/m^3). These values correspond to the as-packaged or as-compacted condition. The EPRI survey (Reference 1) found that BWRs and PWRs were not compacting the waste to the same degree, even though the composition of the waste is basically similar for the two types of plants. For PWRs the typical compaction ratio or volume reduction ratio was 3.78, while for BWRs it was only 2.27. Thus in the as-generated state, i.e. prior to compaction, the average specific activity levels for compactible trash correspond to 0.185 mCi/ft^3 (6.5 mCi/m^3) for PWRs and 0.110 mCi/ft^3 (3.9 mCi/m^3) for BWRs. As with noncompactible trash, the specific activity of compactible trash can vary widely from one plant to another and from one batch of trash to another. A factor of 10 variation from the nominal activity is not unlikely for a given case.

3.1.2 Wet Waste Characteristics

3.1.2.1 Ion-Exchange Resins (IXRESINS)

Ion-exchange resins are small porous beads used to process various liquid waste streams through a combination of absorption and adsorption of soluble ionic material (both chemical and radiochemical), and through the filtration of insoluble material. These resins can be regenerated and are typically used in reactor condensate polishing systems. Resins used for cleanup of liquid radwaste streams are generally not regenerated but must be disposed of as waste once they have lost their filtering and demineralizing qualities. Ion-exchange resins from PWRs are generally in bead form, while that from BWRs is often in the form of a powder. Both the powder and bead forms of the resins can be treated similarly regarding their disposal.

PWR resins from the liquid radwaste processing systems had an average specific activity of 0.078 Ci/ft^3 (2.75 Ci/m^3) for resins in the as-shipped condition. Bead resins from BWR radwaste cleanup systems were reported to have an average specific activity of 0.125 Ci/ft^3 (4.41 Ci/m^3), while powdered resins from this source had an average activity of 0.13 Ci/ft^3 (4.60 Ci/m^3).

3.1.2.2 Concentrated Liquids (CONCLIQ)

Many nuclear plants have employed evaporator systems to reduce the volume of liquid radwastes. Concentrated liquid wastes are a combination of the liquid stream and accumulations of solids and solutes carried in the stream. Concentrators (evaporators) are used in processing laundry waste water, decontamination solutions, liquids from floor drains, and other such sources.

Many plants are phasing out this method of treating liquid wastes. Several plants have shifted to the filter/demineralizer type of system. Nevertheless, a number of plants still employ the evaporator-concentrator system for processing liquid radwaste streams.

For PWRs, the average specific activity from evaporator concentrates was reported to be 7.2 mCi/ft^3 (0.254 Ci/m^3), while, for BWRs, the average value was 0.12 Ci/ft^3 (4.24 Ci/m^3).

3.1.2.3 Filter Sludges (FSLUDGE)

Filter sludges refer to powdered ion-exchange resin generally used as a precoat material on filter demineralizers, and flocculating agents (filter aids) used to extend the processing life of the filter. Most plants use powdered resin not only for filtration of insoluble material but also for its ion-exchange properties. Sludge from precoat filters can be a combination of the original precoat material, insolubles such as dirt removed from the liquid stream being processed, corrosion particles, and other suspended solids and flocculating agents used in the system.

This type of radioactive waste is generated primarily by boiling water reactors since PWRs rarely use precoat filters. Filter sludges from BWR liquid radwaste processing systems had an average specific activity of 0.13 Ci/ft^3 (4.59 Ci/m^3).

3.1.3 Other Wastes

Other types of waste may also be generated as a result of NRC-mandated changes to nuclear plants. One such item is filter cartridges. These are typically used in PWR liquid radwaste processing systems to remove insoluble wastes. The reported typical activity for these filter cartridges was 200 mCi/ft^3. The quantity of these filters disposed of each year is small compared to the volumes of most of the other waste streams. Because the typical activity levels of these filters is essentially the same as that used for FSLUDGE wastes, and because they are often disposed of in cement-filled drums, the cost of disposing of this type of waste is assumed to be approximately the same as that for disposing of PFSLUDGE. Inaccuracies due to this assumption are not expected to be large since the total quantity of these filters is estimated to be quite small compared to the quantities of other types of wastes.

3.2 VOLUME REDUCTION TECHNIQUES

Radioactive waste volume reduction processes have always been employed at nuclear power plants. Volume reduction is attractive from practical as well as economic standpoints. In recent years, the cost aspects of disposing of low-level radioactive wastes have risen dramatically. This is particularly true of burial costs (Ref. 2). Since burial costs are generally assessed on a per unit volume basis (i.e., \$/ft^3), generally speaking, the lower the volume of waste from a given plant requiring burial, the lower the disposal costs to that plant. Thus, there is an incentive for nuclear utilities to improve their effectiveness in reducing the volume of radioactive wastes which must ultimately be disposed.

Enhanced volume reduction efforts have occurred on two fronts. First, the problem of waste generation is getting renewed attention at nuclear plants. Utilities are changing their procedures and administrative controls to help reduce the amount of low-level wastes generated. One of the waste streams most amendable to improvement in this way is compactible trash. Measures that have been employed to reduce the volume of waste generated include substitution of reusable items and materials for disposable materials, careful monitoring of waste activity levels to separate clean trash from that which must be classified and treated as radioactive, limiting the materials brought into contaminated areas to prevent their becoming contaminated, and more prompt attention to liquid leakage from radioactive systems to minimize the buildup of liquid wastes. Many other waste generation minimization measures are also employed. Many of these techniques and ideas are discussed in Ref. 1.

Once waste has been generated, it is generally subjected to some type of volume change process. For compactible trash, the as-shipped volume is less than the as-generated volume. For wet wastes, the processing may either increase or decrease the final volume. For example, solidification of spent resin in cement increases the volume to be disposed, while incineration processes can substantially decrease the final volume.

The following sections discuss the various waste processing methods available to nuclear plant operators. Section 3.2.1 reviews conventional practices and techniques, while Section 3.2.2 presents an overview of improved processes that have recently become available.

3.2.1 Conventional Low-Level Radwaste Processing Methods

3.2.1.1 Dry Active Wastes (DAW)

Dry active wastes are the noncompactible trash, compactible trash, and certain filters used in removing particulates from liquid waste streams. Normally noncompactible trash receives no volume reduction treatment or processing. This is because this class of waste has a substantial quantity of materials generally not amenable to further volume reduction. This waste stream contains items such as steel pipe, valves, wood, and electrical conduit. At best, noncompactible trash can be carefully hand-packed into the transport and burial containers. Some utilities cut sections of pipe longitudinally and employ other such techniques to improve the packaging factor for this type of waste. The hand packing requires considerable labor. Also, the low VRFs for this waste necessitate the use of a relatively large number of containers to package a given volume of as-generated waste. These factors make processing of NCTRASH considerably more expensive than processing for COTRASH.

Compactible trash in the as-generated state typically has a density of about 8 lb/ft^3. Until recently, most plants employed mechanical compactors to reduce the volume of this waste. These conventional compactors can generally increase the density of this waste stream to about 20 to 30 lb/ft^3. According to Ref. 1, at least through 1982, most plants were packaging this waste in 7.5-ft^3 (55 gallon) drums.

Contaminated filters can be classed as noncompactible trash, compactible trash, or as separate items. When these filters are highly contaminated, they are typically placed in separate containers which include a significant amount of shielding material. Thus, the shipped volume for filters can be substantially greater than the volume of just the filters.

3.2.1.2 Wet Wastes

Wet wastes generated at nuclear plants consist of the concentrated liquids, ion-exchange resins, and filter sludges generated in processing liquid radioactive streams. The conventional approach in handling these wastes, at least until recently, was to solidify them in cement or other binding agents. Cement is often used because of its relatively low cost. Mixing the wet wastes with the solidification agent increases the volume of waste to be disposed. The following volume increase ratios are believed to be typical (Ref. 1,2, & 4).

Waste Type	Volume Increase with Solidification
Ion-Exchange Resins	1.1 - 1.4
Concentrated Liquids	1.4
Filter Sludges	1.8

3.2.2 Improved Volume Reduction Processes

The increased costs of disposing of radioactive wastes, particularly the sharp rise in burial costs, has led to the development of several techniques and processes for significantly reducing waste volume relative to conventional processing methods. These more advanced techniques generally employ one or more of three basic processes:

- mechanical compaction
- incineration
- evaporation

The following sections briefly describe these advanced processing methods. Much more complete descriptions of specific systems is presented in Ref. 2, Vol. 3. Also, the following sections describe a limited number of advanced waste processing systems and techniques. The discussions are by no means exhaustive. However, the approaches discussed are believed to be representative of what is available to utilities at the present time and into the near future.

3.2.2.1 Mechanical Compaction

Section 3.2.1.1 noted that mechanical compaction of compactible trash is a standard processing method for this waste stream. Conventional compactors increase the waste density from about 8 lb/ft^3 to 20 or 30 lb/ft^3. These conventional compactors typically employ hydraulic cylinders to compress the waste. More advanced compactors are now available which exert higher forces to achieve greater compaction. In addition, some plants have gone to the use of shredders in conjunction with the compactors to further enhance the compactibility of the waste. One improved compactor available for use with 7.5-ft^3 drum containers achieves waste densities for compactible trash of about 45 lb/ft^3. Thus, it offers a volume reduction factor of about 5.6 compared to the 3.8 factor for the standard compactor. This improved compactor can be used as a retrofit in plants with older, less effective equipment. The capital cost of applying this improved device in a nuclear plant is estimated to be less than $200,000 (Ref. 2, Vol. 3).

An ultra-high pressure compaction device is also available. This "supercompactor" exerts a force of about two million pounds on the waste to produce densities on the order of 55 to 70 pounds per cubic foot for compactible trash. This system is much larger than standard compactors and requires more building space. The capital cost of this system is reported to be about $3.5 million (Ref. 2).

It is possible that devices such as the supercompactor could be used with noncompactible trash as well as with compactible wastes. This type of compactor could be used to improve "nesting" of waste articles, to crush components such as thin-walled electrical conduit and tubing, and generally to reduce the void space in shipping containers for noncompactible wastes. Application of supercompactors to NCTRASH is not a common practice at this time.

Both the improved compactor and the supercompactor have gas aspiration and filtration systems which minimize the spread of contaminated aerosols during the processing of the waste.

3.2.2.2 Incineration

A number of different incineration processes are available. Most will handle the combustible materials present in the compactible trash waste stream. Some processes will also handle ion-exchange resins, filter sludges, and organic liquid wastes.

The incineration processes produce radioactive ash and radioactive smoke as a result of the combustion. The ash is collected and typically mixed with a solidification agent (cement, polymer, bitumen). The exhaust gases or smoke must be carefully scrubbed and filtered to remove particulates which may be radioactive. The exhaust gas must also be treated to remove vapors and to neutralize acids that may be present in the gas stream. Iodine removal features are also present on some of these systems.

The incineration systems are highly effective at reducing the volume of waste. However, as with other volume reduction techniques, the resulting volume of waste has an increased specific activity since all of the radioactive material originally present is now concentrated in a smaller volume. For dry combustible wastes the volume reduction factor with incineration is about 113:1. For ion-exchange resins and filter sludges, these factors are about 4:1. These factors include the effect of binding/solidification agents used to encase the incineration products. Thus, the specific activity levels of the waste will be increased by factors ranging from 4 to about 113 compared to the activity of the original waste stream. If the original waste has a high specific activity, extensive volume reduction may not be practical due to limitations imposed by handling, shipping, and burial considerations.

The waste incineration system costs vary considerably, depending on the system capacity, and the overall capabilities of the system. The costs cited in Ref. 2, Vol. 3, range from $2.6 million to more than $24 million.

Incinerators have another problem associated with them. Because they discharge combustion products to the air, they must be licensed by the Environmental Protection Agency. Many utilities have found the regulatory burden of this option expensive. At the time of this report, only one incinerator has been licensed and is being operated by a radwaste services vendor (Scientific Ecology Group, Inc.) in Oak Ridge, TN.

3.2.2.3 Evaporators

Evaporator systems are used to treat liquid waste streams in nuclear plants. Evaporator systems have been in use for many years in nuclear plants to reduce the volume of liquid wastes. The newer, more advanced systems are similar to the older systems except they produce more highly concentrated effluents or completely dry waste products.

Several of the evaporator systems can handle both liquid, and slurry type wastes. They can process concentrated liquids and ion-exchange resin and filter sludge slurry wastes. All of these systems heat the waste streams to induce evaporation of the water in the waste. Typically, steam is used to accomplish the heating. The effluents from the evaporation process are typically solidified in cement, a polymer binder, or bitumen. The net volume reduction achieved varies, depending on the nature of the waste feed. Nominal volume reduction factors achieved through evaporation processes for various waste streams are as follows (Ref. 2, Vol.3).

Concentrated Liquids	2.4 to 6.6
Ion-Exchange Resins	1.4 to 2.0
Filter Sludge	~ 2.0

The above factors include the effect of solidification of the wastes.

The capital cost of evaporator systems is estimated to be in the $4 million to $9 million range.

3.2.2.4 Combined Systems

The mechanical compaction equipment discussed previously is suitable for reducing the volume of dry active wastes. It is not suitable for treating wet wastes. Conversely, the evaporation processes cannot treat dry wastes. Certain of the incinerator systems can accommodate both dry and wet wastes, but these tend to be somewhat expensive. Combined systems may be needed and desirable to achieve effective volume reduction for all waste streams. Several combinations of systems were considered in References 2 and 4.

3.2.3 Summary of Volume Reduction Processes

Table 3.3 summarizes the various waste processing systems and associated volume reduction factors for each waste stream. The different volume reduction techniques were discussed in Section 3.2. Table 3.3 emphasizes the fact that a given volume reduction factor for a given waste stream applies to a specific waste processing system. In some cases, different systems employing the same basic technique, e.g., evaporation, will reduce the volume of a given waste stream to different extents. An example of this is shown for the concentrated liquid waste stream (CONCLIQ). Three different evaporation systems are noted, each resulting in a different final volume for the processed waste. Also, with this particular waste stream the extent of volume reduction achieved by a given system is dependent on whether the waste stream was generated in a BWR or a PWR.

3.3 CURRENT PRACTICE AND FUTURE TRENDS

As noted previously, nuclear power plant operators have had increasing incentives over the past several years to reduce the volume of radioactive waste which must be shipped to disposal sites. The principal reasons for this include the high and ever increasing costs of disposal, and the volume limits and surcharges imposed on waste generators as a result of the Low-Level Radioactive Waste Policy Amendments Act of 1985.[1] This Act provides the framework and guidance for interstate compact regions and independent states to develop a nationwide system for low-level waste disposal.

Currently, most nuclear utilities are using a two-pronged strategy for reducing the volume of low-level radwaste (LLRW) which must be shipped to disposal sites. On the front end there is growing emphasis on reducing the amount of LLRW which is generated. The methods used include those described previously in Section 3.2. Also, many plants have formed interdisciplinary radwaste volume reduction committees to find innovative ways to reduce the amount of waste generated. On the back end, nuclear plants are using a variety of radwaste processing techniques and systems (see Table 3.3) to reduce the volume of LLRW which has to be shipped to disposal sites.

The analysis of the costs and benefits of the different processing techniques described in Table 3.3 is very complicated and site dependent. For this and other reasons, it is difficult to discern any clear and definite trends within the nuclear industry regarding the current and future selection of techniques and systems for dry active waste and wet waste processing. However, based on a review of current technical literature, and contacts with both nuclear utility personnel and suppliers of LLRW services and equipment, the following observations can be made.

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[1]The effects of this law on radioactive waste disposal costs are discussed in Section 5.2.4.2.

Table 3.3
Waste Processing and Volume Reduction Techniques

Waste Stream	Volume Reduction Factor	Processing Technique
COTRASH	2.3	Standard Compactor
	3.8	Standard Compactor, complete filling of waste containers
	5.7	Improved Compactor
	8.7	Supercompactor
	113.4	Incinerator, solidification of ash
NCTRASH	0.2	Hand packing
	0.4	Careful hand packing
	0.6	Cutting plus careful hand packing
	0.8	Cutting, careful hand packing, and supercompactor
IXRESIN	0.7	Solidification in Cement
	0.95	Dewatered, placed in high integrity containers
	1.4	Mobile evaporator, solidification in binder
	2.0	Evaporation of water, grinding of resins, mixing with binder
	4.0	Incineration, mixing ash with binder
CONCLIQ	BWR/PWR	
	0.7/0.7	Solidification in cement
	1.9/3.7	Evaporator/crystallizer process, solidification in binder
	2.4/5.4	Mobile evaporator, solidification in binder
	3.8/6.6	Evaporator, grinding of residue, solidification in binder
	4.5/10.4	Dryer/incinerator, solidification in binder
FSLUDGE	0.56	Solidification in cement
	2.0	Evaporator, solidification in binder
	4.0	Incinerator, solidification in binder

3.3.1 Regulatory and Technical Risks

Uncertainty within the nuclear utility industry regarding waste form requirements of state compacts, EPA requirements regarding incineration and disposal of mixed toxic wastes, and the performance and cost-effectiveness of different waste processing systems and techniques has caused many utilities to delay decisions regarding the purchase of capital systems and equipment for LLRW processing. As a consequence, there continues to be a definite trend towards the purchase of radwaste contractor services, including leasing of mobile processing equipment, rather than purchase of permanently installed systems. This approach provides more flexibility, especially if waste form requirements change.

3.3.2 High Capital Cost of Waste Processing Systems

The disincentives towards capital investment in relatively high cost and difficult to operate and license waste processing systems and equipment (e.g., those involving evaporation and incineration), coupled with the performance problems which have plagued some of those systems, has resulted in a growing preference for simple, less costly, waste processing methods. Examples of these preferred techniques include processing resins by dewatering in high integrity containers (HIC), and using filters or a combination of filters and ion exchange to process concentrated liquids.

3.3.3 Shredding and Supercompactors

The trend towards shredding and supercompaction of dry active waste is clear. Several service companies have or are in the process of establishing regional centers for dry active waste processing using supercompactors. Mobile shredding and compaction equipment is also being used by a number of utilities and waste processing service companies.

3.3.4 Incineration

Incineration has not proven, as yet, to be a viable alternative for volume reduction for a number of reasons, including the strict emissions control requirements which must be met, the difficulty in obtaining permits from the EPA and other agencies, and the performance problems which have been experienced with incineration systems and equipment. Such systems have had little testing and operating experience at nuclear plants. The volume reduction advantage of incineration may, however, prove to be enough incentive to ensure its place in the future. Some evidence for this is the continuing interest by the private sector in the design and development of incinerators for processing both radwaste and other hazardous waste.

3.3.5 Decontamination and Recycling

The increasing emphasis on front end reduction in waste generation has created a demand for decontamination and recycling services. A number of regional facilities have been set up to decontaminate and recycle tools, equipment and materials. These centers typically include means for sectioning and repacking noncompactible waste such as conduit, piping, valves, wood, and other similar materials. Mobile decontamination services are also being used by utilities.

3.3.6 Onsite Storage

The uncertainty with regard to the future requirements for LLRW disposal has prompted a number of utilities to develop contingency onsite storage as an interim measure for handling LLRW and as a hedge against the possible disruption of burial site availability in the future. Onsite storage capability also is useful for providing temporary storage during short-term operational surges. Two approaches are presently being used. The first involves construction of radwaste holding facilities for the interim storage of radwaste containers. The second involves the use of specially designed stand-alone storage containers for temporary above-ground storage.

3.3.7 Radwaste Minimization

The clear need to reduce front-end generation of LLRW has prompted many utilities to initiate radwaste minimization programs in order to track down and characterize the specific sources of LLRW and find innovative ways to reduce the generation of such waste. These programs typically involve the use of interdisciplinary committees.

3.3.8 Below Regulatory Concern

The NRC has an effort underway to develop a generic rule for "below regulatory concern" (BRC) low-level radwaste. The prospect is that some LLRW may be designated BRC and could be released or disposed of in essentially an uncontrolled manner, i.e., not regulated as radioactive. The immediate impacts of this development are two-fold. First, it adds to the justification utilities already have to delay decisions regarding purchase of high-cost volume reduction systems and equipment. Second, it increased the value of strategies aimed at segregation of uncontaminated from contaminated waste. There is a growing interest, for example, in manual and automated monitoring and sorting systems for segregation of dry active wastes.

3.3.9 Volume Reduction

Finally, although an EPRI study published in 1984 concluded that "VR is generally more cost-effective at BWRs (boiling water reactors) than PWRs (pressurized water reactors), and at multi-unit stations than at single-unit stations," the implications of these conclusions are not clearly evident in the decisions made by utilities regarding LLRW processing. Most if not all nuclear utilities are concerned with LLRW volume reduction and the methods being used do not appear to be a function of reactor type.

4.0 ESTIMATES OF WASTE VOLUME GENERATION

4.1 INTRODUCTION

In order to develop estimates of the cost of disposing of radioactive waste, it is necessary to know the volume of waste generated. For NRC-initiated plant modifications, this capability to predict waste volume generation will be required for a wide range of specific tasks. Since the cost of waste disposal depends upon the type of waste handled, it will be necessary to predict the waste types generated as well as the volumes. Predicting waste volume generation by specific task is difficult because very few of the operating nuclear stations track waste volume generation by source within the plant.

Based upon visits to two nuclear stations that do track waste volume generation by source within the plant, supplemented by discussions with waste handling equipment vendors and information in the open literature, some simple notions relating to the estimation of waste volume generation have been developed. Table 4.1 on the following page summarizes these notions of waste volume generation, applying them to specific waste streams.

The derivations and sources are documented in the discussion which follows, so that limited or outdated information can be replaced as data become available in the future. It is reasonable to expect that more plants will track waste volume generation by sources in the near future, owing to the pressures on plant operators to minimize waste volume generation.

4.2 NONCOMPACTIBLE DRY ACTIVE WASTE

In general, the primary waste stream for a plant modification is noncompactible DAW (P- or B- NCTRASH). Constituents of this waste stream are the identifiable plant components and materials that are removed in the course of the plant modification; i.e., piping, conduit, insulation, valves, pumps, cable trays, concrete, dirt. Tools and equipment (i.e., scaffolding, ladders, utility lines, mops, vacuum cleaners, carts, welding machines, submersible pumps, crane slings, etc.) can be assumed to be controlled and reused. Sometimes wood components, such as those used in scaffolding, are planed (approximately 1/8 inch); however, the wood shavings can probably be neglected.

The first step in the estimation of the volume of this primary waste stream is to evaluate the actual physical volume of the identifiable plant components and materials. The next step is to determine the packing fraction of the constituents in the shipping container. In 1981, noncompactible DAW was typically packaged in 98 to 122 ft^3 Low Specific Activity (LSA) boxes (Ref. 1). The dimensions of a 98-ft^3 LSA box are 6 ft x 4 ft x 4 ft. To estimate packing fraction, the optimum configuration of the constituents in the box is estimated. The packing fraction is the ratio of the volume of the constituents to the volume of the box. At one plant, packing fractions for noncompactible DAW range from approximately 0.2 to 0.75.

To achieve higher packing fractions, large constituents can be cut into smaller pieces. The decision whether or not to cut involves a tradeoff between cutting costs (plus radiation exposure costs incurred during cutting) and disposal costs. Shipping weight limitations during transport may constitute a constraint in the tradeoff. As an example, one utility contractor (Impell Corporation) evaluated the feasibility of cutting 200-ft. of 28" pipe into clam shell segments. It was assumed that a four-man crew would be needed (1 cutter, 1 assistant, 1 fire watch, and 1 H.P. technician), each at a cost of

TABLE 4.1 Summary Approach to Waste Volume Estimating

WASTE STREAM	COMPONENTS	APPROACH	QUANTITATIVE GUIDANCE
Noncompactible DAW (P- or B-NCTRASH)	Piping, conduit, insulation valves, pumps, cable trays, concrete, dirt, etc.	1. Estimate physical volume of plant components.	Use geometry.
		2. Estimate approximate VRF (packing fraction) to waste containers.	Range of 0.2 to 1.2 in ~100 ft^3 boxes. (Typical values are 0.2 to 0.4)
		3. Might be able to decontaminate and recycle at a lower cost.	Overall, estimated cost of recycle ~ 80-85% cost of disposal
Compactible DAW (P- or B-COTRASH)	Largely paper and plastic.	Correlation based on 1981 data for industry-wide, as-shipped volumes of compactible and noncompactible DAW	BWRs: $\frac{\text{Vol Comp DAW}}{\text{Vol Noncomp DAW}} \approx 2.1$
			PWRs: $\frac{\text{Vol Comp DAW}}{\text{Vol Noncomp DAW}} \approx 0.9$
Ion Exchange Resin (P- or B-IXRESIN)	From cleanup of primary system, fuel pool water, or plant drain water.	Depletion of resin is a function of concentration of dissolved solids in liquid stream.	For ~2 µmho conductivity: ~1.5 ft^3 of waste/10^5 gal.
			For ~150 µmho conductivity: ~1.5 ft^3 of waste/10^3-10^4 gal.
	From cleanup of decontamination solution.	Depletion of resin is a function of volume and condition of system being decontaminated, and the decon solution used.	For LOMI decon solution: ~0.1 ft^3 of waste/gal. decon soln.
Filters	From decontamination of personnel respirators.	Use actual data.	~1×10^{-3} ft^3 of waste/respirator deconned (~1/2 comp. & ~1/2 non-comp.)
	From laundering protective clothing.	Use actual data.	~2×10^{-3} ft^3 of waste/dressout (all compactible)

* Volumes and ratios are given on as-shipped basis. To estimate on as-generated basis, use following relationship with appropriate volume reduction factors (VRF): As-Generated Volume = As-Shipped Volume x VRF

$40/hr (probably high). The cutting speed was estimated to be 3 ft/hr.[1] The total cost of cutting was estimated to be roughly $21,000, exclusive of radiation exposure costs. Such a tradeoff analysis may be beyond the scope of NRC's requirements for estimates of radioactive waste disposal costs.

An option other than disposal is available for some constituents of noncompactible DAW. This is decontamination and recycle, which can be applied to essentially anything metallic, e.g., welding machines, chain falls, lead bricks, cable trays, etc.[2] Other materials, such as rubber hoses and cables, may also be recycled. In this option, the vendor takes possession of the waste and is responsible for decontamination, recycle and disposal of the residual. Decontamination is performed using chemicals (acid, caustic solutions, or Freon™) or mechanical methods (grit blasting or hand scrubbing). The residual wastes from decontamination (sludge bottoms, grit, resins) constitute roughly 20% of the volume of the input stream. Thus, recycle can be viewed as a volume reduction process providing a factor of roughly five reduction in volume. In general, the costs of recycle are roughly 15 to 20% lower than disposal costs, according to one vendor (Quadrex Corporation) (The cost of disposal of the residual waste is borne by the vendor). Given this degree of difference, it is probably adequate for NRC's purposes to assume disposal, a conservative assumption which may offset the tendency to underestimate the volume of the primary waste stream. However, for some specific cases, the differences in cost between disposal and recycle may be more substantial.

4.3 COMPACTIBLE DRY ACTIVE WASTE

The volume of compactible DAW (P- or B-COTRASH) generated in the course of a specific task is difficult to estimate. This is because this waste stream is composed mostly (approximately 65% in 1981, according to Reference 1) of paper and plastic (including PVC). The quantities of disposable paper and plastic generated in the course of a task is a function of general housekeeping considerations at any particular plant, and cannot be derived from first principles. It may be possible to correlate the quantities of compactible DAW generated for a specific plant, or for all LWRs, against the number of containment entries, the number of man-hours, and/or collective radiation exposure (person-rem).[3] However, the development of such a correlation was beyond the scope of the current study.

Reference 1 presents data obtained from a significant portion of the industry in 1981 on as-shipped volumes of compactible and noncompactible wastes. From these data, the following ratios can be derived:

$$\text{At PWRs:} \quad \frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} = 0.9$$

$$\text{At BWRs:} \quad \frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} = 2.1$$

To provide analogous estimates for the as-generated condition, the as-shipped volumes should be adjusted according to the approximate volume reduction factors. For example, for both BWRs and PWRs, typical volume reduction factors for noncompactible trash are about 0.2 to 0.4, while those for compactible trash are about

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[1]For cutting speed estimates, contact Newport News Industrial Corporation.

[2]There are some exceptions. For example, intricate pieces such as motor windings may not be candidates for decontamination and recycle.

[3] Reference 1 indicates thta the amount of compactible DAW generated at PWRs correlates against person-rem, but not at BWRs.

3.8 to 5.7. The ratio of the as-generated compactible trash volume to the volume of noncompactible trash generated at each type of plant can be approximated as follows:

At PWRs: $\frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} = \frac{0.9 \times (3.8 + 5.7)}{(0.2 + 0.4)} = 14.3$

At BWRs: $\frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} = \frac{2.1 \times (3.8 + 5.7)}{(0.2 + 0.4)} = 33.3$

Given the estimated volume of noncompactible DAW generated, these ratios can be used to estimate the associated volume of compactible DAW.

The foregoing algorithm presupposes that the ratio derived for all tasks is applicable to any one task, and that the ratios derived in [illegible] are applicable today. Both of these assumptions are questionable. With respect to the latter one, we know that the technology of waste volume reduction has evolved considerably over the past five years. In 1981, the average volume reduction for compactible DAW was 3.8 at PWRs and 2.3 at BWRs (Ref. 1). Typical volume reduction factors range between approximately four and seven today. However, the volumes of noncompactible DAW generated have also been substantially reduced at some plants the past several years through the application of a number of control measures. Therefore, the ratios of compactible to noncompactible volumes derived in 1981 may still be valid.

Data from two nuclear stations provide partial corroboration of this conjecture.[1] For the PWR visited the ratio of compactible to noncompactible trash volume shipped was about 1.2. This is reasonably close to the 0.9 ratio cited above. For the BWR visited, however, the ratio of as-shipped compactible to noncompactible waste was less than 1.0, whereas the 1981 survey data indicated the ratio at that time was typically about 2.0. This disagreement for the BWR case may simply due to practices unique to the utility supplying the data. Until a more comprehensive survey of current utility practices is made, it is recommended that analysts use as-shipped volume ratios of compactible to noncompactible trash of 1.0 to 2.0 for BWRs.

4.4 ION-EXCHANGE RESIN

The generation of ion-exchange resin (P-or B-IXRESIN) is a function of the quantity of dissolved solids in the liquid stream being processed. Primary system or fuel pool water, which is very clean (approximately 2 micro-mho conductivity or 2 ppm dissolved solids), results in the generation of approximately one cubic foot of resin per 10^5 gallons (approximately the volume of the primary system) of liquid. After volume increase from solidification, one cubic foot of generated resin results in roughly 1.5 cubic feet of as-shipped resin. Draining of the primary system does not necessarily result in the depletion of resin, since the primary system fluid may be stored in tanks and re-used.

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[1]As a test of this hypothesis, we derived these ratios for the two stations visited in the course of this study, using data applicable to 1984. The results, based on as-shipped conditions, are:

Visited PWRs: $\frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} = 1.2$

Visited BWRs: $\frac{\text{Volume Compactible DAW}}{\text{Volume Noncompactible DAW}} = 0.25 - 0.5$

Plant floor drain water is considerably dirtier (approximately 150 micro-mho conductivity) than primary system water. Accordingly, approximately one cubic foot of resin is generated per 103 to 104 gallons of liquid.

Ion-exchange is also generally used to clean up solutions which are used to chemically decontaminate LWR systems. The quantity of resin generated depends on the volume and condition of the system being decontaminated, and the decontamination solution which is used. Chemical decontamination has been widely used to clean up these LWR systems -- the BWR recirculation piping system, the BWR reactor water cleanup system, and the PWR steam generator channel head. Three decontamination solutions have been used -- LOMI, Candecon, and NS1.

Using LOMI as the solution, decontamination of a BWR recirculation piping system takes approximately 4,000 to 6,000 gallons of solution and results in the generation of roughly 400 cubic feet of ion-exchange resin. Decontamination of a BWR reactor water cleanup system takes approximately 2,000 to 3,000 gallons of solution and results in the generation of roughly 200 cubic feet of ion-exchange resin. Decontamination of a steam generator channel head takes approximately 100 cubic feet of ion-exchange resin. All other factors being equal, use of Candecon rather than LOMI as the decontamination solution results in approximately the same waste volume as LOMI. After volume increase from solidification, one cubic foot of generated resin results in approximately 1.5 cubic feet of as-shipped waste (based on solidification in cement). Particulates entrained in the decontamination solution are removed using filters. However, the volume of waste filters generated is typically negligible in comparison with the spent ion-exchange resin.

4.5 FILTERS

At one BWR utility the system used to decontaminate personnel respirators generates roughly 1 x 10^{-3} ft^3 of waste filters per respirator decontaminated. Approximately one-half of this waste is compactible DAW; the remainder is noncompactible DAW. At this same utility, respirators are worn in approximately one-third of containment entries. Many stations, recognizing the high impact of disposable clothing on radwaste volumes, have converted to launderable clothing. Several use a Freon™ system for laundering the clothing. At one utility, roughly 2 x 10^{-3} ft^3 of waste filters are generated per dressout (coveralls, shoecovers, hoods, booties). These waste filters are compactible DAW. At this same utility, there are typically four dressouts per 10-hour shift.

5.0 WASTE DISPOSAL COST ELEMENTS AND COST METHODOLOGY

There are four primary cost elements that contribute to the costs of disposing of low-level radioactive wastes generated at nuclear power plants. These elements are those associated with processing, interim-storage, transportation, and burial of the wastes. This section discusses each of these elements. The costing methods and their basis are presented to help the user of this document understand how the disposal costs are derived. Hopefully, this section will also allow the user to adjust the cost basis as necessary to reflect the effects of changing conditions relative to disposal costs.

There are certain characteristics of each waste stream which strongly influence several or all of the cost elements. These characteristics are discussed and presented in Section 5.1. Section 5.2 then elaborates on the cost elements and the costing methodology.

All cost estimates generated in this study were based on a fixed volume of waste for each waste stream. That is, given a fixed volume of waste in the as-generated (unprocessed) condition, the costs of disposing of that waste were determined. The value selected for this fixed volume in the as-generated state is 1000 ft^3. This value is quite arbitrary, but it does provide a reasonable basis on which to proceed. The volumes of wastes generated as a result of NRC-mandated repairs or modifications to nuclear plants can easily be in this range, especially for the COTRASH and NCTRASH waste streams. Table 5.1 shows the quantities of the various waste types generated in typical BWRs and PWRs during 1981 (Ref. 1). The quantities shown are as-shipped, i.e., after processing. They indicate that the reference volume of 1000 ft^3 selected as the basis for the present cost estimates is reasonably small compared to the yearly total waste generated in typical LWRs.

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TABLE 5.1
WASTE PRODUCTION SUMMARY FOR 1981

Waste Type	Cubic Feet*/Unit Year Averages	
	BWR	PWR
Dry		
Compactible	15350	5800
Noncompactible	7200	6150
Other	100	250
Subtotal	22650	12200
Wet		
Resins	2800	1250
Sludges	5500	-0-
Concentrates	2850	2400
Subtotal	11150	3650
Totals	33800	15850

*All values refer to the as-shipped conditions.

5.1 WASTE KEY CHARACTERISTICS

Several waste stream characteristics which enter into the determination of waste disposal costs are presented in Tables 5.2 and 5.3. Each of the ten waste streams are noted, along with the applicable volume reduction factors, the as-shipped volume

Table 5.2 BWR Waste Stream Characteristics

Waste Stream	Volume Reduction Factor	As-Shipped Volume (a) (cubic feet)	As-Shipped Density (b) (pounds per cubic foot)	Activity Concentration (Curies per cubic foot)	Activity Concentration (Curies per cubic meter)	Surface Dose (c) (R/hr)
B-COTRASH	2.3	440.3	18	2.50E-04	8.83E-03	0.02
	3.8	264.7	30	4.16E-04	1.47E-02	0.03
	5.7	176.4	45	6.23E-04	2.20E-02	0.03
	8.7	115.1	70	9.57E-04	3.38E-02	0.03
	113.4	8.8	93.3	1.25E-03	4.40E-02	0.32
B-NCTRASH	0.2	5000	42.6	2.66E-04	9.39E-03	0.01
	0.4	2500	85.2	5.32E-04	1.88E-02	0.02
	0.6	1666.7	127.8	7.98E-04	2.82E-02	0.02
	0.8	1250	170.4	1.07E-03	3.76E-02	0.02
B-IXRESIN	0.7	1408.4	93.3	1.25E-01	4.41E+00	3.33
	0.95	1052.6	70.9	1.67E-01	5.90E+00	4.84
	1.4	714.3	70.8	2.46E-01	8.69E+00	8.95
	2	500	75.3	3.52E-01	1.24E+01	12.08
	4	250	93.3	7.04E-01	2.49E+01	19.87
B-CONCLIQ	0.7	1408.4	47.8	1.02E-01	3.60E+00	3.61
	1.9	526.3	68	3.21E-01	1.13E+01	11.43
	2.4	416.7	56.5	4.06E-01	1.43E+01	14.77
	3.8	263.2	88	6.42E-01	2.27E+01	18.95
	4.5	222.2	93.3	7.60E-01	2.68E+01	22.44
B-FSLUDGE	0.56	1785.7	96	1.30E-01	4.59E+00	3.29
	2	500	69.3	4.64E-01	1.64E+01	15.78
	4	250	69.3	9.28E-01	3.28E+01	31.56

Notes:

(a) For 1000 cubic feet of as-generated waste

(b) Including binder where applicable

(c) Based on typical stream activity concentration

Table 5.3 PWR Waste Stream Characteristics

Waste Stream	Volume Reduction Factor	As-Shipped Volume (a) (cubic feet)	As-Shipped Density (b) (pounds per cubic foot)	Activity Concentration (Curies per cubic foot)	Activity Concentration (Curies per cubic meter)	Surface Dose (c) (R/hr)
P-COTRASH	3.8	264.7	30	7.00E-04	2.47E-02	0.06
	5.7	176.4	45	1.05E-03	3.70E-02	0.07
	8.7	115.1	70	1.89E-03	6.69E-02	0.07
	113.4	8.8	93.3	2.10E-03	7.42E-02	0.7
P-NCTRASH	0.2	5000	46.6	5.32E-04	1.88E-02	0.03
	0.4	2500	93.2	1.07E-03	3.77E-02	0.03
	0.6	1666.7	139.8	1.60E-03	5.65E-02	0.03
	0.8	1250	186.4	2.13E-03	7.53E-02	0.03
P-IXRESIN	0.7	1408.4	91.3	7.82E-02	2.76E+00	1.84
	0.95	1052.6	76	1.05E-01	3.69E+00	3.55
	1.4	714.3	74.1	1.54E-01	5.45E+00	5.03
	2	500	93.3	2.00E-01	7.07E+00	6.97
	4	250	93.3	4.40E-01	1.56E+01	10.64
P-CONCLIQ	0.7	1408.4	91.3	7.10E-03	2.51E-01	0.15
	3.7	270.3	76	3.74E-02	1.32E+00	1.08
	5.4	185.2	74.1	5.47E-02	1.93E+00	1.85
	6.6	151.5	93.3	6.68E-02	2.36E+00	1.85
	10.4	96.2	93.3	1.05E-01	3.72E+00	2.27
P-FSLUDGE	0.56	1785.7	96	3.94E-02	1.39E+00	1.17
	2	500	69.3	1.41E-01	4.96E+00	5.61
	4	250	69.3	2.81E-01	9.93E+00	11.23

Notes:
(a) For 1000 cubic feet of as-generated waste
(b) Including binder where applicable
(c) Based on typical stream activity concentration

resulting from 1000 ft^3 of the as-generated waste, the as-shipped waste density and the activity concentration and surface dose rate for the as-packaged wastes. The latter two characteristics are based on the typical activity for each waste stream as reported in Ref. 1.

There are some differences in the waste stream characteristics due to the reactor type involved. The concentrated liquids, for example, will be different between BWRs and PWRs. Their chemical makeup is different as is their typical activity levels. These liquid waste streams have different levels of solids concentrations, and thus, their densities after processing will be somewhat dependent on whether they originated in a BWR or a PWR. This also effects the extent of volume reduction achieved with a given process. A range of volume reduction factors is shown for each waste stream. The specific values shown in the tables correspond to what can be achieved with a specific volume reduction system. For COTRASH, for example, the volume reduction factor (VRF) of 3.8 is generally achievable with a standard drum compactor. The VRFs of 5.8 and 8.7 correspond to an improved compactor and a "supercompactor", respectively. The 113.4 factor corresponds to the volume reduction achieved when the compactible trash is incinerated and the ash products are chemically stabilized prior to burial. For BWRs, the lowest VRF for COTRASH is 2.3. This is the norm reported for BWRs up through the early 1980s (Ref. 1).

The noncompactible trash waste stream is not amenable to extensive volume reduction. The 0.2 and 0.4 VRFs imply hand packing of these waste materials but with different degrees of care. Even the 0.4 factor may be optimistic. The 0.6 VRF corresponds to careful cutting and hand packing of the noncompactibles to leave as little void space in the disposal containers as possible. The final NCTRASH case, that with a VRF of 0.8, assumes careful cutting and hand packing plus compaction of the waste in a supercompactor. Some compaction should be possible which could reduce void spaces. Some of the scrap materials in this waste stream can be compressed into more condensed forms. Examples of this are thin-walled electrical conduit and thin-walled piping. These can be flattened. The density corresponding to NCTRASH with a VRF of 1.0 is the theoretical density of this waste stream based on the compositions defined in Section 3.1.1.1.

The activity concentrations noted in Tables 5.2 and 5.3 are based on the typical waste stream activity as reported in the EPRI-sponsored utility survey (Ref. 1). The activity concentration obviously increases as the waste itself is concentrated in the volume reduction processes.

The specific activity for a given waste stream can vary widely from one plant to the next and from one batch of waste to the next within a given plant. To account for such variations, an activity range of -10x to +100x was assumed and used in assessing the importance of activity in determining waste disposal costs. This factor of 1000 range generally encompasses the ranges reported in Ref. 1.

Tables 5.2 and 5.3 present rough estimates of the surface dose rate applicable to each waste stream and the extent of volume reduction achieved. These surface doses apply to the waste following its processing and placement in unshielded burial containers. The surface dose was estimated using the following approximation:

$$\text{Dose Rate} = \frac{\text{Constant x curies per Container}}{\text{Weight of Filled Container}}$$

where

Weight of Filled Container =

Weight of Container (7.5-ft^3 barrel = 60 lbs) + Weight of Contents (volume x density)

The constants are different for each waste stream. They are shown in Table 5.4 (from Ref. 2). The dose measured at the surface of a waste container is roughly proportional to the number of curies per unit mass of disposed material. The proportionality constant is a function of the material density, its compaction, radioactivity, and the container geometry.

TABLE 5.4
CONTACT DOSE RATE CONSTANTS

Waste Stream	Constant (R/hr/Ci/lb)
B-COTRASH	2.60×10^3
B-IXRESIN	2.86×10^3
B-CONCLIQ	2.99×10^3
B-FSLUDGE	2.63×10^3
B-NCTRASH	2.64×10^3
P-COTRASH	3.38×10^3
P-IXRESIN	2.45×10^3
P-CONCLIQ	2.81×10^3
P-FSLUDGE	3.09×10^3
P-NCTRASH	2.98×10^3

5.2 WASTE DISPOSAL COST ELEMENTS

The major waste disposal cost elements are those resulting from processing, interim-storage, transportation, and burial. Each of these is discussed in the following sections. These discussions present the cost basis and important assumptions used in quantifying waste disposal costs.

5.2.1 Processing Costs

Processing encompasses all activities and costs associated with converting and/or packaging raw wastes (as-generated) into states or conditions wherein they are suitable for storage, transportation, and burial. For the simplest case, this may only involve placing the waste into suitable containers. On the other extreme, it may involve drying or incinerating, mixing of the residue in a solidification or stabilization agent, and placing in appropriate containers. The nature of the processing will influence the costs associated with this element of waste disposal.

Two major aspects make up processing costs. These are labor costs and the costs of consumables. Manpower is needed to control the physical movement of waste from its origination points in the plant to the processing equipment and from this point to on-site storage or to the point where it is shipped off-site for burial. Manpower is also needed to carry out the actual processing and packaging of the wastes. And finally, labor is expended in maintaining the processing equipment.

The category of consumables associated with waste processing includes the waste containers (drums, boxes, high integrity containers, etc.), energy used in processing and materials used to solidify or otherwise stabilize the wastes.

Table 5.5 displays values of the pertinent parameters used to calculate processing costs. The values vary, depending on the waste stream and the extent of volume reduction achieved. The information presented in the table is largely derived from Ref. 2. Where practical, the information was cross-checked based on actual utility experience, although this was possible in only a few cases. The information in Ref. 2 is oriented toward the use of 7.5 cubic foot drums for the waste containers for all waste streams. This type of container is still widely used in the U.S. nuclear industry. Many utilities use larger containers such as 100 and 200 ft^3 boxes for waste such as compactible and noncompactible trash. Our assessment has assumed the use of 7.5-ft^3 drums as the disposal container. The cost projections on this basis should be somewhat on the high side, but not to any significant degree. Aspects such as operator time and container handling time could be expected to decrease on a per unit basis (hrs/ft^3) for larger containers than the 7.5-ft^3 drum.

The equipment operator time is based on total annual operator manpower requirements and total annual system throughput, i.e., total volume of waste shipped annually. Thus, the values tabulated in Table 5.5 are averages across all waste streams.

The unit energy costs can vary widely, depending on the waste stream and volume reduction process involved. The larger costs are associated with incineration and evaporation processes. These processes require supplemental fuel and other heat sources.

All unit values displayed in Table 5.5 are referenced to the as-shipped condition, i.e., to the state of the waste after it has undergone its volume reduction treatment and has been placed in containers together with solidification agents (as applicable).

The costs associated with waste processing as defined for the present purposes excludes the capital costs of the processing equipment and related structures. The equipment and facilities are needed on a routine basis at all nuclear plants to process wastes generated during the course of routine operation and normal repairs and maintenance. On the other hand, operator time and volume reduction equipment maintenance costs have been charged as part of the overall processing costs. Here the assumption is that operators and waste handlers could usefully be applied elsewhere in the plant on other activities were it not for the specific incremental waste processing requirement of interest here. It is also assumed that wastes generated as a result of NRC-mandated repairs or modifications to plants will generate incremental maintenance requirements on the waste processing equipment.

The actual calculation of waste processing costs proceeds as follows.

<u>Container Costs</u>:

$$\text{No. Required} = \frac{\text{As-generated Waste volume } [ft^3]}{\text{Container Volume } [ft^3] \times \text{Volume Reduction Factor}}$$

Table 5.5 Waste Processing Unit Cost Components (1988 dollars)

Waste Stream	Volume Reduction Factor	Waste Unit Mass * [lbs/cu ft]	Binder Unit Mass * [lbs/cu ft]	Binder Unit Cost [$/cu ft]	Equipment Operator Time [hrs/cu ft]	Container Handling Time [hrs/cont]	Energy Unit Cost [$/cu ft]	Maintenance Unit Costs [$/cu ft]
COTRASH	2.3	18.02	--	--	0.14	1.0	0.02	4.16
	3.8	30	--	--	0.14	1.0	0.03	4.16
	5.7	45	--	--	0.15	1.0	0.03	4.93
	8.7	70	--	--	0.18	1.5	0.08	8.51
	113.4	66.67	26.7	1.55	0.27	1.0	126.51	11.45
		BWR/PWR						
NCTRASH	0.2	42.6/46.6	--	--	0.14	1.0	0.00	0.01
	0.4	85.2/93.2	--	--	0.27	1.0	0.00	0.02
	0.6	127.8/139.8	--	--	0.41	1.0	0.03	0.02
	0.8	170.4/186.4	--	--	0.41	1.0	0.08	0.02
			BWR/PWR					
IXRESIN	0.7	48	51.3/48.0	0.05	0.14	0.8	0.05	3.33
	0.95	64.2	0.0/0.0	0.00	0.14	1.0	0.05	4.84
	1.4	30.1	40.7/36.9	0.13	0.33	0.5	1.66	8.95
	2	34.67	40.7/34.7	0.13	0.80	0.5	7.35	12.08
	4	66.67	26.7/26.7	1.55	0.60	1.0	7.35	19.87
B-CONCLIQ	0.7	46.67	44.7	0.05	0.14	0.8	0.05	3.61
	1.9	49.33	26.7	1.55	0.22	1.0	0.05	11.43
	2.4	33.33	40.8	0.13	0.33	0.5	7.50	14.77
	3.8	56	37.3	0.13	0.80	0.5	12.22	18.95
	4.5	66.67	26.7	1.55	0.52	1.0	30.07	22.44
P-CONCLIQ	0.7	42.67	51.3	0.05	0.14	0.8	0.05	3.61
	3.7	41.33	26.7	1.55	0.22	1.0	1.17	11.43
	5.4	26.67	29.9	0.13	0.33	0.5	16.51	14.77
	6.6	44	44.0	0.13	0.80	0.5	20.89	18.95
	10.4	66.67	26.7	1.55	0.52	1.0	46.14	22.44
FSLUDGE	0.56	48	48.0	0.05	0.14	0.8	0.05	3.29
	2	34.67	34.7	0.13	0.45	0.5	7.37	15.78
	4	34.67	34.7	0.13	1.15	0.5	7.35	31.56

* Note: Cost components and unit masses are based on the as-shipped conditions of the wastes.

$$\text{Container Cost} = \text{Container Unit Cost} \left[\frac{\$}{\text{Container}}\right] \times \text{No. Required}$$

Based on recent vendor estimates, the cost of 7.5-ft^3 drums is $60.00 each.

Binder Cost:

Binder Cost =

Binder Unit Mass [lb/ft^3] x Binder Unit Cost [$/lb] x No. of Containers x Container volume [ft^3]

Three different binder materials were considered, depending on the waste stream and volume reduction process used.

Binder	Cost, $/lb
Cement	0.05
Bitumen	0.13
DOW	1.55

Note that the binder unit mass is per unit volume of processed waste.

Energy Cost

Energy Cost =

Energy Unit Cost* [$/$ft^3$] x No. of Containers x Container Volume [ft^3]

Labor Cost

Container Handling Cost =

Unit Handling Time [hrs/container] x No. of Containers x Labor Rate [$/hr]

Equipment Operator Cost =

Equipment Operator Unit Time* [hrs/ft^3] x No. of Containers x Container Volume [ft^3] x Labor Rate [$/hr]

Suitable labor rates for equipment operators and waste handlers were assumed to be $32.00/hr, including overheads and fringe benefits.

Maintenance Costs:

Maintenance Costs =

Maintenance Unit Costs* [$/$ft^3$] x No. of Containers x Container Volume [ft^3]

The overall processing cost is the sum of the foregoing individual costs. These are the costs of processing a given volume of as-generated waste.

* Per ft^3 of processed waste

5.2.2 Transportation Costs

Transportation costs encompass all activities necessary to transport radioactive waste from the nuclear plant to the burial site. It includes shipping charges and fees associated with shielded van or cask rental if such casks are needed. This element does not include costs of plant personnel labor needed to load the radioactive wastes onto the transport vehicle. This labor is accounted for in the processing costs.

The calculation of transportation costs used a number of assumptions and bases. These assumptions and bases are as follows:

1. All shipments are made via licensed and qualified commercial carriers using trucks. Shipment by rail was not considered. This is consistent with prevalent practice in the U.S. nuclear industry.

2. All wastes are shipped in 7.5-ft^3 drums. This is not the most effective container size for some waste streams but is still widely used at the present time. The use of larger containers may result in somewhat lower transportation costs.

3. Shipments to the burial site are made only when full-truck-load shipments are available. When the quantity of waste of interest would not make up a full load or where a combination of full loads plus a partial load was involved, the partial load was essentially assumed to be stored at the plant until the next full-load shipment was available. In this way the partial load was assessed transport costs only in proportion to the fraction of the full-load represented by these wastes. For example, if the particular wastes of interest would constitute 2 1/2 truck shipments the transportation costs for this case would be the costs of two full shipments plus half the cost of another full shipment.

4. It was assumed that all shipments employ only a single driver. The average distance traveled by truck with a single driver is 500 miles per day.

5. The maximum payload capacity for non-overweight vehicles is 45000 pounds. The maximum payload capacity for shielded vans is 26000 lbs.

6. The time required to load the waste onto the trucks plus the time required to off-load at the burial site is one day or less.

7. Transportation costs are assessed as if they are present day costs, even though wastes may be stored on- site for lengthy periods of time prior to shipment.

8. Transportation fees are based on present day rates charged by licensed radioactive waste carriers. Where different rates would apply in different parts of the country, these rates were averaged and a single rate was used.

9. Shielded vans or shipping casks, when needed, are rented or leased rather than purchased by the utility.

10. The maximum practical number of 7.5-ft^3 containers that can be transported on a single truck load is 80.

11. Inspection fees for safe packaging and transportation of low level radioactive wastes can be substantial, for example, $2500 in the State of Nevada; these costs, however, are assumed to have been already incurred

by the utilities whose wastes travel through states requiring these one-time inspections or have been exempted from the fee based upon past performance.

12. Liability insurance costs are assumed to be reflected in the rates charged by transporters and it is assumed that the transporters are insured for hauling radioactive materials through industry pools.

Several factors determine the magnitude of waste transportation costs. One primary factor is distance. Another is the number of shipments that will be required to transport a fixed quantity of waste. A third factor is whether or not shielding must be provided during transport.

Three conditions determine how much waste can be transported in a single truck shipment. These conditions determine how many separate shipments must be made to transport a fixed quantity of waste. First, barring other limitations a maximum of 160 7.5-ft^3 containers of waste can be accommodated on a single truck shipment. However, the current practice is not to haul more than 80 7.5-ft^3 drums on a single truck load. Loads with more than 80 drums are possible, but such loads entail greater care and effort in loading and unloading. A maximum of 80 containers per shipment was used in the present cost assessments.

The second limiting condition on quantity of waste transported in a single truck load is gross payload weight. The maximum shipment load is about 45000 pounds. This is the maximum waste payload if the activity level is low enough that shielding is not required. If shielding is required and a shielded van is used, this payload drops to about 26000 pounds.

The third condition limiting the quantity of waste transported per truck is that imposed by shielded cask size and weight. The surface dose of the packaged waste generally determines the type of cask needed to meet transport regulations. A host of cask sizes and capabilities are available to meet utility needs. The cask weights and sizes are such that generally only a single cask can be accommodated on a truck bed at one time.

Table 5.6 presents a listing of typical shipping cask capabilities and limitations. The listing shown is not exhaustive but is felt to be representative. The surface dose of the waste determines the minimum cask shielding requirements needed for a given shipment of waste. The table also indicates typical cask rental fees and payload limits used in the present analysis. Competitive pricing may have temporarily reduced the cost of leasing shipping casks. The cost reductions on bid work have ranged from 5-20% over a three-year period. This cost reduction appears to be minor and temporary until the number of competitors decreases.

TABLE 5.6
SHIPPING CASK CAPABILITIES (1988 DOLLARS)

Shipping Cask Description	Maximum Drum Surface Dose Rate, R/hr	Maximum Drums per Shipment	Lease Cost, $/day	Payload Limit, lb
Unshielded Van	.20	80	--	45000
Shielded Van	.75	75	100	26000
21 Drum Cask	3.0	21	225	--
14 Drum Cask*	15.0	14	250	--
14 Drum Cask	50.0	14	500	--
8 Drum Cask	750.0	8	750	--

*Heavier shielding

Shipping casks are assumed to be leased or rented on a daily basis rather than purchased. Utility ownership of casks may be more economical in the long run, but this option was not considered here. Cask rental fees typically are not the major contributor to shipping costs.

If a shielded van or cask is required, it is assumed that the van or cask must be transported to the plant from a terminal near a burial site before use. The analysis assumes that rental fees are charged for the deadhead time when the cask is being sent empty to the plant. One day is allowed for loading and unloading of the wastes. Thus, if a cask is needed the cask rental time is taken to be the round trip time plus the one day for loading and unloading.

Shipping rates typically vary with distance traveled, and they may vary from one part of the country to the other. Certain states require permits for the transport of radioactive materials within or through their boundaries. Typical fees for such permits range from $50 to about $125 per shipment per state or municipality. Only seven states require such permits at the present time. These charges are relatively small compared to total transportation costs. Therefore, they were not included in the present evaluations.

The shipping rates used were based on commercial shipper rate schedules effective through at least mid-1988. The rates apply to low-level radioactive waste and the related shipping casks. The schedule used specified separate rates for destinations west of the Mississippi River and east of the Mississippi River. These two rates were averaged to define a single rate for use in the cost calculations.

Table 5.7 presents the mileage rate schedule. It shows charges per mile for both one-way shipments and round trip shipments. Round trip shipments apply whenever a shielded van or shielded cask is used to transport the radioactive wastes.

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TABLE 5.7
WASTE TRANSPORTATION RATES (1988 DOLLARS)

Maximum One-way Distance, Miles	One-Way Rate, $/Mile	Round-Trip Rate, $/Mile
100	5.12	3.58
250	3.18	2.30
500	2.25	1.61
750	2.03	1.51
1000	1.85	1.51
over 1000	1.80	1.51

In the present analysis several one-way distances were used in calculating transportation costs. These distances were 250, 500, 1000, 2000 and 3000 miles. Costs were calculated for each waste stream for each of these distances.

As a general aid to the user of this document, a survey was made of the distances from nuclear plants to each of the three burial sites. The survey was made for each NRC region. Table 5.8 indicates the average, minimum, and maximum distances between the reactor sites in each of the 5 NRC regions and the 3 waste depository sites (Barnwell SC; Beatty, NV; and Richland, WA). The mileage were estimated by measuring the straight line distances on a map, scaling to miles, then multiplying by a factor of 1.2 to account for actual road miles.

In Region V, about half the sites are within 380 miles of Beatty, Nevada and the other half are within 260 miles of Richland, Washington. Similarly, in Region IV, one-third of the plants are approximately 1370 miles from Beatty, NV and the others range from 820 to 1820 miles from Beatty. Two-thirds of the Region IV plants are within 1100 miles of Barnwell, SC. Regions I-III are sufficiently detailed in Table 5.8.

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TABLE 5.8
APPROXIMATE DISTANCES FROM POWER PLANT SITES TO WASTE REPOSITORIES FOR EACH NRC REGION

NRC Region	Barnwell, SC Avg.	Barnwell, SC Min.	Barnwell, SC Max.	Beatty, NV Avg.	Beatty, NV Min.	Beatty, NV Max.	Richland, WA Avg.	Richland, WA Min.	Richland, WA Max.
I	860	570	1200	2740	2300	3020	2690	2350	3020
II	310	140	670	2260	1780	2780	2450	2160	3120
III	910	720	1300	1870	1630	2300	1870	1490	2300
IV	960	720	1630	1370	820	1820	1680	103[illegible]	2300
V	2500	2160	2880	620	290	1010	560	30	1200

The calculation of transportation costs is described below.

Number of shipments required:

The number of containers of waste generated from the reference volume of 1000 ft^3 of unprocessed waste is determined as discussed in Section 5.2.1. The contact dose rate is also determined as noted in Section 5.1.

Given the number of containers of waste and the surface dose rate, a comparison is made with the limits specified in Table 5.6 describing shipping cask capabilities. That comparison determines the need for a cask, the cask capabilities, and maximum weight limitations. The maximum number of containers per truck is determined from that comparison. The number of shipments is then determined.

$$\text{No. Shipments per 1000 ft}^3 \text{ of unprocessed waste} = \frac{\text{Total No. of Containers}}{\text{No. of containers per shipment}}$$

As pointed out previously, where fractional loads enter into the assessment of the transport costs of a given 1000 ft^3 of as-generated waste, the partial load segments are assumed to be stored at the plant until a full-truck-load shipment is available for transport. The transport costs are apportioned to the waste according to the fraction of a full load occupied by the waste in question.

If a cask or shielded van is required, round-trip distances and rates are used. Cask rental fees are charged as appropriate. Trip duration is calculated as follows:

$$\text{Trip Time} = \frac{\text{One-way Distance [mi] x RT}}{\text{500 [mi/day]}} + 1$$

Where RT is 1 if an unshielded van is used, or 2 if a shielded van or casks are used.

Cask Rental Costs:

Cask Rent = TIME [days] x Rental Rate [$/day]

Mileage Costs:

The mileage costs are determined from the transportation rates (Table 5.7), the one-way distance from the plant to the burial site, and the RT factor as determined above.

Mileage Costs Per Trip = Rate [$/mi] x Distance [mi] x RT

Transportation Costs:

Total transportation costs = (mileage costs [$/trip] + cask rental [$/trip]) x number of shipments

5.2.3 Storage Costs

The uncertainty in the availability of permanent burial sites for low level radioactive wastes has caused many nuclear utilities to plan for interim on-site storage of these wastes. The limited survey of utilities revealed that about half of those contacted had already made such provisions. The amount of waste that can be stored on-site varies considerably, ranging from what is produced in a six month period to that which would be produced over as much as a five year period.

The present cost assessment has included costs associated with on-site storage of radioactive wastes. The assumption is made that a given amount of storage floor space is required for each container of waste produced by the plant. Thus wastes generated as a result of NRC requirements are assumed to generate incremental storage space needs. The capital costs associated with this incremental space are added to the other costs associated with waste disposal.

The capital costs for on-site storage facilities are based on information presented in Ref. 2. That source gives storage facility requirements and costs for a specific type of facility. It is assumed here that these costs and requirements are reasonable, but they may not represent industry-wide average costs for such facilities.

The data reported in Ref. 1 indicates that LWRs generate on the order of 3000 drums of packaged waste each year, assuming that nominal volume reduction processes are used and that the wastes are packaged in 7.5-ft^3 drums. The wastes generated as result of NRC mandated repairs or modifications are typically a small fraction of this total (Ref. 1), i.e. 10% or less.

Reference 2 states that storage facility costs would basically be made up of a fixed component and a variable component. The fixed component includes costs for handling equipment (cranes, fork lifts), loading bays, fixed walls, a control room, and engineering design and construction management. The variable component is the cost of the storage space itself, which varies depending on the amount of waste which can be accommodated.

The present assessment has included only the variable component of the storage space costs. This is because the fixed cost component is assumed to be incurred by the utility in allowing for the storage of wastes generated as a result of routine operations and maintenance. Also, as noted above the volume of wastes generated as a result of NRC requirements is small compared to the normal annual volume of waste produced by a typical LWR.

Reference 2 indicates that, beyond a certain size, about 0.72 ft^2 of storage area floor space is needed for each 7.5-ft^3 drum. This floor space requirement per drum assumes that the drums are stacked one on top of another, several high. This incremental amount of floor space is appropriate for facilities which can hold about 1000 drums or more. As indicated above, typical LWRs produce the equivalent of about 3000 drums per year. Thus even a one-year storage capability would be expanded to accommodate incremental wastes at the rate of about 0.72 ft^2 per drum. This value was used in determining the incremental space requirements used in the present assessment. The cost per square foot of storage area varies, depending on the dose rate of the wastes. The capital costs cited in Ref. 2 (in 1982 dollars and escalated to 1988 dollars) are as follows:

Capital Costs of Interim-Storage Facilities

	1982 costs ($/$ft^2$)	1988 costs ($/$ft^2$)
Surface dose <100 mR/hr	98.00	105.91
Surface dose >100 mR/hr	108.00	116.71

The storage costs associated with a given volume of as-generated waste is calculated as follows:

$$\text{Storage space floor area required } [ft^2] = 0.72\ (ft^2/\text{drum}) \times \frac{\text{No. of drums}}{1000\ ft^3 \text{ of waste}}$$

$$\text{Cost} = \text{Storage area } [ft^2] \times \text{Unit Cost } [\$/ft^2]$$

5.2.4 Burial Costs

Burial costs have been rising more sharply in recent years than the other elements of waste disposal costs. In many instances, this is the dominant cost component.

Burial costs include the fees charged for cask and waste handling, burial of the radioactive materials, and fees such as those set up to provide perpetual care of the burial sites. Other fees and taxes are also assessed by some of the states with commercial low-level radioactive waste burial sites. Different inspection requirements and different fees are charged by the different states involved.

Currently there are only three sites available in the U.S. for the disposal of low-level radioactive wastes. Two sites are operated by U.S. Ecology, Inc. These are located in Beatty, Nevada, and Richland, Washington. The third site is located at Barnwell, South Carolina, and is operated by Chem-Nuclear Systems, Inc.

Section 5.2.4.1 discusses present-day burial costs as determined from rate schedules obtained from the operators of the three existing low-level waste burial sites. Legislation was passed in the U.S. Congress in 1980 which required the formation and development of additional burial sites to serve regional needs. Most states have joined compacts to develop regional burial sites, and Congress has legislated a surcharge schedule to ensure that these new burial sites are operating by 1992. This legislation will have a significant impact on burial costs. These potential impacts are discussed in Section 5.2.4.2.

5.2.4.1 Current Burial Costs

The contacts with utilities made during the course of this study indicated that all three of the existing commercial burial sites are being used by utilities for disposal of their low-level radwastes. Some utilities will ship one type of waste to one site and another type of waste to another site, although there is no uniformity from one utility to another in regard to this practice. Thus it is impractical to attempt to predict where a given utility or the plants in a given region of the country will ship to in the future.

In determining suitable burial cost algorithms, investigators obtained present day rate schedules applicable to the three available burial sites. The rates charged by U.S. Ecology for their Beatty, Nevada, and Hanford, Washington, sites are not vastly different. These were averaged to establish a single U.S. Ecology rate schedule.

The costs of burial at sites operated by U.S. Ecology, Inc. are dependent on the dose rate at the waste container surface, the weight of the containers, and the total curie inventory per truck load of wastes. Charges are also assessed for cask handling, decontamination services, and unusual exposure to personnel, if applicable.

The averaged rates charged for waste disposal at the Beatty, Nevada, and Hanford, Washington, burial sites are shown in Table 5.9. Special case charges, such as those levied for unusual personnel exposure or decontamination are not shown. The assumption used in the present calculations is that these unusual charges should not be

Table 5.9
Average of US Ecology's Beatty, NV and Hanford, WA Rate Schedules for Burial of Low-Level Radioactive Wastes
Effective August 17, 1987

Disposal Charge (Packages 12.0 cu ft or less):

R/hr at Container Surface	Price per cubic foot
0.00 - 0.20	$28.98
0.201 - 1.00	$30.10
1.01 - 2.00	$31.43
2.01 - 5.00	$32.50
5.01 - 10.00	$36.38
10.01 - 20.00	$41.93
20.01 - 40.00	$48.13

Minimum charge per shipment, excluding surcharges and specific other charges, is $485.00

Surcharges

Surcharge for Heavy Objects

Weight of Container	Surcharge per Container
0 - 10000 lbs	No surcharge
Over 10000 lbs	$214.76 plus 10¢/lb above 10000 lbs

Curie Surcharges:

Curie Content per shipment	Surcharge per Shipment
0 - 100	No surcharge
101 - 300	$1561.50 plus 20.5¢/Ci above 100 Ci

Other Charges

Cask Handling Fee: $550.00 per cask, minimum

Note: The above rate schedule is abridged. Charges for weights and curies and container volumes not mentioned are available from the burial site.

incurred if reasonable care is taken by utilities in processing their wastes and properly packaging them.

The current rate schedule applicable for the disposal of wastes at the Barnwell, SC, site is shown in Table 5.10. At Barnwell, a basic charge is assessed based on a $\$/ft^3$ rate which is independent of the surface dose rate of the waste containers. Surcharges are then assessed for container weight and the total curie content of the shipment. The weight surcharge applies only if the waste containers must be offloaded using a crane. Drums which are on pallets or waste which is in boxes can be handled by a fork lift and the weight surcharges do not apply in most cases. However, if the waste was shipped in shielded casks, then a crane must be used for offloading and the weight charges do apply. Barnwell also assesses a curie surcharge which depends on the total curie content of the shipment. Other charges include a cask handling fee and county taxes.

Both Barnwell and the sites operated by U.S. Ecology will assess charges for special nuclear materials (SNM) in the wastes. SNM includes U-233, U-235, Pu-241 and similar fissile materials. Most of the waste streams contain small quantities of these isotopes. The highest concentrations appear to be in the filter sludge waste stream (see Tables 3.1 and 3.2). There the nominal concentration for Pu-241 in B-FSLUDGE, for example, is $1.15X10^{-2}$ Ci/m^3. For a thousand cubic feet of this waste, the total mass of Pu-241 would be on the order of $3.0X10^{-3}$ grams. Thus the masses of these special nuclear materials are very small and the SNM charges were not included in the calculation of burial costs.

The predicted costs of burial at Barnwell are significantly higher than those for burial at Beatty, NV, or Hanford, WA. Costs are higher by from 10% or 40% to as much as a factor of 2 or so, depending on the waste stream. The higher costs are due to the higher curie and weight surcharges assessed for disposal of waste at Barnwell.

The evaluation of low level radwaste burial costs calculated the present day costs for burial both at Barnwell and at the sites operated by U.S. Ecology, Inc. A single cost number was then generated by taking a linear average of these two cost figures. This average burial cost was used in arriving at the estimated total cost for disposing of each waste stream.

The calculation of burial costs proceeds as follows.

<u>Burial at U.S. Ecology Sites</u>

Compare container surface dose rate against rate schedule shown in Table 5.9. Select the appropriate burial rate.

Basic burial charge = rate $[\$/ft^3]$ x No. of containers x container volume $[ft^3]$

Check for application of weight charges.

Check for total curie content of shipment, assuming only one type of waste with uniform activity levels is transported on a single shipment.

curie content = activity per container[Ci] x no. of containers per shipment.

Determine curie charge rate from schedule in Table 5.9.

Curie charge = charge per shipment [\$] x no. of shipments per 1000 ft^3 of unprocessed waste.

Table 5.10
Barnwell, SC Rate Schedule for
Burial of Low-Level Radioactive Wastes
Effective January 15, 1988

Base Disposal Charge: $35.32/cu ft

Minimum charge per shipment, excluding surcharges and specific other charges, [illegible]50.00
The base disposal charge includes charges for the Extended Care Fund ($2.80/cu ft), the South Carolina Low-Level Radioactive Waste Disposal Tax ($6.00/cu ft), and the Southeast Regional Compact Fee (66¢/cu ft).

Surcharges

Weight Surcharges (Crane Loads Only):

Weight of Container	Surcharge per Container
0 - 1000 lbs	No surcharge
1001 - 5000 lbs	$405.00
5001 - 10000 lbs	$710.00
10001 - 20000 lbs	$1,010.00
20001 - 30000 lbs	$1,310.00

Curie Surcharges for Shielded Shipments:

Curie Content per shipment	Surcharge per Shipment
0 - 5	$2,500.00
5 - 15	$2,820.00
15 - 25	$3,750.00
25 - 50	$5,650.00
50 - 75	$6,900.00
75 - 100	$9,350.00
100 - 150	$11,200.00
150 - 250	$15,000.00
250 - 500	$18,800.00

Other Charges

Cask Handling Fee: $1,000.00 per cask, minimum

Barnwell County Business License Tax: 2.40% surcharge added to each bill

Note: The above rate schedule is abridged. Surcharges for weights and curies not mentioned are available from the burial site.

Check container weight against minimum weight above which weight charges are assessed. If greater than minimum weight, calculate charges as specified in Table 5.9.

If a cask was used for transporting the waste, include the cask handling fee.

Total costs for burial at U.S. Ecology sites

$$\text{Total Cost} = \text{Basic Weight Charges} + \text{Container Burial Charges} + \text{curie Charges} + \text{Cask Handling Charge}$$

Burial at Barnwell, SC

Basic charge = rate [$/ft^3$] x No. of containers x container volume [ft^3]

Check if a cask is used for waste transport. If yes, determine applicable weight charges per container from Table 5.10.

Weight charge = rate [$/container] x No. of containers per 1000 ft^3 of unprocessed waste

Determine curie surcharges based on rates shown in Table 5.10.

curie charge = charge per shipment [$] x No. of shipments per 1000 ft^3 of unprocessed waste

If a cask is used in transport, assess the cask handling fee.

$$\text{Total Cost} = \text{Basic Weight Charges} + \text{Container Burial Charges} + \text{Curie Charges} + \text{Cask Handling Charge}$$

Tax is applied to get the overall cost.

Average burial cost:

$$\text{Average} = \frac{\left[\text{Barnwell Burial Cost} + \text{US Ecology Burial Cost}\right]}{2}$$

As noted previously, burial costs have been rising rapidly in the past few years. Users of this document should contact the burial site operators to determine current burial rate schedules. Changes relative to the rates presented in Tables 5.9 and 5.10 must be factored into the intended analysis to determine the prevailing burial costs.

5.2.4.2 Regional Burial Sites and Surcharges

In 1980, Congress passed the Low-Level Waste Policy Act. By this act, Congress directed the states to set up regional, multistate groups responsible for disposing of waste produced in each region. The interstate groups were to be approved by Congress by January 1, 1986. After that date, those states then bearing the burden for waste burial --

Washington, Nevada, and South Carolina -- could refuse to accept wastes generated outside of their respective regions. Although several regional compacts had been formed as a result of the 1980 legislation, no new burial sites were developed as was intended.

On January 15, 1986, Congress passed the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240) (Ref. 7). Key aspects of this legislation are as follows:

- It approves several of the regional compacts (Rocky Mountain, Southeast, Northwest, Midwest, Central Midwest and Central States).
- It extends the deadline for access to the three existing low-level waste disposal sites from January 1, 1986 to January 1, 1993.
- It allows the imposition of surcharges by host states on out-of-region generators.
- It puts a cap on the maximum volume of waste required to be accepted by the three existing LLW disposal sites.
- It provides for a pool of additional disposal volume in the event of unusual circumstances.
- It allocates to each nuclear plant a set amount of capacity at the three existing disposal sites.
- It provides for rebate of surcharges for waste generators in compacts meeting milestones for establishing their own waste disposal sites.

The 1986 legislation extended the time period wherein nuclear plants will be allowed to dispose of their wastes at the existing burial sites. However, the provision for surcharges on wastes produced by out-of-region generators could increase disposal costs substantially. The schedule of surcharges was tied to several milestones that must be met by compacts or single states "going-alone" by providing for their own radwaste disposal facility. These milestones are:

- States must join compacts or declared themselves as a single state providing their own disposal site by July 1, 1986
- Compacts or single states must select a state and develop a siting plan by January 1, 1988.
- Compacts or single states must file an application for a low-level radioactive waste disposal facility with the NRC (or appropriate state body if the sited state is an agreement state) by January 1, 1990, or the non-compact state must prove that is capable of storing, managing, and disposing of all low-level radwaste generated within its borders.
- All compacts or single-states must file a complete application for a disposal facility with the NRC by January 1, 1992.
- Access to out of state or compact disposal sites ends on December 31, 1992.

If these milestones are not met, the state or compact may be denied access to the existing disposal sites. In addition, all unsited states and compacts pay surcharges of $\$20/ft^3$ during 1988 and 1989, and $\$40/ft^3$ during and after 1990 (Note that states in the Northwest, Rocky Mountain, and Southeast compacts do not pay these charges since they are in a sited compact). A one-year grace period, broken into two six-month segments, has been allowed for the 1988 milestone. The penalty surcharge for the first six-month period is twice the applicable charge, i.e., $40/ft^3$. The penalty surcharge for the second six-month period is four times the applicable charge, i.e., $80/ft^3$. After January 1, 1989, states or compacts not in compliance with the milestones can be denied access to a current disposal facility. There is no grace period for the 1990 milestone.

The surcharges are collected by the currently sited states. Twenty-five percent of the funds are transferred to the Department of Energy and returned to states as further incentive to meet the deadlines. This incentive money is be used for site selection, development, and regulation. The incentive money is paid to states and compacts that meet the milestones. If a state or compact fails to meet the 1993 deadline, the utility may transfer possession of the waste to the state or receive its proportion of the incentive payment that would have gone to the state. The unsited state also is liable for any damages resulting from the unburied waste.

If a surcharge is applicable to the generic estimate being calculated, the following formula should be used:

$$\frac{\text{Surcharge}}{1000\ \text{ft}^3\ \text{Unproc. Waste}}\ [\$] = \frac{1000\ \text{ft}^3\ \text{Unproc. Waste}}{\text{VRF}} \times \text{Surcharge Rate}\ [\$/\text{ft}^3]$$

For example, for typical activity BCOTRASH, if the surcharge rate is $20/ft^3$, and the VRF is 3.78, then

$$\text{Total Surcharge} = \frac{1000\ \text{ft}^3}{3.78} \times \frac{\$20}{\text{ft}^3} = \$5291$$

Tables 5.11 and 5.12 contains a list of surcharges for each waste type, VRF, and various surcharge rates for BWRs and PWRs, respectively.

Several states and compacts are already working on the design of the new disposal facilities. The design of these new sites is tending toward the use of engineered barriers rather than the traditional shallow landfill. The engineered barrier designs will dramatically increase the capital cost of these new sites and these costs will be passed on to the users. These high capital costs, coupled with the trend toward volume reduction in the nuclear power industry, will increase costs far higher than today. One utility radwaste services vendor predicted burial costs on the order of $500/ft^3$ when the first new burial site opens.

Altogether, there are eight regional compacts consisting of a total of 39 states. Figure 5.1 shows the boundaries of the regional compacts (Ref. 8). Several compacts have made decisions regarding their sites.

- The Appalachian compact consists of Pennsylvania, Maryland, Delaware, and West Virginia. Pennsylvania is host state.
- The Central Midwest compact consists of Illinois and Kentucky. Illinois has been selected as the host state and is currently performing site characterization studies.
- The Central States compact consists of Nebraska (host), Kansas, Oklahoma, Arkansas, and Louisiana.
- The Midwest compact consists of Michigan (host), Ohio, Indiana, Wisconsin, Minnesota, Iowa, and Missouri.

Table 5.11 BWR Waste Disposal Surcharges (1988 dollars)

Waste Stream	Volume Reduction Factor	Typical Activity Base Costs *	$20 per cu ft Surcharge	Percent of Base Cost	$40 per cu ft Surcharge	Percent of Base Cost	$80.00 per cu ft Surcharge	Percent of Base Cost
COTRASH	2.27	$29,362	$8,811	30%	$17,621	60%	$35,242	120%
	3.78	$17,882	$5,291	30%	$10,582	59%	$21,164	118%
	5.67	$12,129	$3,527	29%	$7,055	58%	$14,109	116%
	8.69	$8,848	$2,301	26%	$4,603	52%	$9,206	104%
	113.4	$3,535	$176	5%	$353	10%	$705	20%
NCTRASH	0.2	$335,311	$100,000	30%	$200,000	60%	$400,000	119%
	0.4	$180,309	$50,000	28%	$100,000	55%	$200,000	111%
	0.6	$176,485	$33,333	19%	$66,667	[illegible]	$133,333	76%
	0.8	$140,667	$25,000	18%	$50,000	36%	$100,000	71%
IXRESIN	0.71	$183,059	$28,169	15%	$56,338	31%	$112,676	62%
	0.95	$142,429	$21,053	15%	$42,105	30%	$84,211	59%
	1.4	$114,429	$14,286	12%	$28,571	25%	$57,143	50%
	2	$105,475	$10,000	9%	$20,000	19%	$40,000	38%
	4	$65,804	$5,000	8%	$10,000	15%	$20,000	30%
CONCLIQ	0.71	$182,606	$28,169	15%	$56,338	31%	$112,676	62%
	1.9	$103,645	$10,526	10%	$21,053	20%	$42,105	41%
	2.4	$70,380	$8,333	12%	$16,667	24%	$33,333	47%
	3.8	$62,397	$5,263	8%	$10,526	17%	$21,053	34%
	4.5	$64,652	$4,444	7%	$8,889	14%	$17,778	27%
FSLUDGE	0.56	$232,390	$35,714	15%	$71,429	31%	$142,857	61%
	2	$95,308	$10,000	10%	$20,000	21%	$40,000	42%
	4	$69,491	$5,000	7%	$10,000	14%	$20,000	29%

* Total Disposal Costs per 1000 cubic feet of Unprocessed Waste Before Surcharges

Table 5.12 PWR Waste Disposal Surcharges (1988 dollars)

Waste Stream	Volume Reduction Factor	Typical Activity Base Costs *	$20 per cu ft Surcharge	Percent of Base Cost	$40 per cu ft Surcharge	Percent of Base Cost	$80.00 per cu ft Surcharge	Percent of Base Cost
COTRASH	3.78	$17,882	$5,291	30%	$10,582	59%	$21,164	118%
	5.67	$12,129	$3,527	29%	$7,055	58%	$14,109	116%
	8.69	$8,848	$2,301	26%	$4,603	52%	$9,206	104%
	113.4	$3,819	$176	5%	$353	9%	$705	18%
NCTRASH	0.2	$331,981	$100,000	30%	$200,000	60%	$400,000	120%
	0.4	$179,393	$50,000	28%	$100,000	56%	$200,000	111%
	0.6	$176,221	$33,333	19%	$66,667	38%	$133,333	76%
	0.8	$139,796	$25,000	18%	$50,000	36%	$100,000	72%
IXRESIN	0.71	$151,856	$28,169	19%	$56,338	37%	$112,676	74%
	0.95	$135,541	$21,053	16%	$42,105	31%	$84,211	62%
	1.4	$106,012	$14,286	13%	$28,571	27%	$57,143	54%
	2	$99,032	$10,000	10%	$20,000	20%	$40,000	40%
	4	$61,214	$5,000	8%	$10,000	16%	$20,000	33%
CONCLIQ	0.71	$98,857	$28,169	28%	$56,338	57%	$112,676	114%
	1.9	$42,904	$10,526	25%	$21,053	49%	$42,105	98%
	2.4	$25,339	$8,333	33%	$16,667	66%	$33,333	132%
	3.8	$28,570	$5,263	18%	$10,526	37%	$21,053	74%
	4.5	$22,757	$4,444	20%	$8,889	39%	$17,778	78%
FSLUDGE	0.56	$193,011	$35,714	19%	$71,429	37%	$142,857	74%
	2	$80,993	$10,000	12%	$20,000	25%	$40,000	49%
	4	$61,064	$5,000	8%	$10,000	16%	$20,000	33%

* Total Disposal Costs per 1000 cubic feet of Unprocessed Waste Before Surcharges

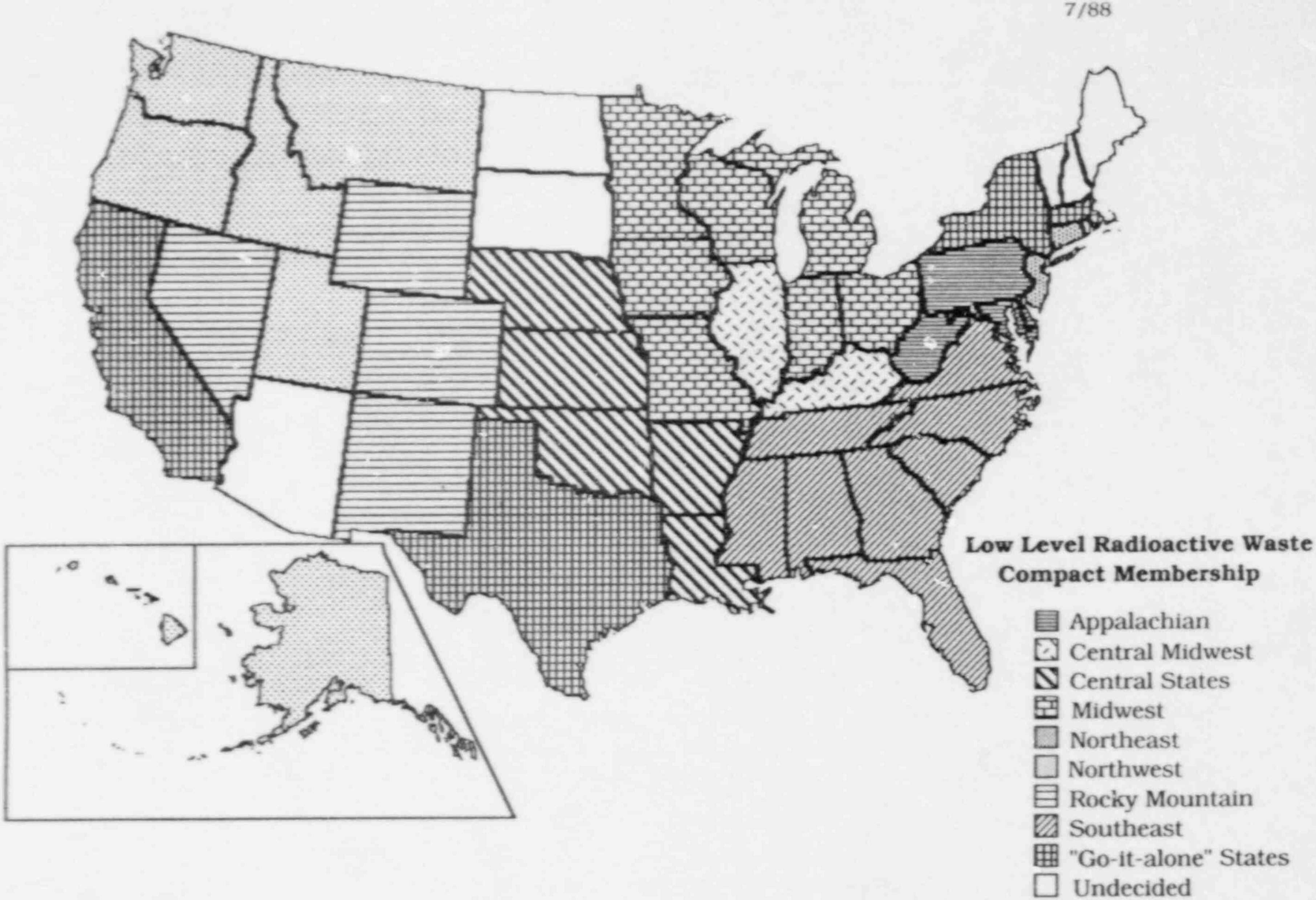

Figure 5.1 Low-Level Radioactive Waste Disposal Compacts

- The Northeast compact consists of New Jersey and Connecticut. They have currently decided for each to host a disposal site: one for Class A waste, and one for Classes B and C waste.

- The Northwest compact consists of Washington (host), Oregon, Idaho, Utah, Montana, Alaska, and Hawaii. The Hanford site in Washington will remain open indefinitely.
- The Rocky Mountain compact consists of Nevada, Colorado, New Mexico, and Wyoming. Nevada will host until 1992 at the Beatty site. Colorado will host thereafter.

- The Southeast compact consists of Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Virginia, and Tennessee. South Carolina will host at the Barnwell site until 1992, and then North Carolina will host a site for 20 years.

Eleven states, the District of Columbia, and all other U.S. territories are presently on their own. The following status of these states is current as of March 1988, but is subject to change:

- Texas, California, and New York are developing their own disposal sites. These states have made substantial progress toward site selection and characterization.

- Massachusetts and Maine have plans to develop their own disposal sites, but are not as far along as the previous group of states.

- Rhode Island, a small LLW producer, has a contract through 1989 with the Rocky Mountain compact to dispose its waste at the Beatty, NV site. Because of this arrangement, Rhode Island was judged in compliance with the milestones by the sited states. The District of Columbia is seeking a similar arrangement with the Rocky Mountain compact. It is likely that the US overseas possessions -- Puerto Rico, Virgin Islands, Guam, etc. -- will follow suit since they are also very small producers.

- Arizona, New Hampshire, North Dakota, South Dakota, and Vermont have no current plans for joining a compact or developing their own site.

Appendix D contains a list of operational nuclear plants and the states and compacts in which they are located. It also lists all applicable surcharges for each state by regional compacts or present compliance status.

The complicated nature of the compacts, "go-it-alone" states, and milestones makes it difficult to factor surcharges into the generic estimates. For example, in 1988, a plant in a sited compact pays no surcharge, while a plant in a state or compact in compliance with the milestones pays a $\$20/ft^3$ surcharge, and a plant in a state not in compliance pays $\$80/ft^3$. As shown in Tables 5.11 and 5.12, the significance of these surcharges range from 5 to 120% of the total disposal cost without the surcharges. The analyst should apply these surcharges at his discretion depending on the nature and scope of the modification he is estimating.

5.3 COMPUTATIONAL MODEL

The foregoing methods for calculating costs for processing, storage, transportation, and burial of low level radwastes as discussed in Section 5.2.1 through 5.2.4 were modeled using a Microsoft Excel™ spreadsheet operating on a Macintosh™ computer. This automated the calculation process such that a large number of cases could be covered. It also helped assure a consistent treatment among the large number of cases studied.

6.0 ESTIMATES OF WASTE DISPOSAL COSTS

This section presents the quantitative results of the waste disposal cost analysis performed as part of this effort. These results were generated using the methodology and bases described in Section 5. The following discussions describe the cost results for each waste stream. Major factors or sensitivities that significantly influence the costs are noted.

6.1 COST BASIS

There are four primary variables or key factors that have prominent influences on waste disposal costs. These key factors are:

- Reactor type (BWR and PWR)
- Waste type (NCTRASH, COTRASH, IXRESIN, CONCLIQ and FSLUDGE)
- Activity level (Low, Typical, High, and Very High)
- Extent of volume reduction (3 to 5 different VRFs for each waste type)

Each of these factors was essentially treated as an independent variable. Costs were calculated for all applicable combinations of these parameters. In addition, for each case transportation distance was treated as an independent variable and costs were calculated for several distinct one-way distances from the nuclear plant to the burial site: 250, 500, 1000, 2000 and 3000 miles. This range of transport distances covers most cases that might arise for U.S. nuclear plants. Sufficient information is provided so that costs for intermediate distances can be estimated.

All costs presented in this section represent the costs to dispose of 1000 cubic feet of as-generated waste for each waste stream. This is the volume of the waste in its as-generated condition, i.e., prior to any type of processing to reduce its volume, solidify it, or otherwise treat it. The selection of the 1000 ft^3 reference volume is arbitrary, but reasonable. Since the annual volume of untreated waste generated by typical light water reactor plants is in the range of 15000 to 35000 cubic feet, the reference value of 1000 represents a relatively small fraction of the total annual waste generation (Ref. 1). Costs for volumes greater than this can readily be estimated using linear scaling. None of the cost elements in this volume range appear to be sensitive to volume throughput, and thus, the linear scaling with volume should give reasonable results. However, costs for volumes less than 1000 cubic feet tend to be overestimated when curie or weight burial surcharges had been assessed against the 1000 ft^3 reference volume. Since these charges are threshold charges, they would not tend to scale linearly downward and burial costs would be overestimated.

The quantitative results show that the extent of volume reduction for any of the waste streams and the radioactivity content of the wastes heavily influence the total disposal costs. It is worthwhile to review the ranges of these parameters and characteristics to better understand their impact on costs.

The extent of volume reduction for a given waste stream basically determines the volume of waste that must be stored, transported, and buried. It also influences the specific activity (Ci/ft^3) of the processed wastes and the container surface dose rate. The greater the volume reduction, the lower the overall costs in general, and the higher the surface dose rate.

Figure 6.1 shows the variation in the number of 7.5-ft^3 containers needed to hold 1000 ft^3 of waste after the waste has been processed. The independent variable is volume reduction factor (VRF). For the cases of interest to this study, the VRFs varied from a low of 0.2 to a high of almost 114. The important area of this overall range is covered in the figure. As indicated in Figure 6.1, the number of containers needed is inversely

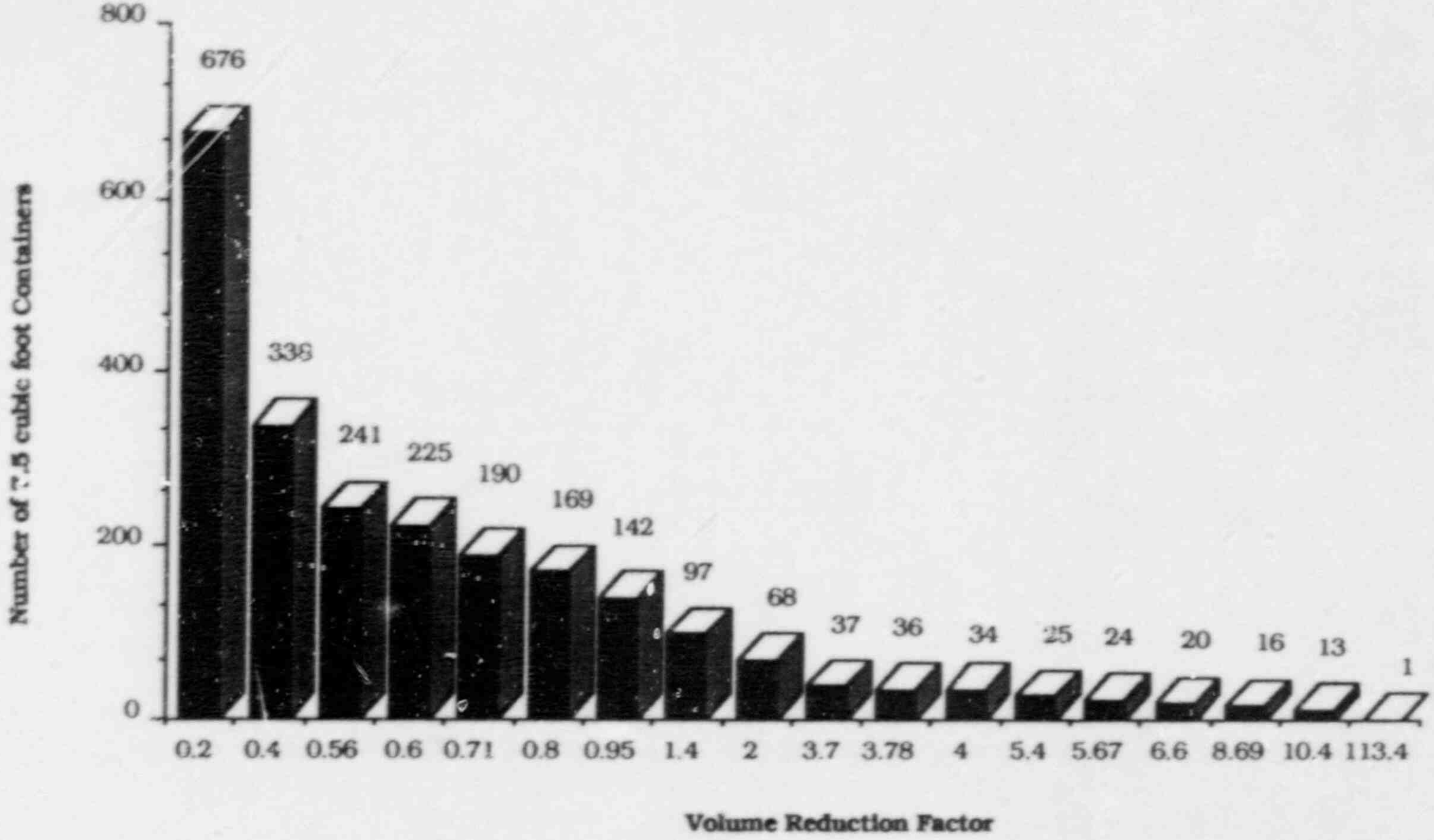

Figure 6.1 Number of 7.5-cubic foot Containers Needed to Hold 1000 cubic feet of Unprocessed Waste as a Function of Volume Reduction Factor

proportional to the volume reduction achieved. For the lowest volume reduction factor, ~ 0.2, over 676 7.5-ft3 drums are needed. At the other end of the spectrum the VRF of ~ 114 only slightly more than one drum would be needed.

The number of containers needed to hold the remains of 1000 ft^3 of as-generated waste is essentially independent of waste type. There is a dependency to the extent that only certain volume reduction factors are applicable to a given waste stream.

The different waste streams vary significantly in their typical activity levels. At the lower extreme, as-generated compactible trash for a BWR (BCOTRASH) has a typical activity concentration of 0.11 mCi/ft^3. At the other extreme, BWR filter sludge (BFSLUDGE) has a typical activity concentration of about 230 mCi/ft^3. Thus, the specific activity from one waste stream to another can vary by at least a factor of 1000, at least for BWR wastes. PWR wastes appear to have less variation, but the difference from one stream to the next is still quite large.

The typical activity for each waste stream was derived from the nuclear plant survey results presented in Ref. 1. The typical values, therefore, are averages of the data obtained from a large number of nuclear plants. For any plant, the specific activity present in a given waste stream will vary from one time to the next. Similarly, it will vary from one plant to the next.

To account for variations in waste stream activity, the effects of both lower activity concentrations and higher concentrations were considered for each waste stream. The lowest level was assumed to be a factor of 10 less than the typical or average activity as reported in Ref. 1. The high activity level was assumed to be a factor of 10 greater than the average, and the very high was assumed to be a factor of 100 greater than average. This range covers most of the range reported in Ref. 1.

6.2 WASTE STREAM DISPOSAL COSTS

The following discussions review the estimated costs for the disposal of each type of low-level radioactive waste. The discussions are presented in the following order:

1. NCTRASH Costs
2. COTRASH Costs
3. IXRESIN Costs
4. CONCLIQ Costs
5. FSLUDGE Costs

Each section discusses costs for both BWR and PWR wastes. Variations in costs due to waste stream activity level, extent of volume reduction, and distance from the plant site to the burial sites are also discussed.

For more detailed cost estimates, users of this document may wish to adjust the costs for specific transportation distances and specific burial sites. Appendix B presents transportation costs for one-way distances of 250, 500, 2000, and 3000 miles. Differential costs compared to the 1000 mile transport case are noted. Data are provided for low, typical, high, and very high activity concentrations for each waste stream. Appendix C gives burial costs specific to the two sites operated by U.S. Ecology, Inc. (Beatty, NV and Hanford, WA) and to the Barnwell, SC burial site operated by Chem-Nuclear Systems, Inc. The differential costs for specific burial sites compared to the average burial costs are also presented in Appendix C.

6.2.1 Disposal Costs for Non-Compactible Trash (NCTRASH)

The primary waste stream likely to result from NRC mandated modifications or repairs to nuclear power plants is non-compactible trash. As noted previously, this waste stream encompasses the piping, components, and similar hardware which are replaced and become scrap as a result of a given regulatory requirement.

Figures 6.2 (a) and 6.2(b) display the total waste disposal costs for BWR and PWR non-compactible trash, respectively. The results are shown for each volume reduction factor applicable to these waste streams. The contributions to the costs for processing, storage, transport, and burial of the wastes are also displayed. Figure 6.2 applies to the case of typical activity wastes being transported a distance of 1000 miles.

For the conditions shown, the costs are almost identical for both BWR and PWR wastes. At the lowest volume reduction factor (0.2) the analysis indicated that the waste disposal costs should be on the order of $335,000 per 1000 cubic feet of waste. This is the as-generated volume of the waste solids and excludes void volume. The figure indicates that costs should drop by roughly a factor of 2.5 if highly effective packing and some degree of compaction can be employed with this waste stream.

The available data indicate that the majority of U.S. nuclear plants today are achieving volume reduction factors for this waste stream on the order of 0.2 to 0.4 (hand packaging, no added compaction or extensive cutting to maximize density). Thus, the higher costs displayed in Figure 6.2 are believed to be most representative of present day practice.

Figure 6.2 indicates the largest cost contribution is made by the burial costs, followed by processing costs. Processing becomes relatively less costly as greater volume reduction is achieved. The burial costs displayed in these figures are averages for Barnwell and the two sites operated by U.S. Ecology. In general, the burial costs, and thus the total costs, would be about $19,000 to $52,000 higher than shown per 1000 cubic feet of waste if the burial site is Barnwell. Conversely, the values would be $19,000 to $52,000 lower if U.S. Ecology burial sites are used. Site-specific burial cost adjustments for all waste types and VRFs are presented in Appendix C.

The cost estimates displayed in Figure 6.2 apply to both typical and low activity NCTRASH. The typical activity of this waste stream is low enough that very little, if any, of the charges are dependent on the activity.

Figures 6.3 (a) and 6.3 (b) show the effects on costs of higher activity levels. The BWR case, Figure 6.3 (a) shows that there is only a very slight cost dependence on activity, at least over the factor of 100 variation in specific activity covered from the (activity = 1.33×10^{-4} Ci/ft^3) low to the high cases. An increase in the activity level to the very high case (activity = 0.133 Ci/ft^3) results in a fairly substantial increase in disposal costs. Figure 6.3(b), for PWRs, on the other hand shows a more pronounced effect of activity on costs throughout the activity range shown. Increases in the transportation and burial cost components are the dominant contributors to the increased costs with the rise in activity level.

Figures 6.2 and 6.3 indicate that the costs of disposing of non-compactible trash vary significantly with both volume reduction and waste activity level. At very high waste activity levels,the costs also become sensitive to reactor type. Increased volume reduction reduces each of the cost components, except for the burial costs. It reduces the number of containers needed to package a fixed volume of as-generated waste. This also reduces the amount of in-plant labor associated with the packaging. Both of these factors contribute to reduced processing costs. Similarly, the higher VRFs translate into fewer containers that have to be stored and transported. Each of these costs are reduced accordingly.

Costs rise with increasing waste activity level because of the effects on transportation and burial. As activity increases, a point is reached where shielded casks are needed for transport. At this point, cask rental charges are incurred and the payload per shipment

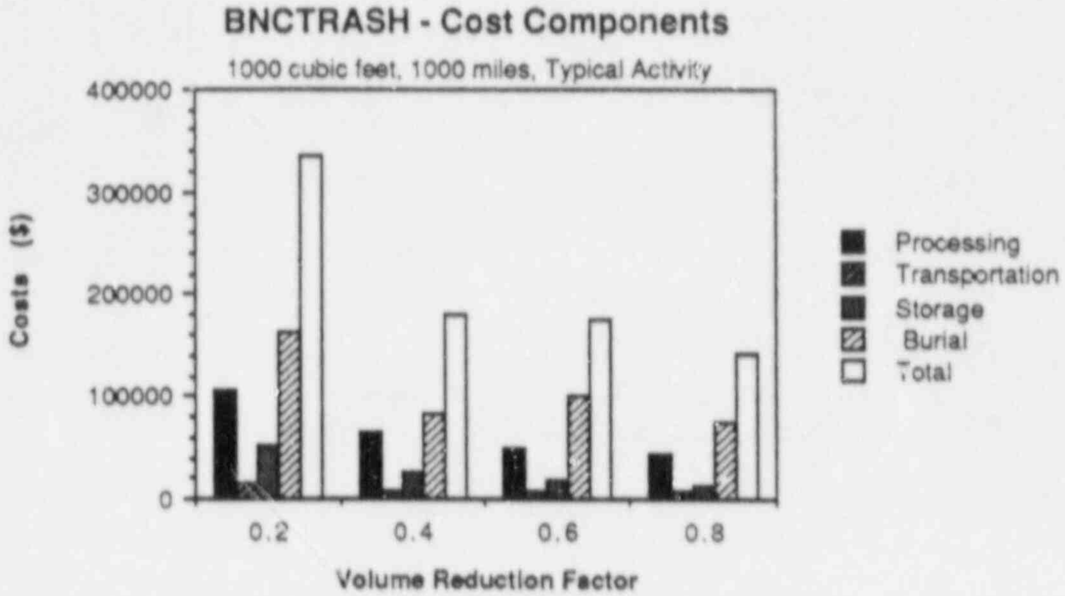

Figure 6.2. (a) Disposal Costs for BWR Noncompactible Trash

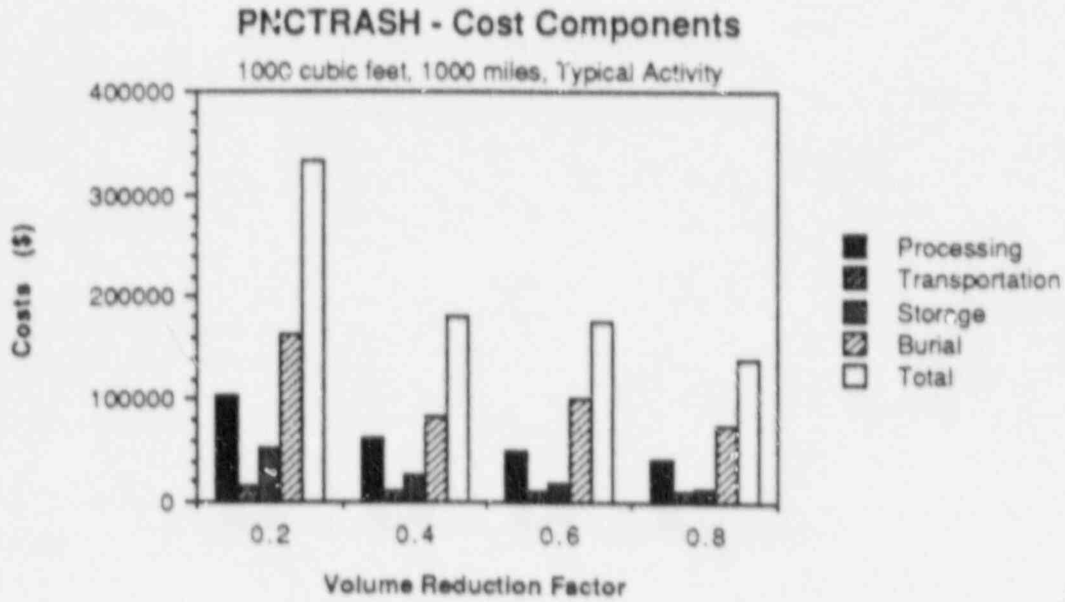

Figure 6.2. (b) Disposal Costs for PWR Noncompactible Trash

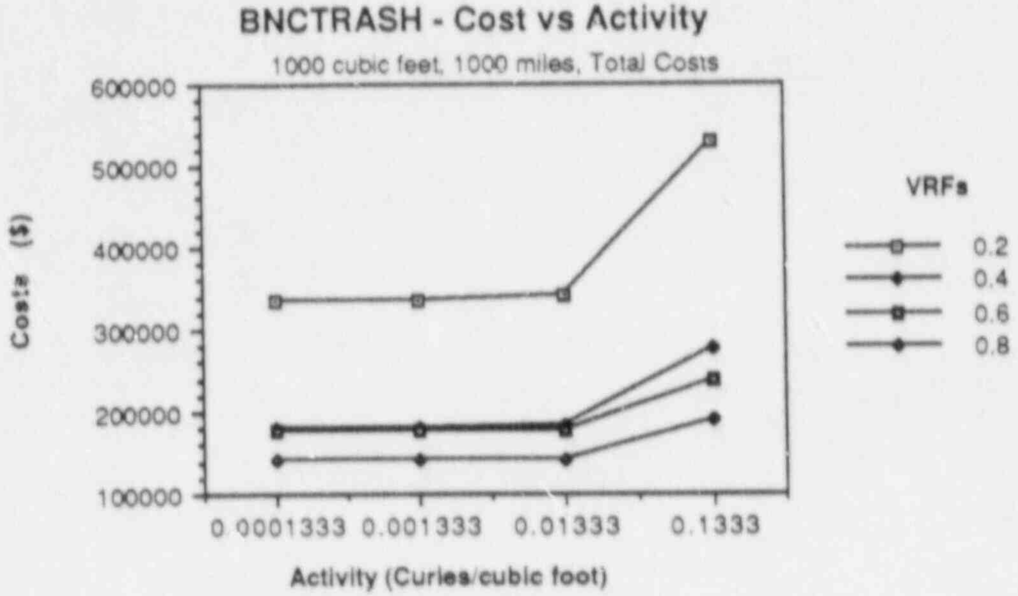

Figure 6.3. (a) Cost Sensitivity of BWR Noncompactible Trash to Activity Level

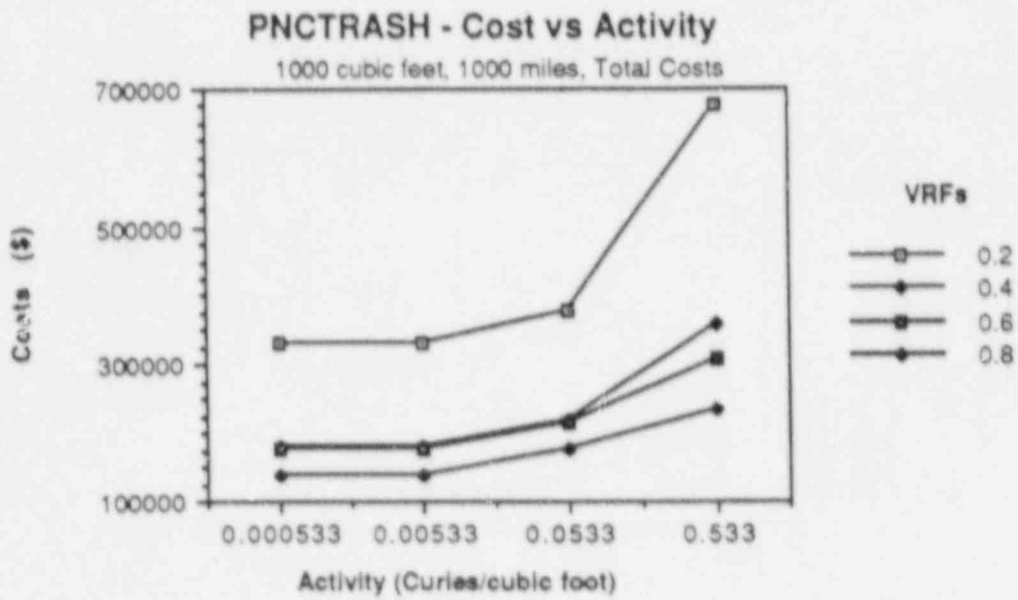

Figure 6.3. (b) Cost Sensitivity of PWR Noncompactible Trash to Activity Level

is reduced, thus necessitating more shipments. A point is also reached where the curie content per shipment is high enough to trigger curie surcharges for burial.

Figures 6.2 and 6.3 are based on transport distances of 1000 miles. Figure 6.4 shows the effects on costs for distances both greater and less than 1000 miles. This figure applies to NCTRASH from both BWRs and PWRs, and it also covers the cases for low and typical activity waste streams. The transportation costs for non-compactible trash are relatively insensitive to volume reduction factor, at least for VRFs greater than 0.2. This is because the quantity of NCTRASH transported on a single vehicle is limited by the total weight rather than by volume or radiation considerations. Therefore, as the VRF increases and more NCTRASH is loaded into a fixed size container its weight increases. The number of containers per shipment must decrease to stay within the vehicle weight limits. Thus, transportation costs remain relatively constant over the range of volume reduction factors applicable to this waste stream.

6.2.2 Disposal Costs for Compactible Trash (COTRASH)

Compactible trash is likely to be generated whenever repairs or modifications are made to radioactive systems of nuclear power plants. The description of this waste stream in Section 3 noted that it is made up largely of paper, plastic, and cloth; materials that are typically used to prevent the spread of contamination, to protect personnel, and to clean up contaminated areas. The previous discussions also noted that the as-generated volume of compactible wastes may often be larger than the volume of non-compactible trash generated during a given repair or modification. On a plant-wide annual basis, the 1981 utility data indicated that the ratio of as-generated compactible trash volume to non-compactible trash volume was on the order of 15 for PWRs and 30 for BWRs (Ref. 1). Thus, from a volume standpoint, one would expect that COTRASH generation, and the related disposal costs, would be a significant consideration in the total waste disposal cost picture.

Figure 6.5 shows the estimated costs to dispose of 1000 cubic feet of compactible trash. Figure 6.5 (a) applies to BWRs and 6.5(b) to PWRs. The 1000 cubic feet refers to the as-generated waste volume, i.e., prior to any compaction or other volume reduction processing. The conditions represented in these figures include a one-way transport distance of 1000 miles and a typical or average activity level for the waste. For BWR COTRASH the typical activity is 0.00011 Ci/ft3 and for PWRs it is 0.000185 Ci/ft3, both in the as-generated condition (Ref. 1).

Figure 6.5 (a) covers one additional VRF (VRF=2.27) than does 6.5(b). This lower-end VRF is included to reflect the conditions reported in Ref. 1.

The total costs and the elements making up the totals are considerably smaller than the disposal costs for non-compactible trash. Figure 6.5 shows that the disposal costs for COTRASH are estimated to be less than $30,000 per 1000 cubic feet of waste. Thus, COTRASH costs are less than one-tenth of the NCTRASH costs for the same as-generated volume. There are several reasons why the COTRASH costs are much less than those depicted in Figures 6.5 (a) & (b) for NCTRASH. First, the average VRF for compactible trash is about 4 to 6 while that for non-compactible trash is only about 0.2 to 0.4. Thus there is over a factor of 10 difference in the volume of packaged waste between the two waste streams. This means that at least 10 times as many containers are consumed in processing a given as-generated volume of non-compactible waste as for the same volume of compactible waste. More containers must be handled and more shipments must be made for the NCTRASH. Similarly, the burial volume, and thus the burial charges, will be much greater for the non-compactible waste as compared to the compactible trash.

A comparison of Figures 6.5 (a) and (b) reveals that the total disposal costs and the various cost elements are virtually identical for BWRs and PWRs over the range of

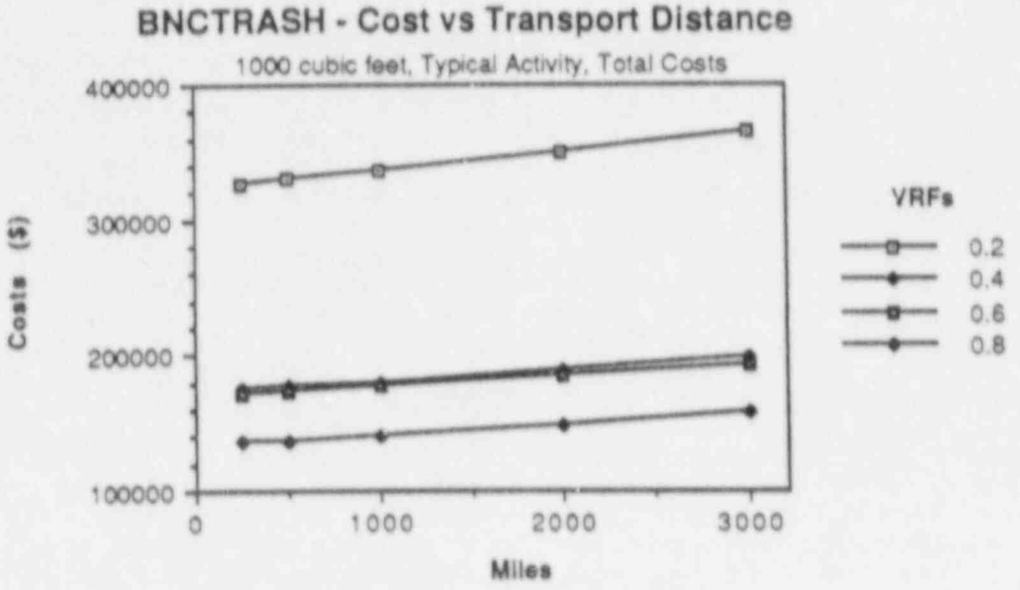

Figure 6.4. (a) Variation in BWR Noncompactible Trash Disposal Cost with Transport Distance

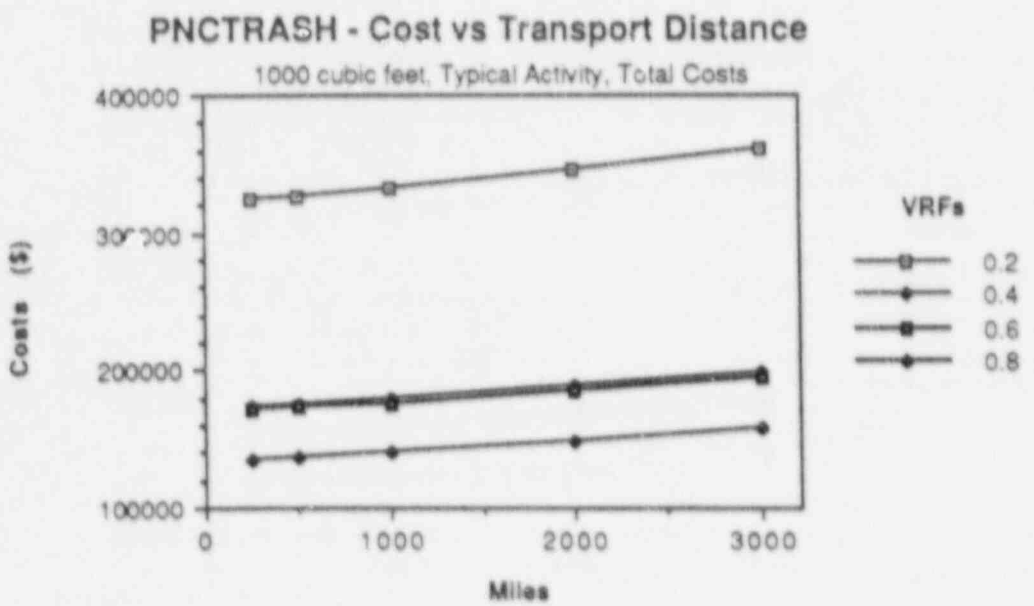

Figure 6.4. (b) Variation in PWR Noncompactible Trash Disposal Cost with Transport Distance

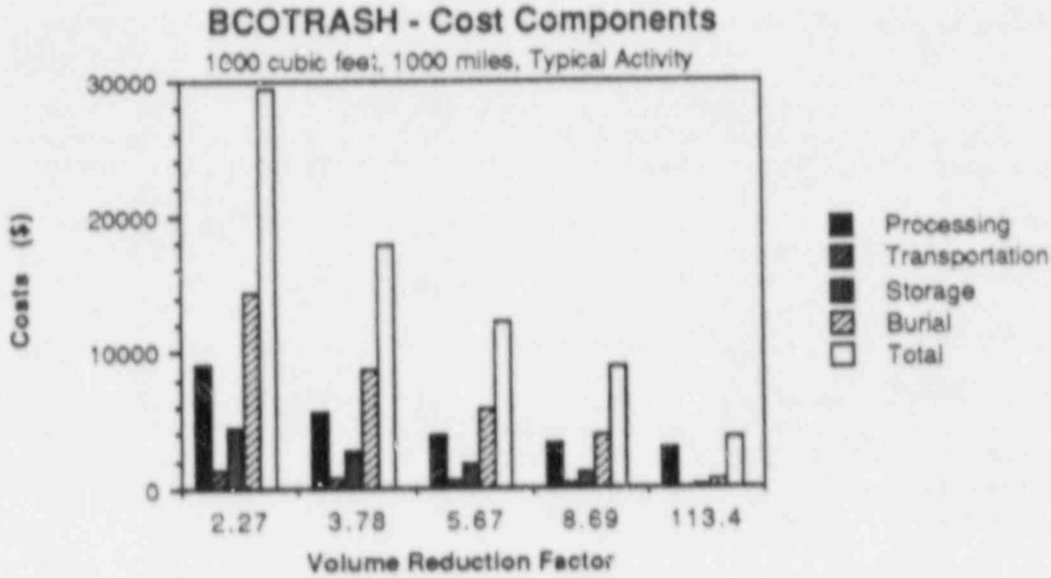

Figure 6.5. (a) Disposal Costs for BWR Compactible Trash

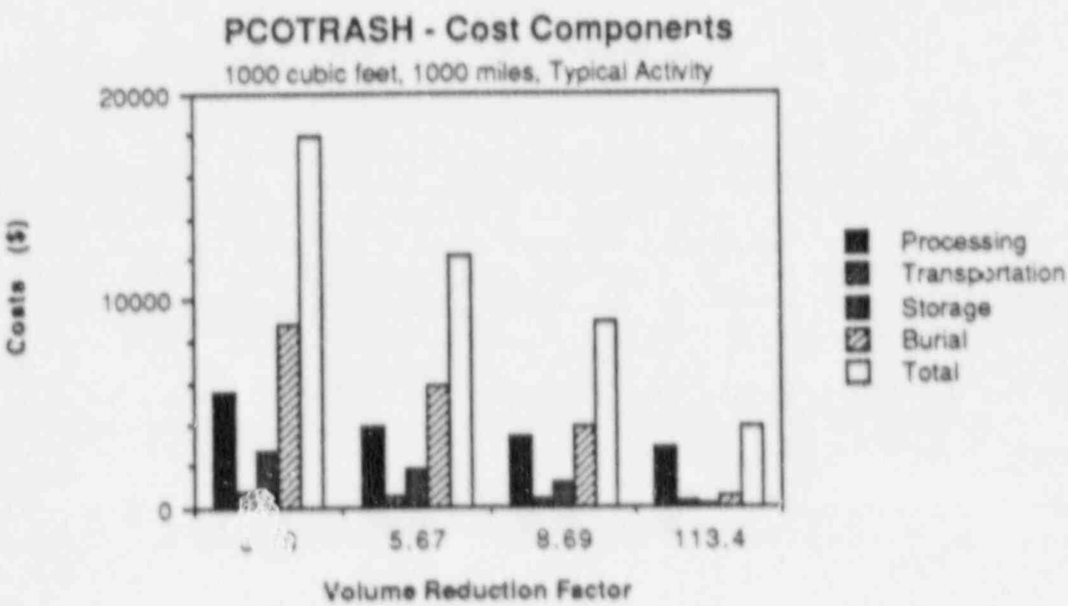

Figure 6.5. (b) Disposal Costs for PWR Compactible Trash

volume reduction factors from 3.78 to 113.4. The lower compaction case for BWRs (VRF = 2.27) reflects practices at BWRs as of the early 1980s (Ref. 1).

The displays in Figure 6.5 indicate that burial costs and processing costs are the largest contributors to the total for this waste stream. Compactible trash is relatively light weight. Therefore, weight is typically not a limitation for either transportation of this waste or in terms of incurring heavy-lift charges at the burial sites. Costs are strongly influenced by the number of containers of processed waste which must be disposed. This, in turn, is inversely proportional to the extent of volume reduction achieved.

The burial costs shown in Figure 6.5 are averages based on distinct rate schedules for the different burial sites available. For COTRASH the difference in costs between the average and specific burial site costs is only on the order of ± $1000 or less per 1000 cubic feet of as-generated waste. The higher cost would be for Barnwell and the lower cost for Beatty, NV, or Hanford, WA (see Appendix C).

The limited survey made of present day utility practices revealed that most utilities are currently achieving volume reduction factors for COTRASH in the range of 3.8 to 5.7. This is true for both BWRs and PWRs. It is estimated that fewer than 20% of the plants are achieving VRFs of 8.7, which corresponds to the use of a "supercompactor", and even fewer are using incineration procedures (VRF = 113.4).

Figures 6.6 (a) and (b) show the effects of waste stream activity level on waste disposal costs. Total estimated costs are shown for low, typical, high, and very high activity wastes. The associated activity concentrations for the waste in the as- generated condition are as follows.

COTRASH Waste Stream Activity Concentration, Ci/ft^3

	BWRs	PWRs
Low	0.00001	0.0000185
Typical	0.00011	0.000185
High	0.0011	0.00185
Very High	0.011	0.0185

The levels of activity for COTRASH are low enough so that total costs are relatively insensitive to this parameter, except when very high activities are considered. A factor of ten higher activity concentration compared to the average level for this waste stream increases disposal costs by at most a few thousand dollars per 1000 cubic feet of waste. However, a factor of 100 increase in activity compared to the average activity level will roughly double the overall disposal costs. There is essentially no difference in cost between the low activity and average activity cases.

The results displayed in Figures 6.5 and 6.6 reveal that the key factors influencing COTRASH costs are the extent of volume reduction achieved and waste activity level. Costs are not very sensitive to reactor type.

Figure 6.7 shows the effects of transport distance on the overall costs. Distance plays a relatively minor role, in general changing the total costs by 10% or less over distances ranging up to 3000 miles.

6.2.3 Disposal Costs for Ion-Exchange Resins (IXRESIN)

Repairs or modifications to nuclear plants mandated by NRC requirements may generate some ion-exchange resin wastes. The resins are used to remove particulates

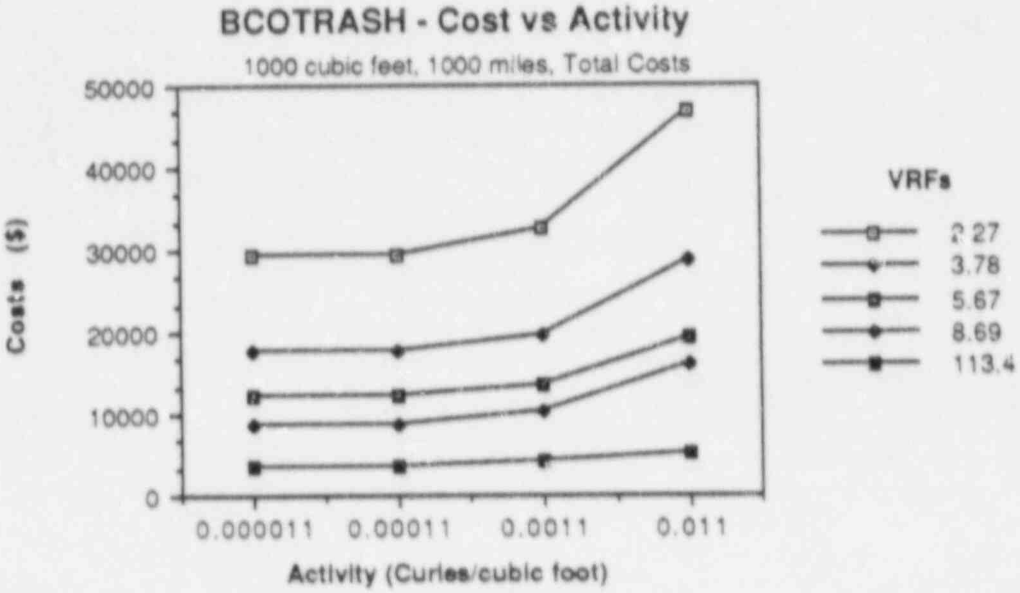

Figure 6.6. (a) Cost Sensitivity of BWR Compactible Trash to Activity Level

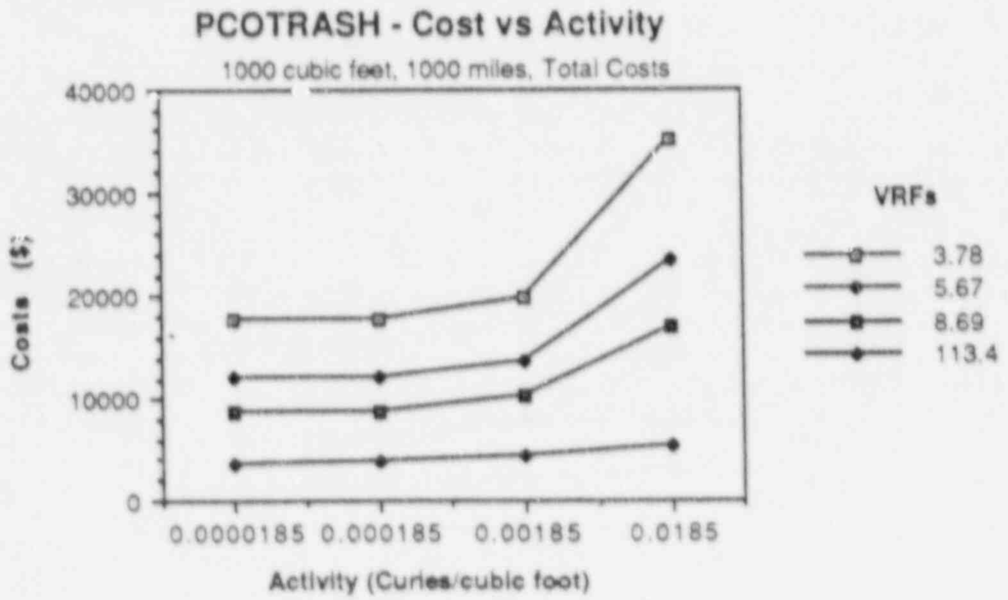

Figure 6.6. (b) Cost Sensitivity of PWR Compactible Trash to Activity Level

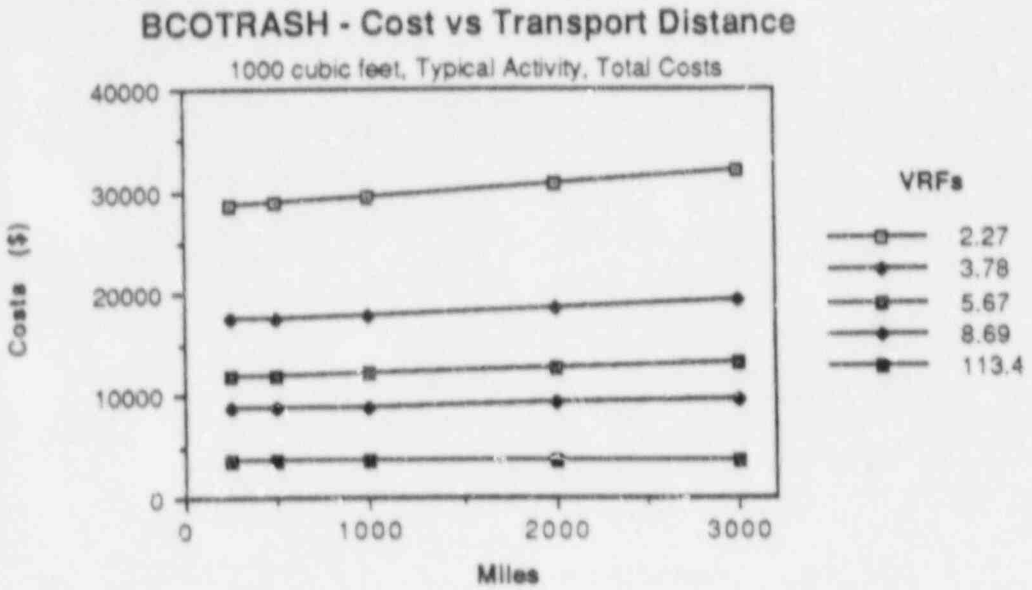

Figure 6.7. (a) Variation in BWR Compactible Trash Disposal Cost with Transport Distance

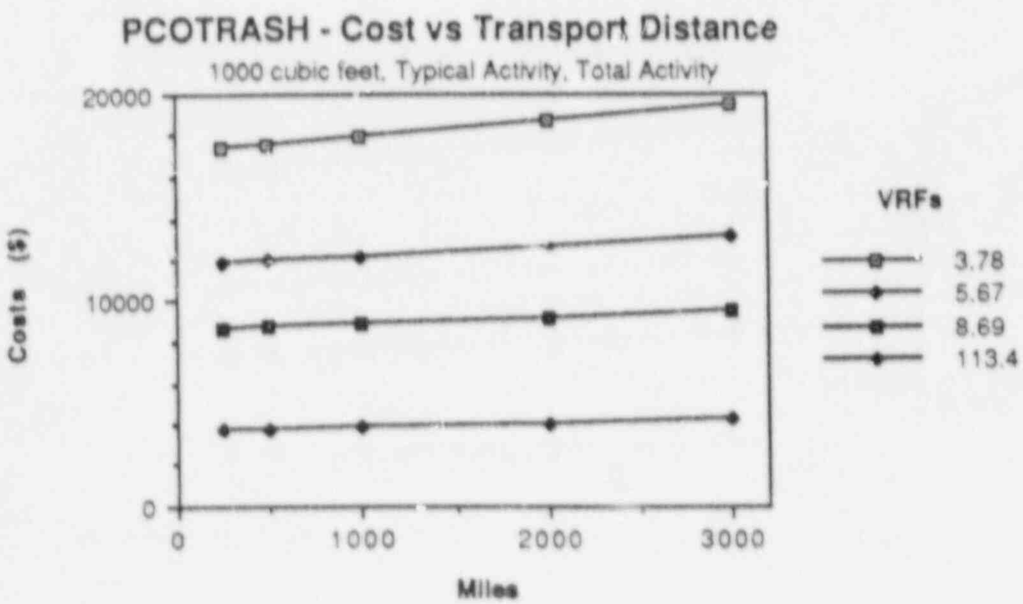

Figure 6.7. (b) Variation in PWR Compactible Trash Disposal Cost with Transport Distance

and dissolved solids from liquid steams. Liquids that must be processed may be generated as a result of cleanup, washing, or decontamination of radioactive systems. They may also be produced from laundering of protective clothing and masks. The amount of contaminated resins generated as a result of maintenance and repair operations is not expected to be large (Ref. 3).

The activity levels which typify ion-exchange resins are several orders of magnitude higher than that which characterize the dry waste streams. This higher activity for IXRESINS generally results in significantly higher storage, transportation, and burial costs as compared to these elements for dry wastes.

Figure 6.8 shows disposal costs for IXRESIN over the range of applicable volume reduction factors. The relative contributions made by processing, storage, transportation, and burial are displayed. Part (a) of this figure applies to BWR wastes and part (b) to PWR wastes. The costs shown are based on the typical activity for this waste stream and on a transport distance of 1000 miles from the plant to the burial site.

The characteristics displayed in Figure 6.8 reveal that burial costs are the largest contributors to total disposal costs, at least for the lower volume reduction factors applicable to IXRESINS. In contrast to the results shown for the dry waste streams (Sections 6.2.1 and 6.2.2), transportation costs play a much more prominent role. The high activity of this waste stream generally requires that shielded casks be used for transport. This decreases the payload and increases the number of trips required per 1000 cubic feet of unprocessed waste. BWR resins typically have an activity concentration which is about 60% higher than that for PWR resins. They require more shielding during transport, which results in heavier casks and fewer containers of waste per shipment. Thus, the BWR waste requires more shipments. The higher curie inventory for BWR wastes also translates into higher burial costs as compared to PWR resins.

The results displayed in Figure 6.8 indicate that costs vary by a factor of about 2.8 between the highest and lowest volume reduction factors. There does not appear to be much difference in costs between volume reduction factors of 1.4 and 2.0.

Each of the volume reduction factors shown in Figure 6.8 represents a different treatment process for the waste. These different processes are noted below.

IXRESIN Volume Reduction Processes

Process	Applicable Volume Reduction Factor
Solidification in cement	0.71
Dewatered, placed in high integrity containers	0.95
Mobile evaporator, solidification in binder	1.4
Evaporation of water, grinding of resins, solidification in binder	2.0
Incineration, solidification of ash in binder	4.0

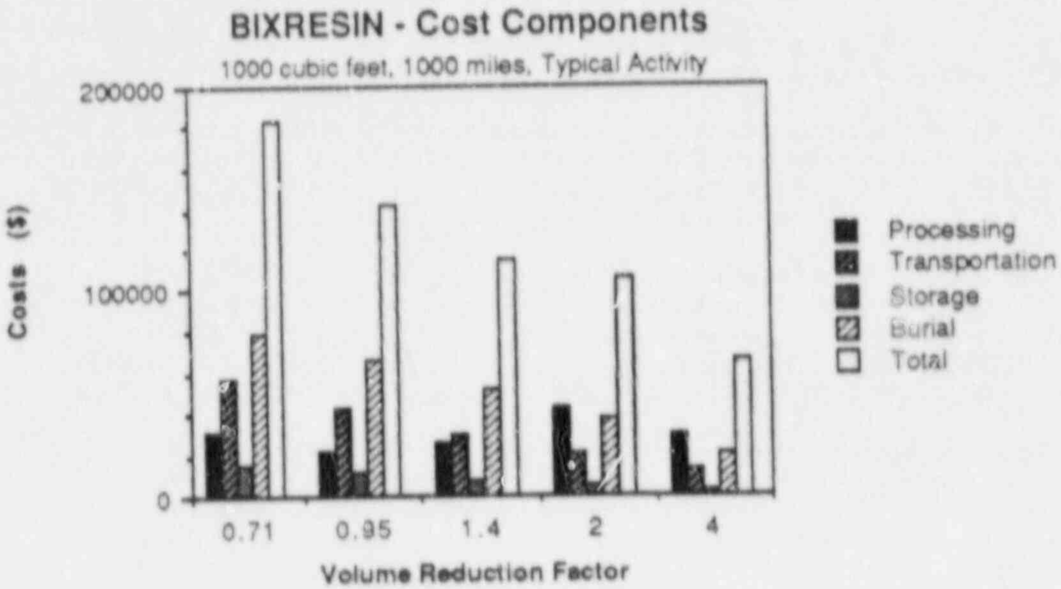

Figure 6.8. (a) Disposal Costs for BWR Ion-Exchange Resins

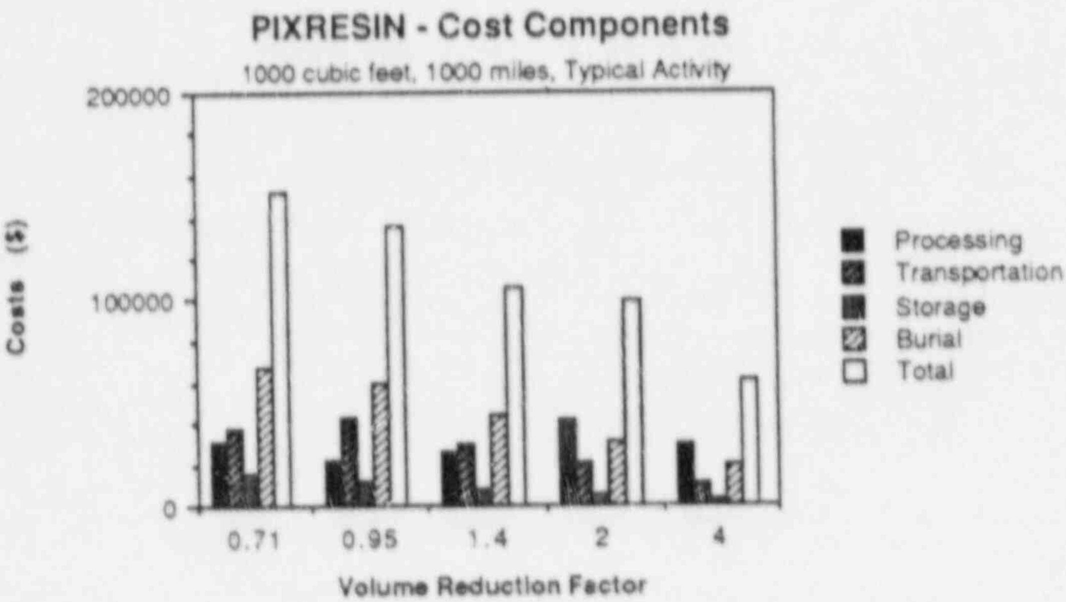

Figure 6.8. (b) Disposal Costs for PWR Ion-Exchange Resins

At the present time, most plants appear to dispose of ion-exchange resins by dewatering them and placing them in high integrity containers for burial. This process is represented by the volume reduction factor of 0.95. A significant number of plants still solidify the resins in concrete (VRF = 0.71). Few plants have gone to the more advanced treatment processes which result in volume reduction factors greater than 1.0.

As with the other waste streams, the effects of higher and lower activity concentrations on disposal costs was studied. Activity level has a much larger influence on costs for IXRESINS than that for the dry waste streams. Figure 6.9 illustrates the effects for IXRESINS. The graphs indicate that a factor of 10 reduction in stream activity, compared to the average, will reduce disposal costs about 30 to 50%, while a waste activity which is a factor of 10 higher than average will increase the total costs about 60 to 100%. Activity levels 100 times greater than average result in costs 2 to 3.5 times higher.

Figure 6.10 shows the quantitative effects of transport distance. The total costs are much more sensitive to transport distance for this waste stream than was the case for NCTRASH and COTRASH. The effect is more prominent at the lower volume reduction factors where more individual waste shipments would be required because of the greater numbers of containers of waste involved.

The results displayed in Figures 6.8, 6.9 and 6.10 indicate that disposal costs for IXRESINS are sensitive to each of the key factors studied. That is, the total disposal costs per 1000 cubic feet of as-generated IXRESIN are sensitive to reactor type, to volume reduction level, to waste stream activity, and to transport distance. Therefore, in estimating the costs of disposing of ion-exchange resins, it is important that the particulars of the case be well defined. The estimator should know the reactor type, the relative level of activity of the resin in question, the volume reduction process used, and the transport distance involved. In addition, the specific burial site used can impact total costs by as much as ±50% (see Appendix C).

6.2.4 Disposal Costs for Concentrated Liquid Wastes (CONCLIQ)

Concentrated liquid radwastes are produced in nuclear plants as a result of efforts to reduce the volume of contaminated liquid wastes. These waste streams are subjected to heating processes which evaporate much of the water but leave behind the non-volatile chemicals and solids. Liquids with high concentrations of such chemicals are also produced by the evaporators normally used in the plant steam generation process. The costs of disposing of this waste stream is of interest here because concentrated liquid wastes may be generated from draining and flushing operations or from wash-down efforts associated with repairs and modifications.

The disposal of wastes in liquid form is discouraged because of the greater potential for contamination of water systems or migration of radioactive materials to uncontrolled areas. Therefore, the concentrated liquid wastes from nuclear plants are generally solidified with cement or otherwise stabilized prior to disposal.

The following table lists the various processes considered herein to treat this waste stream. The associated volume reduction factors are also shown.

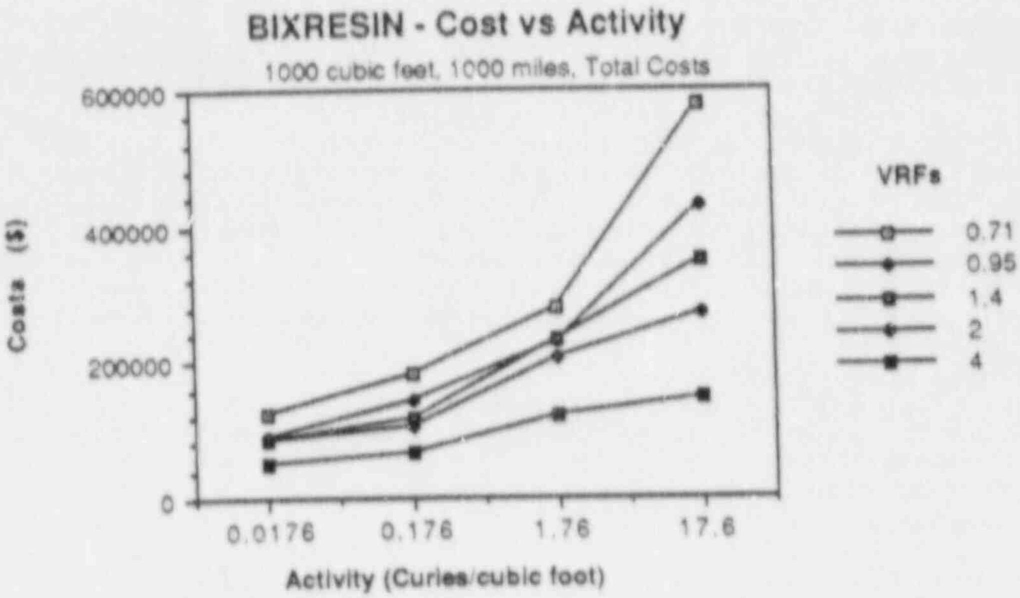

Figure 6.9. (a) Cost Sensitivity of BWR Ion-Exchange Resins to Activity Level

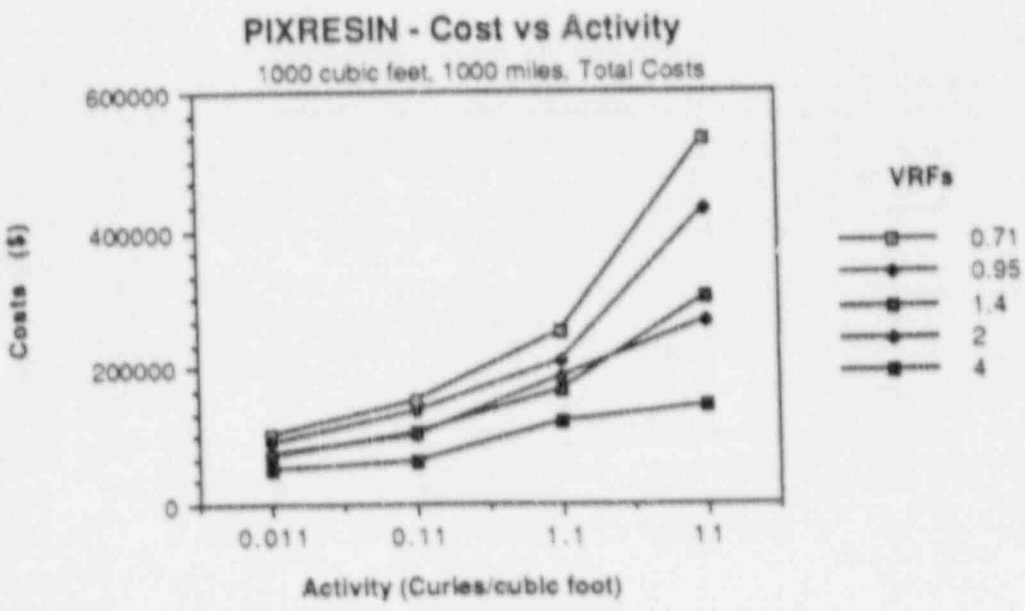

Figure 6.9. (b) Cost Sensitivity of PWR Ion-Exchange Resins to Activity Level

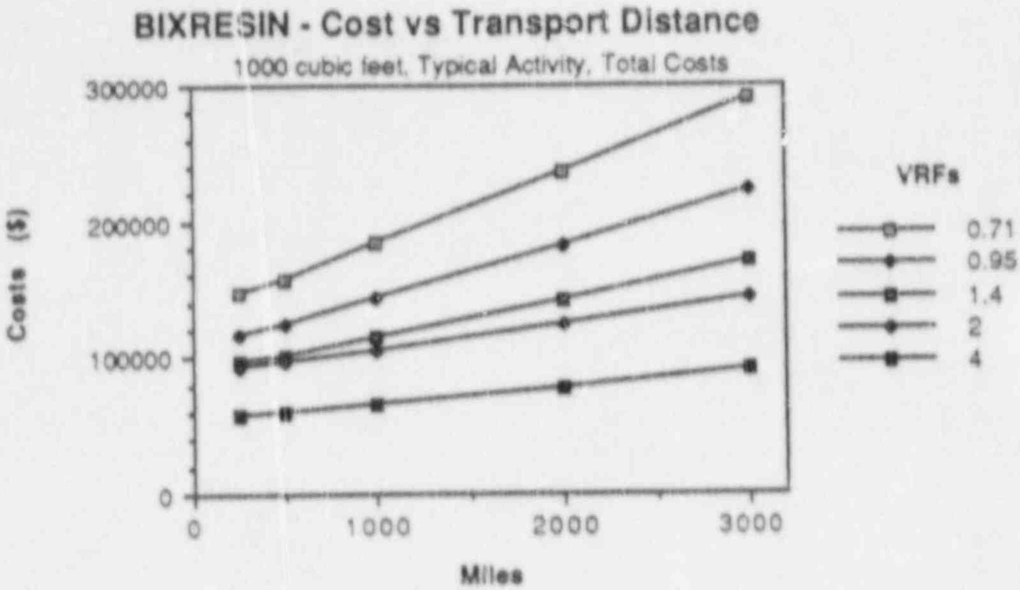

Figure 6.10. (a) Variation in BWR Ion-Exchange Resins Disposal Cost with Transport Distance

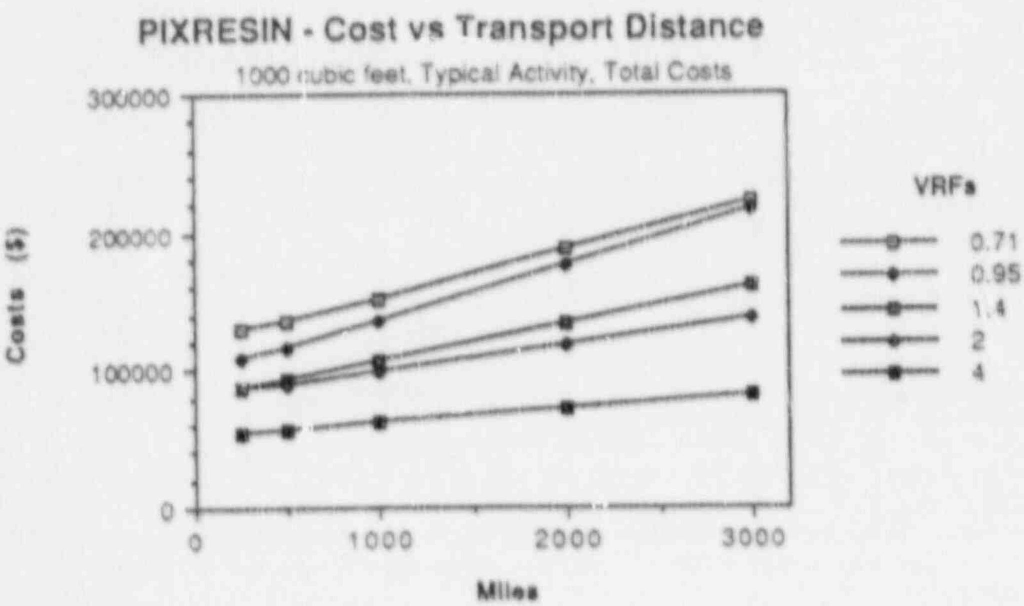

Figure 6.10. (b) Variation in PWR Ion-Exchange Resins Disposal Cost with Transport Distance

CONCLIQ Volume Reduction Processes

Process	Volume Reduction Factor BWR	PWR
Solidification in Cement	0.71	0.71
Evaporator/Crystallizer, solidification in binder	1.9	3.7
Mobile evaporator, solidification in binder	2.4	5.4
Evaporator, grinding of residue, solidification in binder	3.8	6.6
Dryer/incinerator, solidification of ash in binder	4.5	10.4

The volume reduction factors are different between BWRs and PWRs for this waste stream because the chemical makeup and chemical concentrations of the unprocessed waste are different. The limited survey of nuclear utilities conducted during this study indicated that most plants solidify the concentrated liquid in cement. This is without more extensive concentration through more advanced evaporation processes. Thus, the VRF of 0.71 represents the type of treatment in most common use at this time.

Figure 6.11 shows the costs of disposing of concentrated liquid radwastes. The BWR case is shown in 6.11 (a) and the PWR case in 6.11 (b). These figures display total costs and the costs associated with processing, storage, transport, and burial of the wastes for each of the applicable volume reduction factors. The costs displayed are for 1000 cubic feet of nominal activity wastes transported 1000 miles to the burial site.

The costs in Figure 6.11 indicate that it is more costly to dispose of BWR concentrated liquids than PWR concentrated liquids. There are two primary reasons for this. First, the activity concentration in this waste stream is typically about 0.17 Ci/ft^3 for BWRs and only about 0.01 Ci/ft^3 for PWRs. This higher activity for BWR wastes translates into significantly higher transportation and burial costs. Second, the BWR wastes are not as amenable to extensive volume reduction with the result that a greater volume of wastes must be disposed of.

Figure 6.11 (a) indicates that disposal of BWR concentrated liquids by solidification in cement should result in total disposal costs of about $183,000 per 1000 cubic feet of unprocessed waste. However, if one of the volume reduction processes with a VRF > 1.0 is employed, the costs should be more on the order of $75,000 for this same volume. For PWR wastes, as displayed in Figure 6.11 (b), the costs are substantially less. Normal disposal by solidification in cement (VRF = 0.71) should result in total disposal costs on the order of $99,000 per 1000 cubic feet of waste (unprocessed volume). The use of more advanced volume reduction processes should lower the costs to roughly $25,000 to $45,000 for this same quantity.

The effects of waste stream activity level are shown in Figures 6.12 (a) and (b). These figures show that the costs for BWR CONCLIQ waste disposal are quite sensitive to this parameter, more so than similar PWR wastes. For the BWR wastes, the costs decrease by about 40% if the waste stream activity level is an order of magnitude lower than the typical or average value used. Conversely, Figure 6.12 (a) indicates that a factor of 10 higher than typical activity essentially doubles the disposal costs, while a factor of 100 higher activity increases costs by about a factor of 3. For PWR concentrated wastes, a factor of 10 lower activity will reduce costs by 0 to 25 percent. A factor of 10 higher activity will increase costs by about 30 to 50 percent depending on the extent of volume reduction achieved.

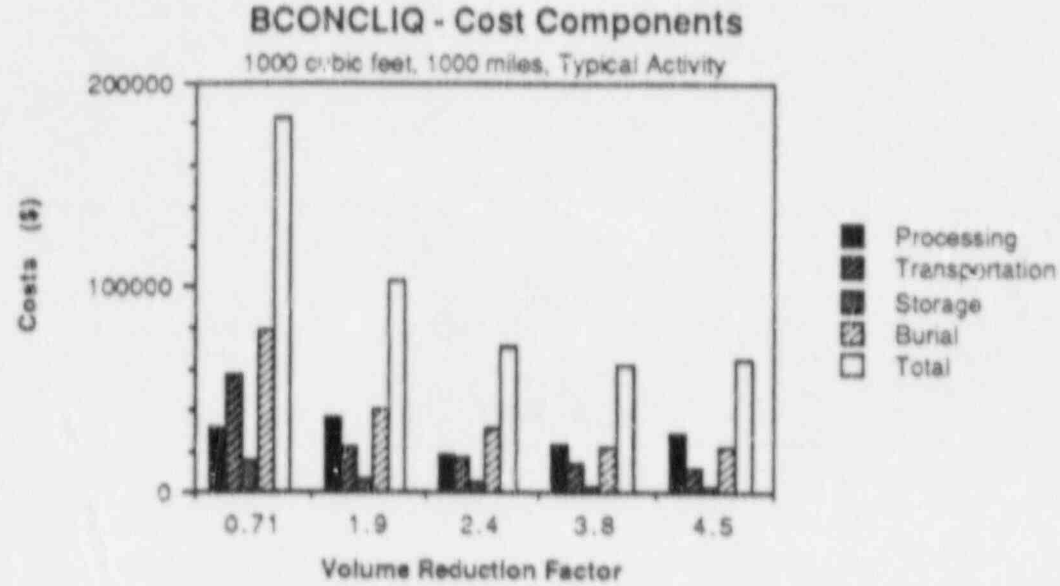

Figure 6.11. (a) Disposal Costs for BWR Concentrated Liquids

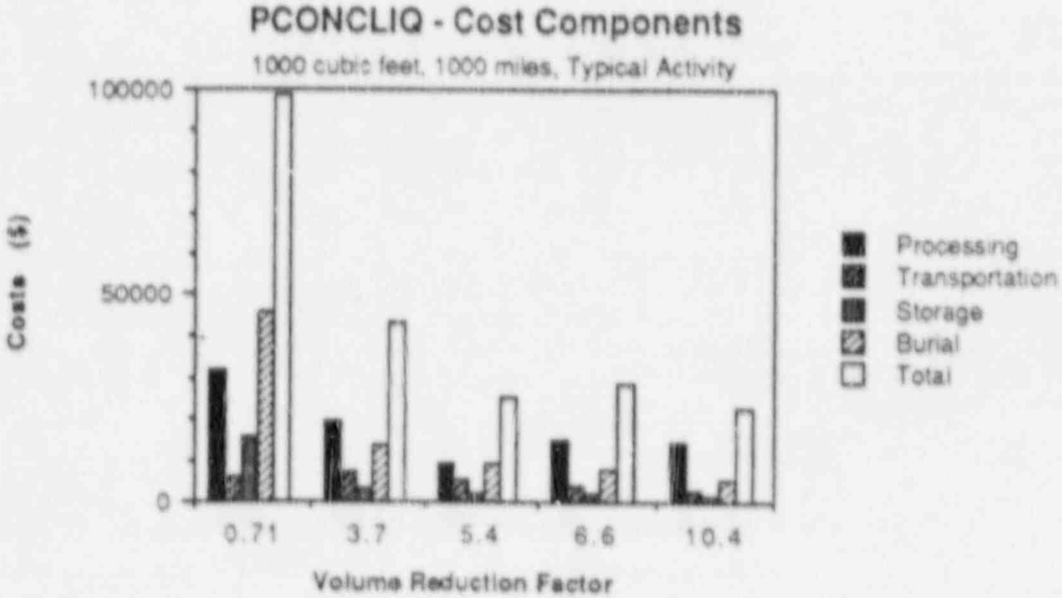

Figure 6.11. (b) Disposal Costs for PWR Concentrated Liquids

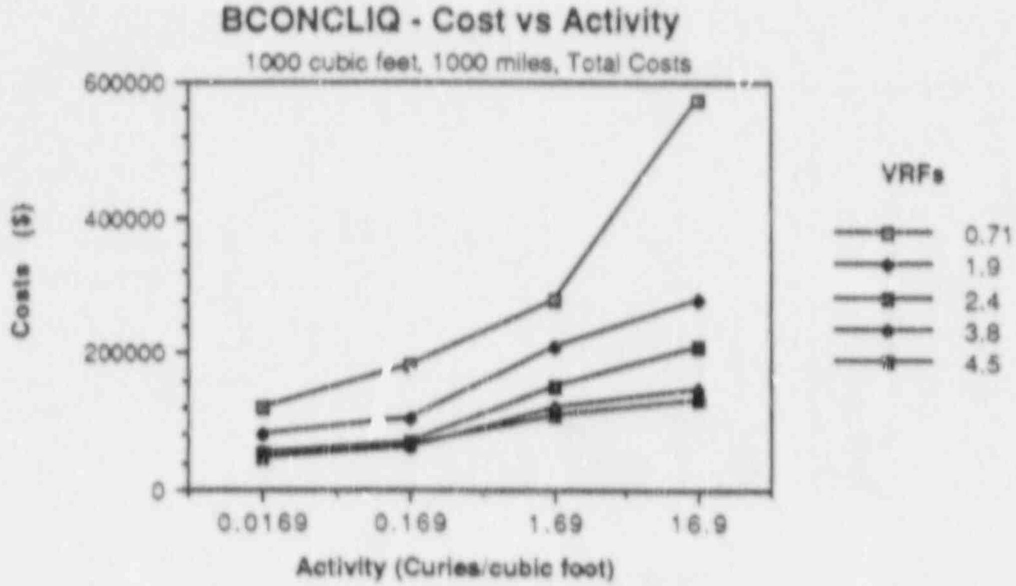

Figure 6.12. (a) Cost Sensitivity of BWR Concentrated Liquids to Activity Level

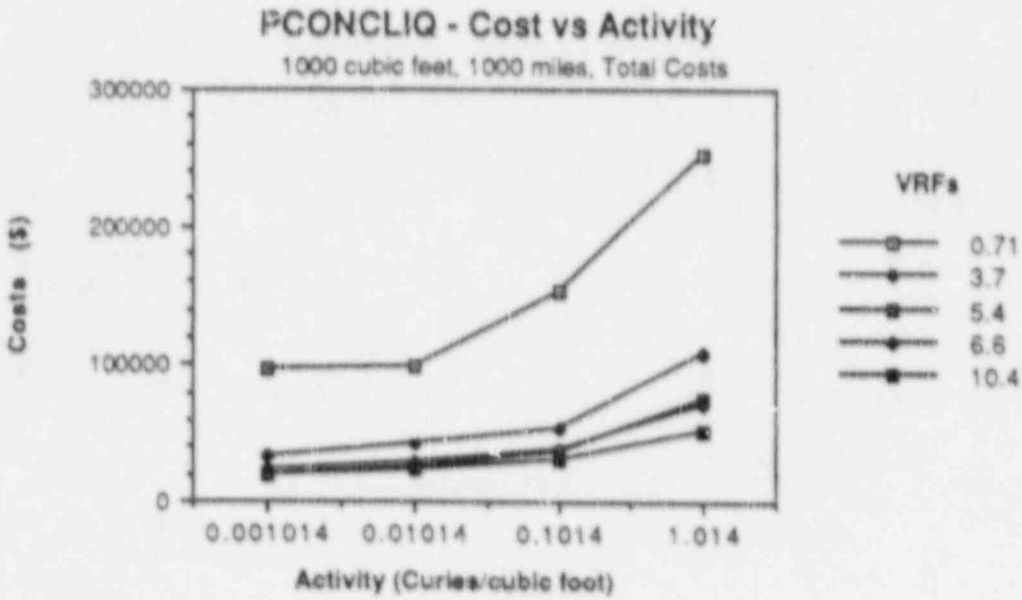

Figure 6.12. (b) Cost Sensitivity of PWR Concentrated Liquids to Activity Level

Transport distance from the plant site to the waste burial location obviously impacts the total disposal costs. The quantitative impacts of distance are illustrated in Figures 6.13 (a) and (b). The BWR wastes are more sensitive to transport distance than PWR wastes, primarily because of the higher average activity levels for the BWR CONCLIQ stream. The higher activity requires more extensive shielding during transport, and thus, necessitates fewer containers of wastes per shipment than is the case for PWR wastes.

The trends shown in Figures 6.13 (a) and (b) are based on typical activity wastes. Appendix B presents data necessary to adjust total costs for various transport distances for higher or lower activity CONCLIQ. Similarly, Appendix C data can be used to estimate disposal costs based on specific burial sites.

6.2.5 Disposal Costs for Filter Sludge (FSLUDGE)

Contaminated filter sludges can be generated as a result of filtering and purification processes on liquid waste streams. Large quantities of these sludges are not expected as a result of maintenance and repair activities. However, some of this type of waste may be produced, so the disposal costs should be taken into account.

Three processes were identified for treating filter sludges prior to disposal. These are as follows:

Process	Volume Reduction Factor
Solidification in Cement	0.56
Evaporation, solidification in binder	2.0
Incineration, solidification in binder	4.0

Typical filter sludges generated during normal plant operation can have quite high activity concentrations. For BWRs the average activity concentration for this waste was 0.23 Ci/ft^3 and for PWRs the value was 0.07 Ci/ft^3 (Ref. 1). These relatively high activity levels cause the transportation and burial costs for this waste to be relatively high.

Figures 6.14 (a) and (b) show total costs and costs of processing, storage, transportation, and burial for filter sludge. The costs apply to 1000 cubic feet of typical activity filter sludge, transported a distance of 1000 miles from the plant to the burial site. The figures indicate that transportation and burial costs are the largest contributors to costs for the low volume reduction factor. As more advanced volume reduction processes are used, the processing costs take on added importance.

The case represented by a volume reduction factor of 2.0 represents about one-fourth as much waste in the processed state as the case with VRF = 0.56. The disposal costs are reduced by more than a factor of 2.0 in going from VRF = 0.56 to VRF = 2.0. Going to a process with VRF = 4.0 gives an additional decrease in cost, but the benefit is relatively small compared to the VRF = 2.0 case.

The cost impacts of higher and lower than normal activity concentrations on costs are shown in Figures 6.15 (a) and (b). As might be expected from the discussions of other waste streams, higher activity can significantly increase the costs. A factor of 10 higher activity increases BWR disposal costs by roughly a factor of 2, while a factor of 100 higher activity can increase costs by a factor of 3. For PWR wastes, the effect of a tenfold increase in activity is to increase costs by factors of 1.4 to 1.9, depending on the volume reduction employed. At the highest activity level considered, costs are higher

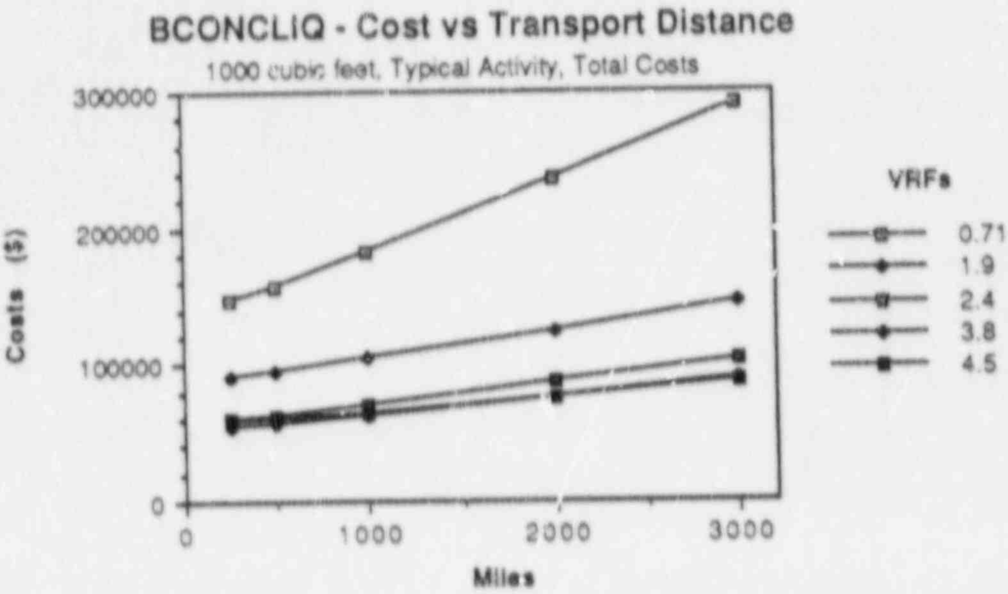

Figure 6.13. (a) Variation in BWR Concentrated Liquids Disposal Cost with Transport Distance

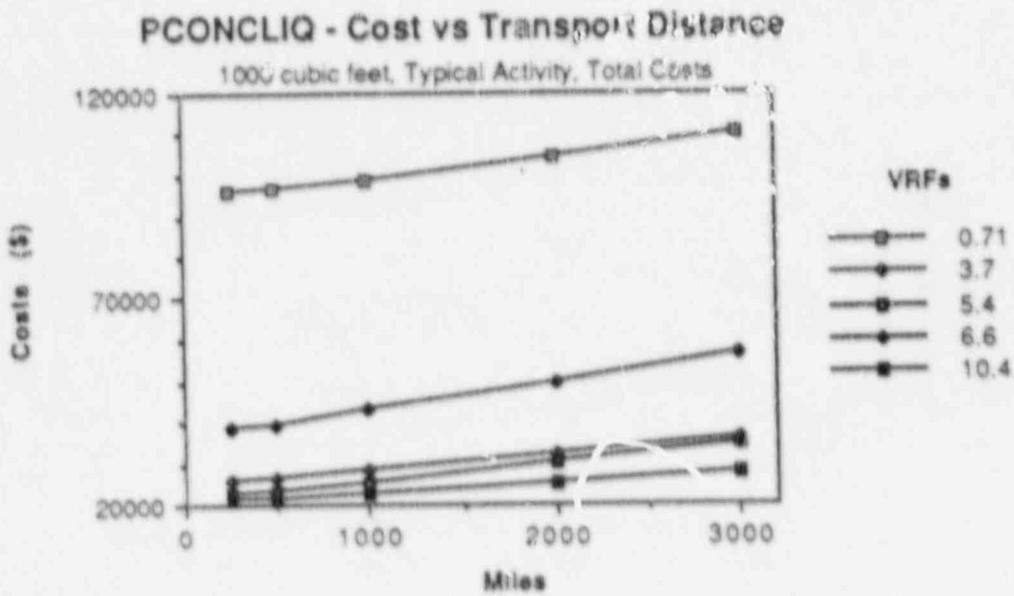

Figure 6.13. (b) Variation in PWR Concentrated Liquids Disposal Cost with Transport Distance

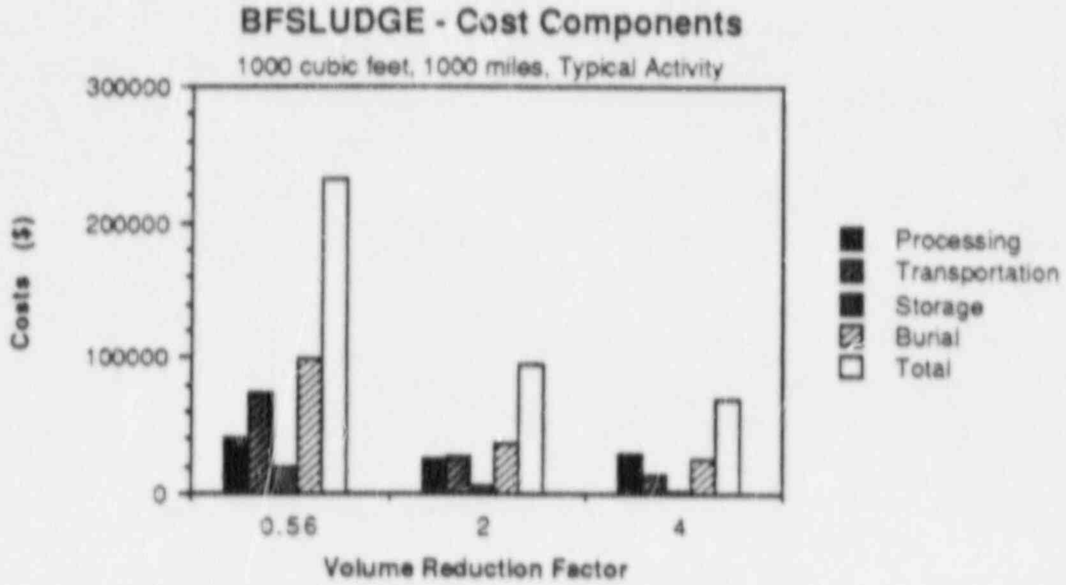

Figure 6.14. (a) Disposal Costs for BWR Filter Sludge

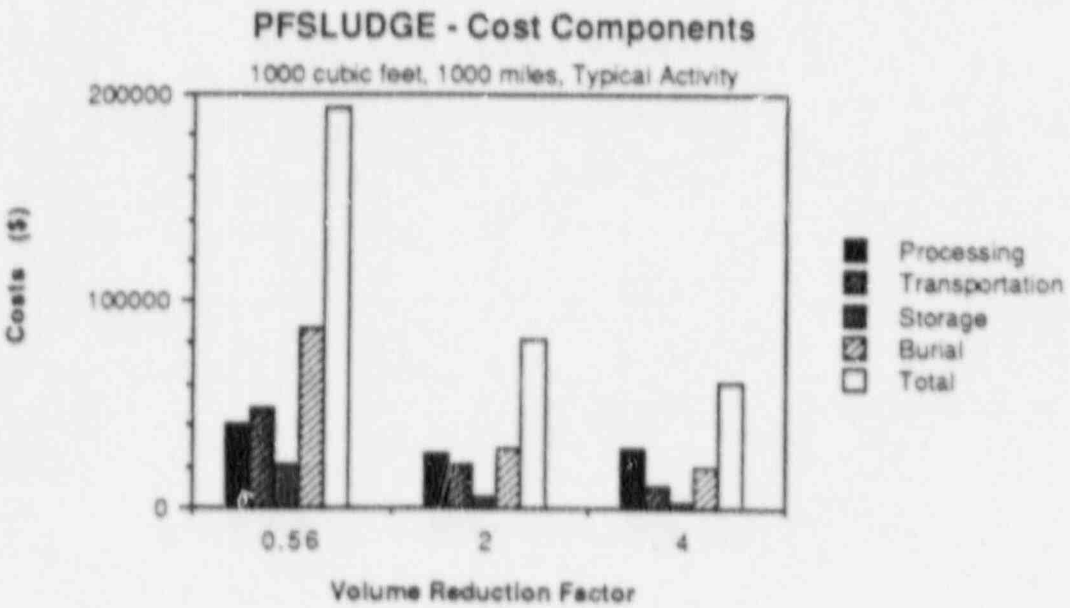

Figure 6.14. (b) Disposal Costs for PWR Filter Sludge

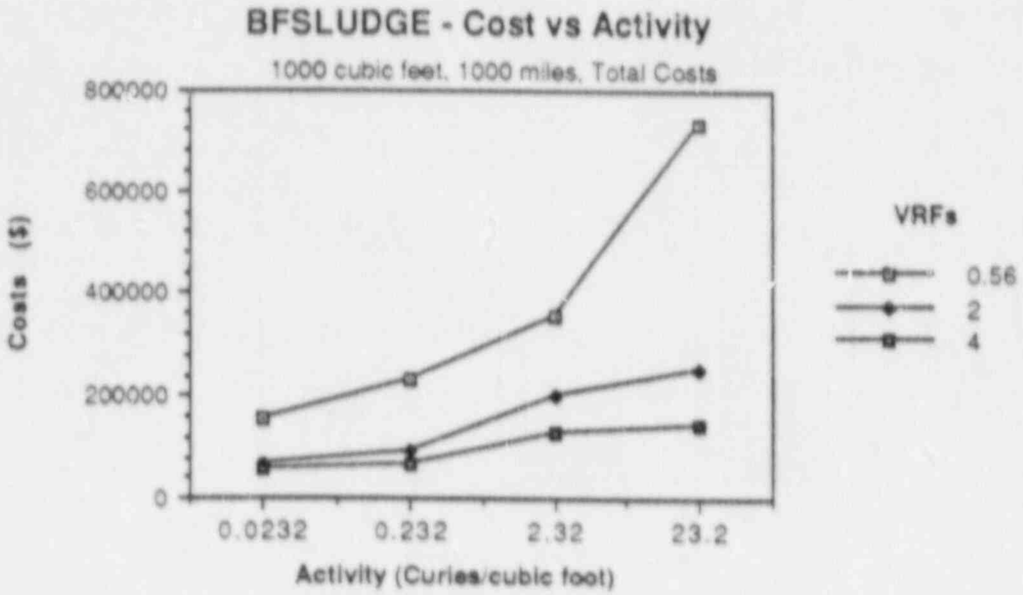

Figure 6.15. (a) Cost Sensitivity of BWR Filter Sludge to Activity Level

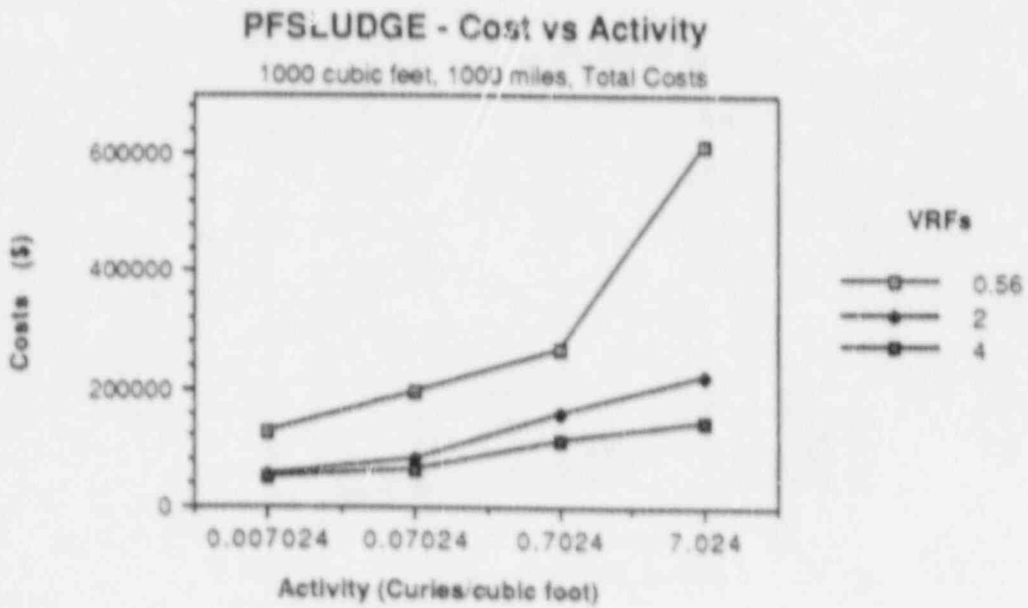

Figure 6.15. (b) Cost Sensitivity of PWR Filter Sludge to Activity Level

than average by about a factor of 3. If the FSLUDGE is characterized by lower than normal activity levels, the disposal costs will decrease. A factor of 10 lower activity concentration will reduce the disposal costs by 20 to 50 percent.

Figures 6.16 (a) and (b) show cost variations with changes in transport distances. Since transportation costs play a relatively more important role at lower volume reduction factors, transportation distance impacts overall costs more at low VRFs than at the higher VRFs. At VRF = 0.56, doubling the 1000 mile transport distance to 2000 miles increases the total costs by $45,000 to $70,000, depending on the reactor type. Halving the distance reduces costs by $20,000 to $30,000. The magnitude of the cost changes with distance decreases for the higher volume reduction processes.

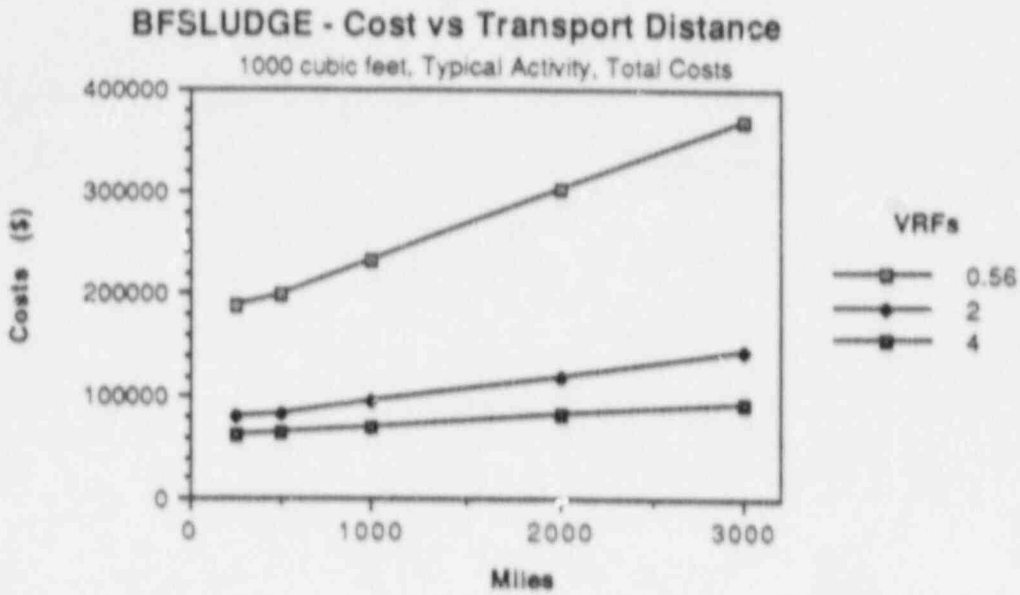

Figure 6.16. (a) Variation in BWR Filter SludgeDisposal Cost with Transport Distance

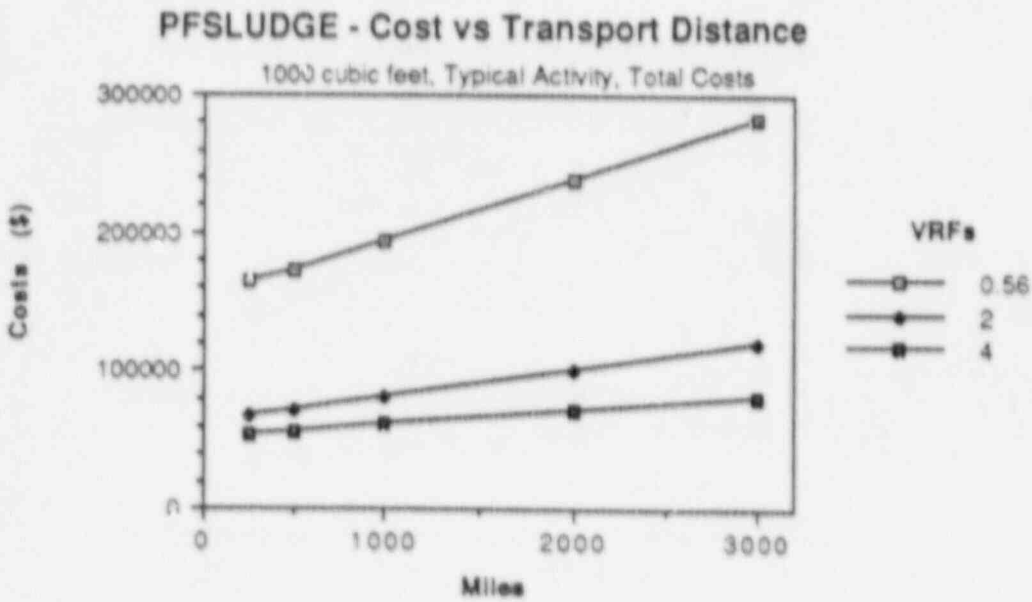

Figure 6.16. (b) Variation in PWR Filter Sludge Disposal Cost with Transport Distance

7.0 EXAMPLE APPLICATIONS: COMPARISON OF GENERIC COST ESTIMATES WITH ACTUAL DISPOSAL COSTS

The waste disposal costs presented in the preceding chapters and in the appendices are based on generalized models of plant-incurred costs (i.e., cost of handling, consumables, and interim storage) and on specific cost schedules for waste transport and burial. The overall model should give reasonable estimates of waste disposal costs even though it is based on certain conditions and assumptions. The question naturally arises as to how well the "generic" estimates compare to actual waste disposal costs.

To address this question, investigators queried a nuclear utility with both BWRs and PWRs for actual waste disposal costs incurred in the recent past. The plants were selected at random. The resulting actual cost data obtained represent a very limited sampling. However, even a small number of cases can be useful in evaluating the validity of cost estimates derived from the generic basis.

The plant data obtained was quoted on a cost-per-container basis. These costs excluded costs associated with in-plant handling of the wastes (i.e., plant labor) and interim storage of the wastes. In addition, the plants sampled shipped all wastes to the Barnwell, SC, waste disposal site. Investigators attempted to obtain adequate representations of the actual wastes in order to make the comparison with the appropriate generic estimate cases. Information regarding such aspects as extent of volume reduction achieved, volume reduction process employed, type of shipping container used, and activity concentration or surface dose rate was solicited.

In making the actual vs generic estimate comparisons, investigators first attempted to adequately characterize the waste relative to the various cases and ranges covered by the generic estimates. The minimum information needed was waste type, actual volume of untreated waste per container and/or volume reduction achieved, and the activity concentration or surface dose rate from the packaged wastes. Given this information, the generic estimates were determined. The generic estimates were adjusted to bring them to the same basis as quoted by the utility contacts, i.e., the costs were adjusted to exclude costs associated with in-plant handling and interim on-site storage of wastes. Similarly, investigators adjusted the generic estimates to reflect burial at Barnwell, SC. The burial location influenced not only the burial costs but also the transport costs.

Table 7.1 presents the overall results of this comparison. Seven distinct cases are shown. All five types of waste are included (NCTRASH, COTRASH, IXRESIN, CONCLIQ, and FSLUDGE), although not for each type of reactor. The table shows the waste type, the associated volume reduction factor and reported container surface dose rate, the quoted (actual) disposal cost, and the costs derived from the generic estimates. It also presents the ratio of the generic estimates to actual quoted costs of disposal for each type of waste. In most cases, the generic estimate compares quite favorably to the actual costs. Most are within 10% of the costs quoted by the utilities. The poorest comparison is for NCTRASH. The ratio of generic estimated costs to actual costs was 1.60.

The utilities providing actual cost data reported that most wastes were packaged in containers other than the 7.5 ft^3-drums assumed for the generic estimates. The generic estimate values shown in Table 7.1 assume the use of this type of container for all waste streams. The results of this comparison tend to indicate that the influence of container type and size on the total waste disposal costs is probably not large.

The following discussions indicate how the individual case comparisons were carried out and calculated. These are provided as examples of how generic costs can be estimated and adjusted for specific cases.

Table 7.1 Estimated vs Actual Cost Summary (1988 dollars)

Waste Type	Quoted VRF	Surface Dose [R/hr]	Quoted * Disposal Cost [$/1000 cu ft]	Generic * Cost Estimate [$/1000 cu ft]	Ratio Generic/Actual Costs
COTRASH	4.4	0.5	14,764	18,068	1.22
NCTRASH	0.2	0.5	325,000	475,084	1.46
BIXRESIN	0.9	3	124,901	159,805	1.28
BCONCLIQ	0.7	3	164,897	203,424	1.23
BFSLUDGE	0.88	3	127,006	161,866	1.27
PIXRESIN	0.88	25	122,720	154,551	1.26

* Excludes costs of in-plant labor and interim storage of wastes.

7.1 COMPACTIBLE TRASH (COTRASH) DISPOSAL COSTS

The utility providing estimates for this waste had both a BWR and a PWR at this site whose COTRASH was mixed and processed jointly. Figure 7.1 presents the details of the cost comparison for Mixed BWR and PWR compactible trash. The disposal cost quoted by the utility for this type of waste was $65/ft^3$ (as-shipped). The stated volume reduction factor was about 4.4, and the container surface dose rate was quoted as being 500 mR/hr. The actual disposal cost is about $14,764 per 1000 ft^3 of as-generated waste.

The determination of the generic estimates requires knowledge of the waste type, the volume reduction achieved, the activity of the waste, and the distance from the plant to the burial site. The high activity for PCOTRASH most closely matched the activity of the mixed waste. Generic costs for PCOTRASH were calculated for volume reduction factors which bracket the stated VRF of 4.4. Therefore, generic estimates based on VRF = 3.78 and VRF = 5.67 were used and were adjusted to reflect the conditions stated for the actual costs. The results were linearly interpolated to arrive at the generic estimates for VRF = 4.4.

The surface dose rate for the utility waste was stated to be 500 mR/hr. Table 5.2 gives approximate surface dose rates for the various BWR waste streams. For typical activity concentrations for PCOTRASH, the surface dose is estimated to be about 0.03 R/hr. The "high" activity case would be a decade higher (~0.3 R/hr). Since the actual case was stated to be 0.5 R/hr , the high activity case was chosen for the generic estimate basis.

To determine the base cost for the generic estimate, Table 1.5 was used. The estimated distance from the plant to the Barnwell burial site is 1000 miles. Therefore, base estimates are chosen for the cases of distance = 1000 miles, typical activity level, and VRFs of 3.78 and 5.67. Table 1.5 presents the total costs for these conditions.

The total estimated costs from Table 1.5 must be adjusted to put them on the same basis as the utility cost quotes. Costs associated with in-plant handling of the wastes and interim storage should be subtracted from the generic estimates. The in-plant handling costs are determined from detailed calculations as described in Section 5.2.1. Storage costs are presented in Table 1.5. The final adjustment to the estimated costs is that for burial at Barnwell, SC. Table C.2 presents the differential cost for burial at Barnwell compared to the average site burial costs. Surcharge costs, presented in Table 5.12, have been included.

There are three sub-elements to the in-plant labor costs. These are the labor costs associated with container handling, compaction or waste processing equipment operation, and equipment maintenance. The unit cost base for each of these sub-elements was presented in Table 5.5 for each type of waste and each volume reduction factor. An example of the calculation of in-plant labor costs for 1000 ft^3 of as-generated BCOTRASH with VRF=3.78 is as follows:

Table 5.5 gives the following unit costs needed to calculate in-plant labor costs.

Equipment operator time: 0.14 (hrs/ft^3) [1]
Container handling time: 1.0 (hrs/container)
Maintenance unit costs: 4.16 ($/$ft^3$) [1]

- Number of containers $= \dfrac{1000\ ft^3}{7.5\ \dfrac{ft^3}{container} \times 3.78} = 35.27\ \dfrac{containers}{1000\ ft^3}$

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[1] Based on as-shipped conditions.

Actual Cost:

Waste Type:	Compactible Trash (COTRASH)
Plant:	NRC Region I BWR and PWR
Container type used:	92.7 cu ft boxes
Surface Dose Rate :	0.5 R/hr
Total Curies:	0.2 Curies per container 4.90E-04 Curies per cu ft as-generated
VRF:	4.4
Quoted disposal costs:	$6,022 per container $65 per cu ft as-shipped (excludes costs for in-plant handling and interim storage)
Distance to Burial Site:	1000 miles
Actual Cost:	$14,764 per 1000 cu ft of as-generated waste

Generic Estimates:

Waste Type: PCOTRASH

Case VRF:	3.78	5.67
Curies per 1000 cu ft (As-generated) high activity	0.00185	0.00185
Total Cost (@ 1000 mi, Table 1.5)	$19,830	$13,697
Adjustments:		
In-plant Handling costs (Section 7.1)	($3,385)	($2,465)
Interim Storage Costs (Table 1.5)	($3,025)	($2,017)
Burial at Barnwell (Table C.2)	$1,434	$1,071
Surcharge Costs (Table5.12)	$5,291	$3,527
Generic Estimates	$20,145	$13,813
Linear Interpolation to VRF = 4.4:	$18,068 per 1000 cu ft	

Ratio of Generic Estimate to Actual Cost	1.22

Figure 7.1 Cost Comparison for Mixed BWR and PWR Compactible Trash

- Container handling labor cost =

$$1.0 \frac{\text{hours}}{\text{container}} \times 35.27 \text{ containers} \times 31.85 \frac{\$}{\text{hour}} \quad = \quad \$1147$$

- Equipment Operating Labor cost =

$$0.14 \frac{\text{hours}}{\text{ft}^3} \times 35.27 \text{ (cont)} \times 7.5 \frac{\text{ft}^3}{\text{cont}} \times 31.85 \frac{\$}{\text{hour}} \quad = \quad \$1138$$

- Maintenance cost =

$$4.16 \frac{\$}{\text{ft}^3} \times 35.27 \text{ containers} \times 7.5 \frac{\text{ft}^3}{\text{cont}} \quad = \quad \$1101$$

Total in-plant labor cost = $3385
(per 1000 ft^3 of as-generated waste)

This total labor cost figure is used in Table 7.1. In-plant labor costs for the other cases are calculated in an analogous manner.

Figure 7.1 shows each of the above adjustments. The resulting estimated costs as determined from the generic basis are \$20,145/1000 ft^3 and \$13,813/1000 ft^3 for VRFs of 3.78 and 5.67, respectively. Linear interpolation to a VRF of 4.4 gives a generic estimate of \$18,068/1000 ft^3. The actual cost quoted by the utility was \$14,764/1000 ft^3. Thus, the generic estimate is about 20% more than the actual cost for this particular case.

7.2 NONCOMPACTIBLE TRASH (NCTRASH) DISPOSAL COSTS

The utility providing estimates for this waste had both a BWR and a PWR at this site whose NCTRASH was mixed and processed jointly. The surface dose for the waste was stated to be 0.5 R/hour. The VRF was given as 0.2. The distance from the plant to the Barnwell, S.C, burial site is roughly 1000 miles.

Figure 7.2 shows the details of the cost comparison for this case. As noted above, this waste contained noncompactible trash from both a BWR and a PWR. The average surface dose of the actual waste is 0.5 R/hr. From Table 5.3, this is very close to the predicted surface dose of PNCTRASH with a "high" activity concentration (i.e., a factor of 10 higher than typical) and with a VRF of 0.2. Therefore, PNCTRASH generic costs were used based on these conditions. The specific generic cost base used was that from Table 1.5 for high activity wastes with VRF of 0.2. The total costs, including surcharges, were \$475,084/1000 ft^3. This data is applicable to the 1000 mile transport distance appropriate for this comparison.

Figure 7.2 shows the cost adjustments made to bring the generic estimate to the same basis as that for the actual cost reported by the utility. The results show that the generic estimate overestimates the actual costs by about 50%.

7.3 BWR ION-EXCHANGE RESINS (BIXRESIN) DISPOSAL COSTS

Figure 7.3 presents a comparison of generic estimates versus actual costs for the disposal of BWR ion-exchange resins. The utility providing the data stated that these wastes are disposed in 202.1 ft^3 containers and that 181 ft^3 of actual waste are put in each container. This gives a VRF of 0.90. The quoted disposal costs are \$124,901 per 1000 ft^3 of as-generated waste. The surface dose rate of the IXRESIN wastes was stated to

Actual Cost:

Waste Type:	Noncompactible Trash (NCTRASH)
Plant:	NRC Region I BWR and PWR
Container type used:	92.7 cu ft boxes
Surface Dose Rate :	0.5 R/hr
Total Curies:	0.2 Curies per container 1.08E-02 Curies per cu ft as-generated
VRF:	0.2
Quoted disposal costs:	$6,022 per container $65 per cu ft as-shipped (excludes costs for in-plant handling and interim storage)
Distance to Burial Site:	1000 miles
Actual Cost:	$325,000 per 1000 cu ft of as-generated waste

Generic Estimates:

Waste Type: PNCTRASH

Case VRF:		0.2
Curies per 1000 cu ft (As-generated) high activity		0.0533
Total Cost (@ 1000 mi, Table 1.5)		$377,111
Adjustments:		
	In-plant Handling costs (Section 7.1)	($35,540)
	Interim Storage Costs (Table 1.5)	($18,739)
	Burial at Barnwell (Table C.2)	$52,252
	Surcharge Costs (Table 5.12)	$100,000
Generic Estimates		$475,084

Ratio of Generic Estimate to Actual Cost	1.46

Figure 7.2 Cost Comparison for Mixed BWR and PWR Noncompactible Trash

Actual Cost:

Waste Type: BWR Ion Exchange Resins (BIXRESIN)

Plant: NRC Region I BWR and PWR

Container type used:	202.1 cu ft boxes
Surface Dose Rate :	3 R/hr
Total Curies:	5 Curies per container 2.76E-02 Curies per cu ft as-generated
VRF:	0.90
Quoted disposal costs:	$22,607 per container $112 per cu ft as-shipped

(excludes costs for in-plant handling and interim storage)

Distance to Burial Site:	1000 miles
Actual Cost:	$124,901 per 1000 cu ft of as-generated waste

Generic Estimates:

Waste Type: BIXRESIN

Case VRF:		0.95
Curies per cu ft (As-generated) typical activity		0.176
Total Cost (@ 1000 mi, Table 1.4)		$142,385
Adjustments:		
	In-plant Handling costs (Section 7.1)	($13,399)
	Interim Storage Costs (Table 1.4)	($11,848)
	Burial at Barnwell (Table C.1)	$21,614
	Surcharge Costs (Table 5.11)	$21,053
Generic Estimate		$159,305

Ratio of Generic Estimate to Actual Cost	1.28

Figure 7.3 Cost Comparison for BWR Ion-Exchange Resins

be 3 R/hr. Generic estimates for this waste are shown in Table 1.4 for VRF = 0.95 and for four different activity concentrations.

Table 1.4 shows that the disposal costs are quite sensitive to the activity level in the waste. Therefore, it is important to establish an estimate which corresponds to the activity levels (or surface doses) reported for the actual wastes. Table 5.2 indicates that typical packaged BIXRESINS with a VRF of 0.95 have an estimated surface dose of about 4.84 R/hr. Therefore, the typical activity costs were used to derive the generic estimate. The resulting generic disposal costs, including surcharges, are about 30% higher than the actual disposal costs reported by the utility.

7.4 BWR CONCENTRATED LIQUID (BCONCLIQ) DISPOSAL COSTS

Figure 7.4 presents the actual versus generic cost estimate comparison for BWR concentrated liquid waste disposal. The conditions and characteristics of the waste as cited by the utility correspond closely to the typical activity case with a VRF of 0.71 as used to produce the generic cost estimate. Therefore, no interpolation was necessary to make this comparison. As noted in Figure 7.4, the generic estimates for this waste stream, including surcharges, were 123% of the reported actual disposal costs.

7.5 BWR FILTER SLUDGE (BFSLUDGE) DISPOSAL COSTS

The actual conditions cited by the utility for their BWR filter sludge lies nearest the low activity generic case of VRF = 0.56. Specifically, the VRF given by the utility for this waste was about 0.88, whereas the generic estimate was calculated for the case of VRF = 0.56. Figure 7.5 shows the details of the cost comparison for BWR filter sludge. The costs derived from the generic estimates are about 25% higher than the actual disposal costs reported by the utility. Surcharge Costs (from Table 5.11) were included in the estimates.

7.6 PWR ION-EXCHANGE RESIN (PIXRESIN) DISPOSAL COSTS

Figure 7.6 presents the comparison of actual versus generic estimated disposal costs for PWR IXRESINS. The utility supplying the cost data stated that 132.4 ft^3 containers were used for the disposal of this waste, and that as much as 117 ft^3 of waste could be disposed in each. Thus, the applicable VRF is about 0.88. Since this falls between the tabulated VRFs of 0.71 and 0.95, the generic estimates were determined by interpolating between the costs calculated for these VRFs.

The utility reported that these containers contained about 50 curies each. This corresponds to 0.28 curies per ft^3 of as-generated waste. This value is closest to the 0.11 Ci/ft^3 given for typical activity for PIXRESIN. Figure 7.6 displays the results. The generic estimate, including surcharges, is about 25% more than the actual disposal costs reported by the utility.

Actual Cost:

Waste Type:	BWR Concentrated Liquids (BCONCLIQ)
Plant:	NRC Region I BWR and PWR
Container type used:	202.1 cu ft HICs
Surface Dose Rate :	3 R/hr
Total Curies:	5 Curies per container 3.52E-02 Curies per cu ft as-generated
VRF:	0.70
Quoted disposal costs:	$23,446 per container $116 per cu ft as-shipped

(excludes costs for in-plant handling and interim storage)

Distance to Burial Site:	1000 miles
Actual Cost:	$164,897 per 1000 cu ft of as-generated waste

Generic Estimates:

Waste Type: BCONCLIQ

Case VRF:		0.71
Curies per cu ft (As-generated) typical activity		0.169
Total Cost (@ 1000 mi, Table 1.4)		$182,606
Adjustments:		
	In-plant Handling costs (Section 7.1)	($16,710)
	Interim Storage Costs (Table 1.4)	($15,798)
	Burial at Barnwell (Table C.1)	$25,157
	Surcharge Costs (Table 5.11)	$28,169
Generic Estimate		$203,424

Ratio of Generic Estimate to Actual Cost	1.23

Figure 7.4 Cost Comparison for BWR Concentrated Liquids

Actual Cost:

Waste Type:	BWR Filter Sludges (BFSLUDGE)
Plant:	NRC Region I BWR and PWR
Container type used:	202.1 cu ft HICs
Surface Dose Rate :	3 R/hr
Total Curies:	5 Curies per container 2.81E-02 Curies per cu ft as-generated
VRF:	0.88
Quoted disposal costs:	$22,607 per container $112 per cu ft as-shipped

(excludes costs for in-plant handling and interim storage)

Distance to Burial Site:	1000 miles
Actual Cost:	$127,006 per 1000 cu ft of as-generated waste

Generic Estimates:

Waste Type: BFSLUDGE

Case VRF:		0.56
Curies per cu ft (As-generated) low activity		0.0232
Total Cost (@ 1000 mi, Table 1.4)		$153,001
Adjustments:		
	In-plant handling costs (Section 7.1)	($21,202)
	Interim Storage Costs (Table 1.4)	($20,083)
	Burial at Barnwell (Table C.1)	$14,436
	Surcharge Costs (Table 5.11)	$35,714
Generic Estimate		$161,866

Ratio of Generic Estimate to Actual Cost	1.27

Figure 7.5 Cost Comparison for BWR Filter Sludge

Actual Cost:

Waste Type:	PWR Ion-Exchange Resins
Plant:	NRC Region I BWR and PWR
Container type used:	202.1 cu ft boxes
Surface Dose Rate :	25 R/hr
Total Curies:	50 Curies per container 2.80E-01 Curies per cu ft as-generated
VRF:	0.88
Quoted disposal costs:	$21,917 per container $108 per cu ft as shipped

(excludes costs for in-plant handling and interim storage)

Distance to Burial Site:	1000 miles
Actual Cost:	$122,720 per 1000 cu ft of as-generated waste

Generic Estimates:

Waste Type: PIXRESIN

Case VRF:	0.71	0.95
Curies per 1000 cu ft (As-generated) typical activity	0.11	0.11
Total Cost (@ 1000 mi, Table 1.5)	$151,556	$135,541
Adjustments		
In-plant Handling costs (Section 7.1)	($16,710)	($13,399)
Interim Storage Costs (Table 1.5)	($15,798)	($11,848)
Burial at Barnwell (Table C.2)	$18,391	$18,868
Surcharge Costs (Table 5.12)	$28,169	$21,053
Generic Estimates	$165,908	$150,215
Linear Extrapolation to VRF = 0.88:	$154,551 per 1000 cu ft	

Ratio of Generic Estimate to Actual Cost	1.26

Figure 7.6 Cost Comparison for PWR Ion-Exchange Resins

8.0 ESTIMATES OF OCCUPATIONAL RADIATION EXPOSURE

A comprehensive evaluation of the costs incurred in handling the wastes generated as a result of regulatory requirements should include an estimate of the radiation exposures received by workers. For consistency with the dollar cost estimates presented elsewhere in this report, it would be desirable to be able to estimate radiation exposures broken down by waste stream. Unfortunately, the data required to derive such detailed estimates are not available. The waste categories in the Effluent and Annual Waste Disposal Reports (Ref. 5) filed by the utilities pursuant to Regulatory Guide 1.21 do not correspond to the waste streams of interest. Moreover, the Occupational Radiation Exposure Reports (Ref. 6) filed pursuant to Regulatory Guide 1.16 do not provide breakdowns of exposure by waste stream. However, the data in these two reports can be used to derive overall estimates for exposure to total wastes shipped, and such an estimate is provided here. The details of the derivation of the estimate are given in Appendix A.

Using data reported by the utilities for the years 1980, 1981, and 1982, the following correlation has been derived:

$$E = 1.2 \times V$$

where:

E = Occupational radiation exposure, in person-rem
V = As shipped volume of waste in thousands of cubic feet.

This correlation captures the in-plant exposure to all wastes handled over the course of a year at both PWRs and BWRs. It captures all in-plant activities, such as operations, maintenance, radiation protection, engineering, and supervision. It does not include exposures outside of the plant, such as those associated with transportation or waste burial. The correlation should be used with caution when it is necessary to consider the exposure associated with any particular waste stream. This is because it was derived using the overall annual exposure to all wastes. Therefore, the correlation is likely to over- estimate the exposures incurred in handling dry active waste, and to underestimate the exposures associated with handling and processing wet and irradiated waste streams.

9.0 REFERENCES

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APPENDIX A

ESTIMATION OF OCCUPATIONAL RADIATION EXPOSURE INCURRED IN HANDLING RADIOACTIVE WASTES

The derivation of the estimate for occupational radiation exposure is described in this Appendix. The data reported in NUREG/CR-2907 (Ref. 5) and NUREG-0713 (Ref. 6) for the years 1980, 1981, and 1982 were used in deriving the estimate. These are the most recent years for which waste volume data for individual plants have been published. The radiation exposure data published in NUREG-0713 include all in-plant job functions associated with waste generation, including operations, maintenance, radiation protection, engineering, and supervision. However, the data do not include waste handling activities conducted outside of the plant, such as transportation and burial.

The first step in deriving the estimate was to eliminate from consideration stations that are atypical. Five stations, Big Rock Point, Fort St. Vrain, Humboldt Bay, LaCrosse, and Yankee Rowe, were eliminated because their designs are atypical of contemporary reactors. Three Mile Island was eliminated because the nature of the waste handling and processing at the station stemming from the accident at TMI-2 is not typical of the work at operating reactors. Data on exposures incurred in waste processing and on the volumes of waste shipped were then compiled for the remaining stations. These data, representing three years of data at two types of reactors, are presented in Tables A.1 through A.6.

In order to determine whether the data from the three years could be treated as a single data set, a variance analysis was performed on the data (separately for PWRs and BWRs). For each reactor type, the annual means and standard deviations of the values of person-rem/m^3 shown in Table A.1 were computed, and an f test for variance between the means was performed. The results for BWRs were the following: 1980, n = 14, $\bar{x}$ = .73E-2, s.d. = 4.48E-2; 1981, n = 12, $\bar{x}$ = 5.46E-2, s.d. = 5.32E-2; and 1982, n=13, $\bar{x}$ = 6.32E-2, s.d. = .69E-2; f = 0.72. The results for PWRs were the following: 1980, n = 25, $\bar{x}$ = 4.07E-2, s.d. = 3.76E-2; 1981, n = 26, $\bar{x}$ = 5.54E-2, s.d. = 6.39-2; and 1982, n = 27, $\bar{x}$ = 7.11E-2, s.d. = 9.46E-2; f = 1.22. In both cases, the value of f is not significant at the 0.01 level, and therefore it is concluded that the variance between years is not as significant as the variation within years. Therefore, the data were treated for all three years as a single data set.

Since total station radiation exposures are known to be generally greater at boiling water reactors (BWRs) than at pressurized water reactors (PWRs), a number of statistical analyses were performed to determine whether different estimating factors were needed for BWRs and PWRs. Initially, the mean radiation exposure incurred in waste processing was computed for both the BWR and PWR stations. Over the three-year period, the mean exposure at BWR stations was 78.35 person-rem (n = 39, s.d. = 126.91), while at PWR stations the mean was 28.55 person-rem (n = 78, s.d. = 36.50). To determine if the difference between the means was statistically significant, a t-Test was performed. The computed t = 3.22 is significant at the 0.01 level, and therefore, the mean exposures are significantly different.

Next the mean volume of waste shipped at BWRs and PWRs was computed. Again, over the three-year period, the mean volume of waste shipped from BWR stations was 1,529 m^3/year (n = 39, s.d., = 1,313), and at PWRs it was 757 m^3/year (n = 78, s.d., = 745). Statistical analysis showed that the difference in these means is also statistically significant (t = 4.06) at the 0.01 level. Since the mean exposure and mean volume of

TABLE A.1

RADIATION EXPOSURES INCURRED IN WASTE PROCESSING AND VOLUMES OF WASTES PRODUCED AT PWRs IN 1980

Station	Exposure (person-rem)	Waste Volume (m^3)	Person-Rem/ m^3
Beaver Valley	6.010	2.84E+2	2.12E-2
Calvert Cliffs 1&2	24.593	2.51E+2	9.80E-2
Cook 1&2	62.707	2.10E+3	2.99E-2
Crystal River	12.450	9.27E+2	1.34E-2
Davis-Besse 1	0.815	3.30E+2	2.47E-3
Farley 1	9.014	4.41E+2	2.04E-2
Fort Calhoun 1	24.609	4.06E+2	6.06E-2
Ginna	15.250	4.00E+2	3.81E-2
Haddam Neck	43.430	1.26E+3	3.47E-2
Indian Point 1&2	37.700	1.03E+3	3.66E-2
Indian Point 3	8.160	3.47E+2	2.35E-2
Kewaunee	14.163	1.03E+2	1.38E-1
Maine Yankee	18.993	4.57E+2	4.16E-2
North Anna 1	25.778	2.64E+2	9.76E-2
Oconee 1,2&3	22.310	1.32E+3	1.69E-2
Palisades	2.469	7.31E+2	3.38E-3
Point Beach 1&2	9.172	4.49E+2	2.04E-2
Prairie Island 1&2	5.138	5.25E+2	9.79E-3
Rancho Seco 1	54.290	4.60E+2	1.18E-1
Robinson 2	61.799	3.99E+3	1.55E-2
San Onofre 1	1.810	7.12E+2	2.54E-3
St. Lucie	20.300	3.12E+2	6.51E-2
Surry 1&2	14.530	2.01E+2	7.23E-2
Turkey Point 3&4	20.606	7.24E+2	2.85E-2
Zion 1&2	15.500	1.64E+3	9.45E-3

Data from the following stations are omitted for 1980:
Arkansas 1&2, no waste volumes reported;
Millstone 2, waste volumes reported, in part, with Millstone 1;
Salem 1&2, exposure data available only for unit 1, waste volumes available only for both units combined;
Sequoyah, no exposure or waste data reported;
and Trojan, exposure reported as 0.00

TABLE A.2

RADIATION EXPOSURES INCURRED IN WASTE PROCESSING
AND VOLUMES OF WASTES PRODUCED AT PWRs IN 1981

Station	Exposure (person-rem)	Waste Volume (m^3)	Person-Rem/ m^3
Beaver Valley	6.790	2.13E+2	3.19E-2
Calvert Cliffs 1&2	15.672	5.00E+2	3.13E-2
Cook 1&2	64.085	9.63E+2	6.65E-2
Crystal River	13.870	1.27E+3	1.09E-2
Davis-Besse 1	0.615	3.25E+2	1.89E-3
Farley 1	6.356	5.64E+2	1.13E-2
Fort Calhoun 1	11.950	2.53E+2	4.72E-2
Ginna	5.852	3.76E+2	1.56E-2
Haddam Neck	75.150	4.38E+2	1.72E-1
Indian Point 1&2	182.500	1.58E+3	1.16E-1
Indian Point 3	6.320	3.17E+2	1.99E-2
Kewaunee	6.121	7.38E+1	8.29E-2
Maine Yankee	15.989	4.14E+2	3.86E-2
North Anna 1&2	33.473	3.02E+2	1.11E-1
Oconee 1,2&3	31.055	2.48E+3	1.25E-2
Palisades	11.820	8.54E+2	1.38E-2
Point Beach 1&2	11.889	1.77E+2	6.72E-2
Prairie Island 1&2	7.537	2.97E+2	2.54E-2
Rancho Seco 1	60.240	2.31E+2	2.61E-1
Robinson 2	40.800	9.02E+2	4.52E-2
San Onofre 1	3.420	1.62E+3	2.11E-3
St. Lucie	43.600	2.50E+2	1.74E-1
Surry 1&2	11.953	2.80E+3	4.27E-3
Trojan	4.510	3.75E+2	1.20E-2
Turkey Point 3&4	55.167	1.25E+3	4.41E-2
Zion 1&2	35.000	1.53E+3	2.29E-2

Data from the following stations are omitted for 1981:
Arkansas 1&2, no waste volumes reported;
Millstone 2, waste volumes reported, in part, with Millstone 1;
Salem 1&2, exposure data available only for unit 1, waste volumes available only for both units combined;
and Sequoyah, no exposure or waste data reported.

TABLE A.3

RADIATION EXPOSURES INCURRED IN WASTE PROCESSING AND VOLUMES OF WASTES PRODUCED AT PWRs IN 1982

Station	Exposure (person-rem)	Waste Volume (m^3)	Person-Rem/m^3
Beaver Valley	5.895	2.94E+2	2.01E-2
Calvert Cliffs 1&2	71.257	1.57E+2	4.54E-1
Cook 1&2	50.452	7.14E+2	7.07E-2
Crystal River	5.770	6.62E+2	8.72E-3
Farley 1&2	3.908	3.46E+2	1.13E-2
Fort Calhoun 1	11.357	3.42E+2	3.32E-2
Ginna	11.339	4.89E+2	2.32E-2
Haddam Neck	16.590	3.12E+2	5.32E-2
Indian Point 1&2	220.917	1.17E+3	1.89E-1
Indian Point 3	4.700	3.79E+2	1.24E-2
Kewaunee	5.208	6.73E+1	7.74E-2
Maine Yankee	8.665	2.20E+2	3.94E-2
McGuire	7.895	9.91E+1	7.97E-2
North Anna 1&2	60.617	4.21E+2	1.44E-1
Oconee 1,2&3	49.660	3.06E+3	1.62E-2
Palisades	1.950	7.31E+2	2.67E-3
Point Beach 1&2	17.073	2.52E+2	6.78E-2
Prairie Island 1&2	20.470	9.91E+1	2.07E-1
Rancho Seco 1	37.050	2.40E+2	1.54E-1
Robinson 2	73.108	1.38E+3	5.30E-2
Salem 1&2	74.056	1.91E+3	3.88E-2
San Onofre 1	1.431	9.27E+2	1.54E-3
Sequoyah	5.200	3.58E+2	1.45E-2
St. Lucie	14.690	3.07E+2	4.79E-2
Surry 1&2	104.205	2.17E+3	4.80E-2
Turkey Point 3&4	40.218	1.01E+3	3.98E-2
Zion 1&2	10.030	8.82E+2	1.14E-2

Data from the following stations are omitted for 1982:
Arkansas 1&2, no waste volumes reported;
Davis-Besse 1, waste valume not reported;
Millstone 2, waste volumes reported, in part, with Millstone 1;
Susquehanna, exposure data not reported;
and Trojan, eliminated because computed person-rem/m^3 was statistically outside the range for PWRs.

TABLE A.4

RADIATION EXPOSURES INCURRED IN WASTE PROCESSING
AND VOLUMES OF WASTES PRODUCED AT BWRs IN 1980

Station	Exposure (person-rem)	Waste Volume (m^3)	Person-Rem/ m^3
Browns Ferry 1,2&3	4.800	2.49E+3	1.93E-3
Brunswick 1&2	233.915	6.73E+3	3.48E-2
Cooper	5.722	4.35E+2	2.52E-2
Dresden 1,2&3	62.700	1.16E+3	5.41E-2
Duane Arnold	19.963	7.35E+2	2.72E-2
Fitzpatrick	129.000	7.50E+2	1.72E-1
Hatch 1&2	6.000	7.23E+2	8.30E-3
Monticello	12.922	7.42E+2	1.74E-2
Nine Mile Point	36.591	8.14E+2	4.50E-2
Oyster Creek	23.834	2.03E+3	1.17E-2
Peach Bottom 2&3	19.614	2.64E+3	7.43E-3
Pilgrim	89.720	2.94E+3	3.05E-2
Quad Cities 1&2	138.700	1.67E+3	8.31E-2
Vermont Yankee	1.637	4.84E+2	3.38E-3

Data from the following station is omitted for 1980:
Millstone 1, waste data includes data for Millstone 2.

TABLE A.5

RADIATION EXPOSURES INCURRED IN WASTE PROCESSING
AND VOLUMES OF WASTES PRODUCED AT BWRs IN 1981

Station	Exposure (person-rem)	Waste Volume (m^3)	Person-Rem/ m^3
Brunswick 1&2	409.882	4.30E+3	9.53E-2
Cooper	4.995	4.99E+2	1.00E-2
Dresden 1,2&3	131.000	1.14E+3	1.15E-1
Duane Arnold	28.556	6.97E+2	4.10E-2
Fitzpatrick	137.000	8.61E+2	1.59E-1
Hatch 1&2	27.000	2.69E+3	1.00E-2
Monticello	7.556	5.54E+2	1.36E-2
Nine Mile Point	61.411	5.31E+2	1.16E-1
Oyster Creek	13.368	1.78E+3	7.51E-3
Peach Bottom 2&3	40.275	2.34E+3	1.72E-2
Pilgrim	60.825	1.06E+3	5.74E-2
Vermont Yankee	5.764	4.39E+2	1.31E-2

Data from the following stations are omitted for 1981:
Browns Ferry 1,2,&3, waste data are not reported;
Millstone 1, waste data includes data for Millstone 2;
and Quad Cities 1&2, exposure data are outside the range of expected values for BWRs.

TABLE A.6

RADIATION EXPOSURES INCURRED IN WASTE PROCESSING
AND VOLUMES OF WASTES PRODUCED AT BWRs IN 1982

Station	Exposure (person-rem)	Waste Volume (m^3)	Person-Rem/ m^3
Brunswick 1&2	677.036	3.53E+3	1.92E-1
Cooper	6.184	4.45E+2	1.39E-2
Dresden 1,2&3	170.200	8.99E+2	1.89E-1
Duane Arnold	21.032	4.57E+2	4.60E-2
Fitzpatrick	120.340	1.64E+3	7.34E-2
Hatch 1&2	20.000	1.69E+3	1.18E-2
Monticello	6.395	7.50E+2	8.53E-3
Nine Mile Point	72.627	5.76E+2	1.26E-1
Oyster Creek	19.618	9.96E+2	1.97E-2
Peach Bottom 2&3	14.688	3.23E+3	4.55E-3
Pilgrim	106.820	2.28E+3	4.69E-2
Quad Cities 1&2	104.826	1.46E+3	7.18E-2
Vermont Yankee	3.007	4.51E+2	6.67E-3

Data from the following stations are omitted for 1982:
Browns Ferry 1,2,&3, waste data are not reported;
and Millstone 1, waste data includes data for Millstone 2.

mean was 0.051 person-rem/m^3 at BWRs (n = 39, s.d. = 0.055) and 0.056 person- rem/m^3 at PWRs (n = 78, s.d. = 0.070). The computed t for the difference of these means is 0.40, which is not significant at the 0.01 level. Therefore, it was concluded that a single estimate could be derived for both types of reactors, since the greater exposure in waste processing at BWRs is accompanied by a greater volume of waste shipped.

To derive the estimate, a linear regression analysis of the exposure and waste volume data was performed. Again, the data in Tables A.1 through A.6 were used, and these data, along with the line that best fits the data, are plotted in Figure A.1. The best fit line intersects the y-axis at 2.9 person-rem, with a slope of 0.042 person-rem/m^3. The correlation coefficient, r = 0.525 (n = 117), demonstrates a reasonable degree of correlation. The computed t for r = 0.525 is 6.61, which is significant at the 0.01 level. Therefore, investigators concluded that the correlation reflects a true relationship between exposure and volume of waste shipped.

The derived correlation is [2.9 + 0.042 x (waste volume in m^3)] person-rem or roughly 1.19×10^{-3} x (waste volume in ft^3) person-rem.* Since the activity associated with different waste streams varies, it should be noted that this correlation is likely to over-estimate the exposures incurred in handling dry active waste, and to under-estimate the exposures associated with handling and processing wet and irradiated waste streams.

Thus, the occupational radiation exposure for waste disposal activities can be estimated directly from the above formula given that the analyst knows the aggregate volume (from all waste streams) of as-shipped waste. For example, 10000 ft^3 of as-shipped waste is estimated to result in $1.19 \times 10^{-3} \times 10000 = 11.9$ person-rem.

Addendum

The above radiation exposure analysis has not been changed. Based upon our survey of the open literature, we concluded that there was not adequate "new" information available to make possible an improvement in the original recommendation for estimating doses associated with processing and handling radioactive waste in the aggregate. We considered it appropriate, however, to investigate the availability of information at the reactor plants that would permit doses attributable to specific classes of wastes (e.g., NCTRASH, COTRASH, IXRESIN, CONCLIQ, etc.) to be identified and used to update the analysis.

Accordingly, we contacted 20 utilities to determine whether it was feasible to obtain information on the doses attributable to handling specific classes of waste at their plants.

None of the utilities that we contacted record their doses attributable to handling specific categories of waste separately from other radwaste activities. Usually, a generic radiation work permit (RWP) is used to cover all radwaste operations such as compaction, packing, resin transfers, resin packaging, radwaste station operation activities, and noncompactible radwaste handling and packaging. Also, compactible and noncompactible radwastes are often packaged together to make maximum use of space in the shipping containers, making it impossible to separate the radiation exposure attributable to the handling of these two classes of waste. When there is a special job such as fuel rack modifications, an RWP may be written which covers the entire operation, including the handling of the radwaste. Therefore, we concluded that

*The least squares fit of the data has not been constrained to pass through the origin. It could be argued that it is physically unrealistic for the line not to pass through the origin.

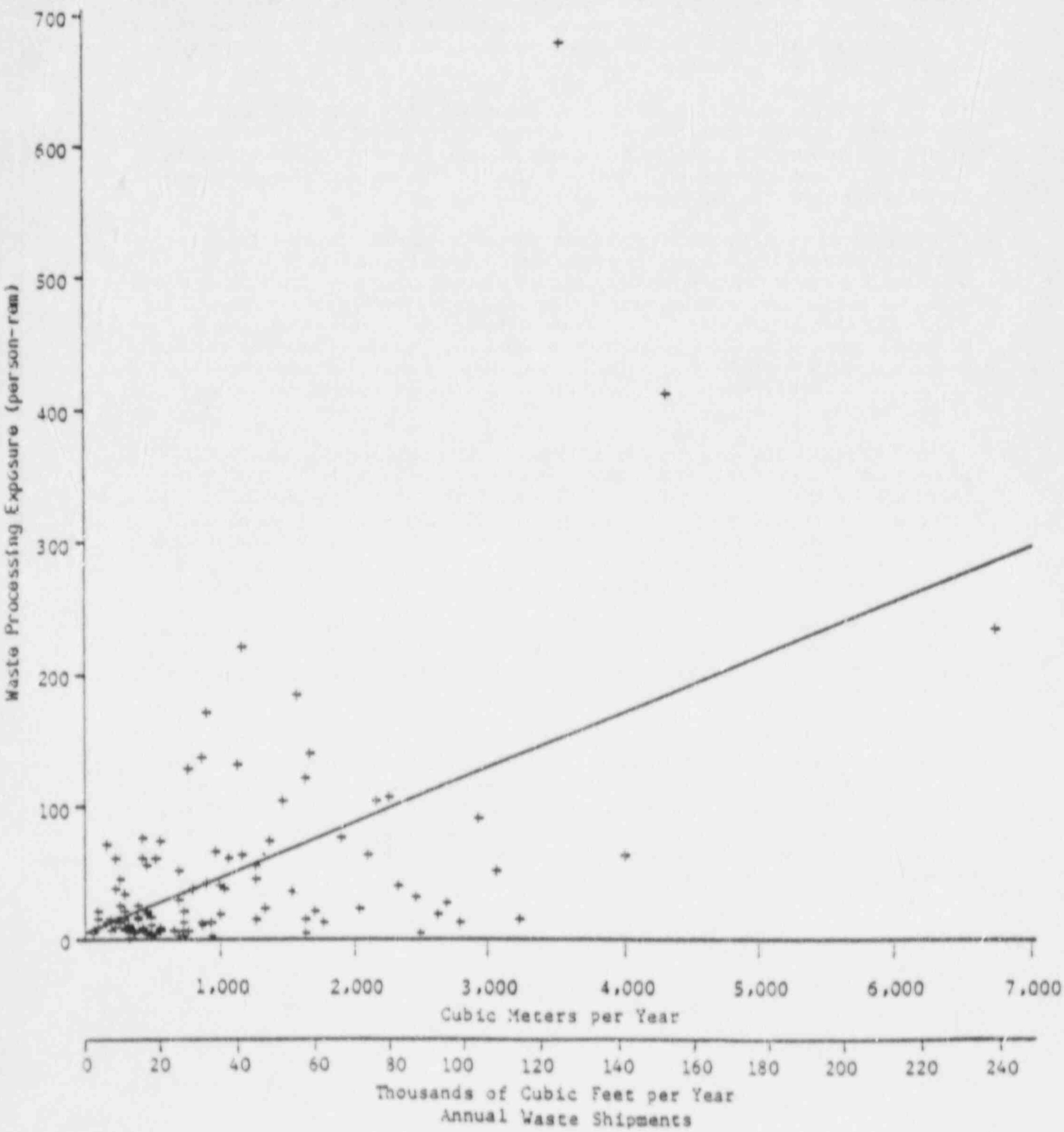

Figure A.1 Plot of Waste Processing Exposure & Waste Volumes Shipped At Commercial Reactors 1980-82 it is not possible to estimate doses attributable to the handling of specific categories of waste from the plant records.

In our conversations with the utilities, we focused on the exposure due to the handling of noncompactible waste, since this is the waste stream of primary interest for purposes of estimating the impact of regulatory changes. All of the utilities felt that the exposure due to noncompactible waste was very small, in most cases less than one man-rem per year. They said that most of the exposure associated with radwaste handling comes from resin and filter operations.

There is another source of data for the exposure associated with the handling of noncompactible trash. Namely, there are vendors who process these wastes as an interim step between the utility and the burial ground. Accordingly, we contacted a number of these vendors to obtain further insight into the exposure associated with the handling of noncompactible waste.

Two of these vendors process noncompactible waste - Scientific Ecology Group, Inc. (SEG) and Quadrex. SEG processes the noncompactibles by, for example, cutting and smelting to reduce the volume before shipping the waste to the burial ground. Quadrex uses an acid treatment to decontaminate the noncompactibles to release most of the material for clean use, and ships the residue to the burial ground. Other vendors perform a variety of services. NuPac has a resin drying process. Chem-Nuclear performs compaction only. Hydro Nuclear does on-site volume reduction and thus the exposure of its workers is included with the utility records. Impell performs consulting only in the area of radwaste.

We were able to obtain some exposure information from SEG and Quadrex. SEG processes 45,000 to 60,000 cu.ft. of noncompactible waste monthly. During the entire year 1987, 550,000 cu.ft. were processed. The total exposure for that year was 44 person-rem or 8×10^{-5} person-rem/ft^3. SEG states that this latter figure is probably more representative because they were handling spent fuel racks reading 1.5 rem/hr earlier in the year, which required cutting and smelting, and resulted in higher doses than normal. The average exposure for their worker in 1987 was 0.5 rem/person/yr.

Quadrex processed 800,000 to 900,000 cu. ft. containing 360 Ci of activity over the past five years. The total exposure over the five-year period was 680 person-rem, or approximately 8×10^{-4} person-rem/ft^3. The average exposure for their workers in 1987 was 0.4 rem/person/yr.

From this limited sample, it appears that an order of magnitude estimate of the exposure attributable to the handling of noncompactible waste is in the range of 1×10^{-3} to 1×10^{-5} person-rem/ft^3. It is of interest to compare this estimate with the estimate for the aggregate exposure to all categories of waste in the original analysis, namely 1×10^{-3} person-rem/ft^3. We judge that the use of the original value, as derived above, to characterize the exposure from handling of noncompactible radioactive waste remains reasonably conservative.

APPENDIX B

VARIATION IN TRANSPORT COSTS

WITH TRANSPORT DISTANCE

Tables B.1 and B.2 indicate the variation in transportation costs and total disposal costs as a function of the distance between the reactor site and the waste burial site. These tables apply to BWR wastes and PWR wastes, respectively. Transport costs and total costs are shown for distances of 250, 500, 2000, and 3000 miles for each waste stream and each applicable waste activity level and volume reduction factor. The 1000 mile cases were covered in Tables 1.4 and 1.5.

The differential cost column shows the difference in costs between the tabulated distance cases and the costs for the 1000 mile case conditions. For example, the first item in Table B.1 for Differential Transport Costs is for a transport distance of 250 miles. Compared to the 1000 miles case for these wastes, the transport costs are less by \$7973 per 1000 ft^3 of as-generated waste.

Table B.1 Transport Costs for BWR Waste Streams (1988 dollars)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
BNCTRASH	LOW	0.2	250	6,618	329,631	-7,973
		0.4	250	4,079	185,184	-4,914
		0.6	250	3,933	191,958	-4,739
		0.8	250	3,899	161,875	-4,697
	TYPICAL	0.2	250	6,618	329,631	-7,973
		0.4	250	4,079	185,184	-4,914
		0.6	250	3,933	191,958	-4,739
		0.8	250	3,899	161,875	-4,697
	HIGH	0.2	250	6,618	334,818	-7,973
		0.4	250	4,079	187,781	-4,914
		0.6	250	3,933	193,692	-4,739
		0.8	250	3,899	163,173	-4,697
	VERY HIGH	0.2	250	50,819	448,494	-80,834
		0.4	250	25,448	237,904	-40,478
		0.6	250	16,990	212,271	-27,025
		0.8	250	12,724	169,152	-20,239
BNCTRASH	LOW	0.2	500	9,380	332,393	-5,211
		0.4	500	5,781	186,886	-3,212
		0.6	500	5,575	193,600	-3,097
		0.8	500	5,526	163,502	-3,070
	TYPICAL	0.2	500	9,380	332,393	-5,211
		0.4	500	5,781	186,886	-3,212
		0.6	500	5,575	193,600	-3,097
		0.8	500	5,526	163,502	-3,070
	HIGH	0.2	500	9,380	337,580	-5,211
		0.4	500	5,781	189,484	-3,212
		0.6	500	5,575	195,334	-3,097
		0.8	500	5,526	164,800	-3,070
	VERY HIGH	0.2	500	72,576	470,251	-59,077
		0.4	500	36,342	248,799	-29,583

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		0.6	500	24,265	219,545	-19,751
		0.8	500	18,171	174,599	-14,791
BNCTRASH	LOW	0.2	2000	29,181	352,195	14,591
		0.4	2000	17,985	199,090	8,992
		0.6	2000	17,344	205,369	8,672
		0.8	2000	17,191	175,167	8,596
	TYPICAL	0.2	2000	29,181	352,195	14,591
		0.4	2000	17,985	199,090	8,992
		0.6	2000	17,344	205,369	8,672
		0.8	2000	17,191	175,167	8,596
	HIGH	0.2	2000	29,181	357,381	14,591
		0.4	2000	17,985	201,687	8,992
		0.6	2000	17,344	207,103	8,672
		0.8	2000	17,191	176,466	8,596
	VERY HIGH	0.2	2000	256,160	653,834	124,507
		0.4	2000	128,272	340,729	62,347
		0.6	2000	85,643	280,924	41,627
		0.8	2000	64,136	220,564	31,173
BNCTRASH	LOW	0.2	3000	43,772	366,785	29,181
		0.4	3000	26,977	208,083	17,985
		0.6	3000	26,017	214,041	17,344
		0.8	3000	25,787	183,763	17,191
	TYPICAL	0.2	3000	43,772	366,785	29,181
		0.4	3000	26,977	208,083	17,985
		0.6	3000	26,017	214,041	17,344
		0.8	3000	25,787	183,763	17,191
	HIGH	0.2	3000	43,772	371,972	29,181
		0.4	3000	26,977	210,680	17,985
		0.6	3000	26,017	215,775	17,344

* Differential costs compared to 1000 mile distance case

Table B.1 Transport Costs for EWR Waste Streams (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		0.8	3000	25,787	185,061	17,191
	VERY HIGH	0.2	3000	380,666	778,341	249,013
		0.4	3000	190,619	403,075	124,693
		0.6	3000	127,269	322,550	83,253
		0.8	3000	95,309	251,737	62,347
BCOTRASH	LOW	2.27	250	585	28,860	-705
		3.78	250	357	17,576	-430
		5.67	250	238	11,925	-287
		8.69	250	165	8,774	-199
		113.4	250	26	3,629	-32
	TYPICAL	2.27	250	585	28,860	-705
		3.78	250	357	17,576	-430
		5.67	250	238	11,925	-287
		8.69	250	[illegible]	8,774	-199
		113.4	250	[illegible]	3,645	-32
	HIGH	2.27	250	[illegible]	31,063	-1,707
		3.78	250	[illegible]	[illegible]	-1,042
		5.67	250	[illegible]	[illegible]	-789
		8.69	250	[illegible]	[illegible]	-772
		113.4	250	[illegible]	[illegible]	-242
	VERY HIGH	2.27	250	4,495	[illegible]	-7,150
		3.78	250	2,743	[illegible]	-4,363
		5.67	250	1,829	16,486	-2,909
		8.69	250	1,886	13,255	-2,994
		113.4	250	307	4,737	-481
BCOTRASH	LOW	2.27	500	830	29,104	-461
		3.78	500	506	17,725	-281
		5.67	500	338	12,024	-188
		8.69	500	234	8,843	-130

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		113.4	500	38	3,640	-21
	TYPICAL	2.27	500	830	29,104	-461
		3.78	500	506	17,725	-281
		5.67	500	338	12,024	-188
		8.69	500	234	8,843	-130
		113.4	500	38	3,656	-21
	HIGH	2.27	500	1,503	31,504	-1,267
		3.78	500	917	19,189	-773
		5.67	500	695	13,52[illegible]	-585
		8.69	500	679	11,112	-572
		113.4	500	218	3,985	-177
	VERY HIGH	2.27	500	6,420	41,536	-5,226
		3.78	500	3,917	25,591	-3,189
		5.67	500	2,611	17,269	-2,126
		8.69	500	2,697	14,066	-2,183
		113.4	500	444	4,874	-344
BCOTRASH	LOW	2.27	2000	2,581	30,856	1,291
		3.78	2000	1,575	18,793	788
		5.67	2000	1,050	12,737	525
		8.69	2000	727	9,336	364
		113.4	2000	117	3,720	58
	TYPICAL	2.27	2000	2,581	30,856	1,291
		3.78	2000	1,575	18,793	788
		5.67	2000	1,050	12,737	525
		8.69	2000	727	9,336	364
		113.4	2000	117	3,735	58
	HIGH	2.27	2000	5,459	35,461	2,690
		3.78	2000	3,331	21,603	1,642
		5.67	2000	2,524	15,350	1,244
		8.69	2000	2,468	12,900	1,216
		113.4	2000	768	4,536	373

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
	VERY HIGH	2.27	2000	22,659	57,775	11,013
		3.78	2000	13,826	35,500	6,720
		5.67	2000	9,217	23,874	4,480
		8.69	2000	9,474	20,844	4,594
		113.4	2000	1,506	5,936	717
BCOTRASH	LOW	2.27	3000	3,872	32,146	2,581
		3.78	3000	2,363	19,581	1,575
		5.67	3000	1,575	13,262	1,050
		8.69	3000	1,091	9,700	727
		113.4	3000	175	3,778	117
	TYPICAL	2.27	3000	3,872	32,146	2,581
		3.78	3000	2,363	19,581	1,575
		5.67	3000	1,575	13,262	1,050
		8.69	3000	1,091	9,700	727
		113.4	3000	175	3,793	117
	HIGH	2.27	3000	8,150	38,151	5,381
		3.78	3000	4,973	23,245	3,283
		5.67	3000	3,767	16,594	2,487
		8.69	3000	3,684	14,116	2,432
		113.4	3000	1,141	4,909	747
	VERY HIGH	2.27	3000	33,672	68,788	22,027
		3.78	3000	20,546	42,220	13,440
		5.67	3000	13,697	28,354	8,960
		8.69	3000	14,069	25,438	9,189
		113.4	3000	2,223	6,653	1,434
BIXRESIN	LOW	0.71	250	7,691	137,628	-12,362
		0.95	250	5,288	97,419	-8,499
		1.4	250	7,314	74,420	-11,634
		2	250	5,105	77,014	-8,120

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		4	250	2,590	46,770	-4,120
	TYPICAL	0.71	250	22,157	147,876	-35,183
		0.95	250	16,618	[illegible]15,998	-26,387
		1.4	250	11,314	[illegible]6,463	-17,966
		2	250	7,896	[illegible]937	-12,539
		4	250	5,221	[illegible]19	-8,[illegible]84
	HIGH	0.71	250	28,871	233[illegible]	-45,254
		0.95	250	21,654	190[illegible]	-33,941
		1.4	250	31,800	183,629	-49,440
		2	250	22,194	168,726	-34,505
		4	250	11,263	101,66[illegible]	-17,510
	VERY HIGH	0.71	250	62,275	478,178	-96,820
		0.95	250	46,706	357,331	-72,615
		1.4	250	31,800	300,760	-49,440
		2	250	22,194	234,669	-34,505
		4	250	11,263	127,663	-17,510
BIXRESIN	LOW	0.71	500	10,881	140,818	-9,172
		0.95	500	7,481	99,612	-6,306
		1.4	500	10,446	77,552	-8,503
		2	500	7,290	79,199	-5,934
		4	500	3,700	47,879	-3,011
	TYPICAL	0.71	500	31,691	157,410	-25,649
		0.95	500	23,769	123,149	-19,236
		1.4	500	16,183	101,332	-13,097
		2	500	11,294	96,335	-9,141
		4	500	7,553	59,951	-5,853
	HIGH	0.71	500	41,763	246,641	-32,363
		0.95	500	31,322	202,867	-24,272
		1.4	500	46,320	198,[illegible]49	-34,920
		2	500	32,328	178,860	-24,371
		4	500	16,405	106,811	-12,368

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
	VERY HIGH	0.71	500	90,710	506,613	-68,385
		0.95	500	68,033	378,657	-51,289
		1.4	500	46,320	315,280	-34,920
		2	500	32,328	244,803	-24,371
		4	500	16,405	132,806	-12,368
BIXRESIN	LOW	0.71	2000	39,537	169,474	19,484
		0.95	2000	27,182	119,313	13,395
		1.4	2000	36,869	103,975	17,920
		2	2000	25,731	97,640	12,507
		4	2000	13,058	57,238	6,347
	TYPICAL	0.71	2000	111,323	237,342	53,983
		0.95	2000	83,492	182,873	40,487
		1.4	2000	56,846	141,994	27,566
		2	2000	39,674	124,714	19,239
		4	2000	25,597	77,995	12,191
	HIGH	0.71	2000	141,537	346,415	67,411
		0.95	2000	106,153	277,698	50,559
		1.4	2000	153,480	305,309	72,240
		2	2000	107,116	253,648	50,418
		4	2000	54,358	144,763	25,585
	VERY HIGH	0.71	2000	[illegible]0,565	716,468	141,470
		0.95	2000	225,424	536,049	106,103
		1.4	2000	153,480	422,440	72,240
		2	2000	107,116	319,592	50,418
		4	2000	54,358	170,758	25,585
BIXRESIN	LOW	0.71	3000	59,021	188,957	[illegible]7
		0.95	3000	40,577	132,708	[illegible]790
		1.4	3000	54,789	121,895	35,840
		2	3000	38,238	110,147	25,013

* Differential costs compared to 1000 mile distance case

Table B.1 Transport Costs for BWR Waste Streams (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		4	3000	19,404	63,584	12,693
	TYPICAL	0.71	3000	165,306	291,025	107,966
		0.95	3000	123,979	223,360	80,974
		1.4	3000	84,411	169,560	55,131
		2	3000	58,912	143,953	38,[illegible]77
		4	3000	37,789	90,186	24,383
	HIGH	0.71	3000	208,949	413,826	134,823
		0.95	3000	156,711	328,257	101,[illegible]17
		1.4	3000	225,729	377,549	144,480
		2	3000	157,534	304,066	100,835
		4	3000	79,943	170,348	51,170
	VERY HIGH	0.71	3000	442,035	857,938	282,940
		0.95	3000	331,526	642,151	212,205
		1.4	3000	225,720	494,680	144,480
		2	3000	157,534	370,909	100,835
		4	3000	79,943	196,343	51,170
BCONCLIQ	LOW	0.71	250	7,251	133,473	-11,656
		1.9	250	5,410	72,930	-8,605
		2.4	250	4,267	46,592	-6,787
		3.8	250	2,743	42,245	-4,363
		4.5	250	2,286	44,594	-3,636
	TYPICAL	0.71	250	22,157	147,423	-35,183
		1.9	250	8,368	90,358	-13,287
		2.4	250	6,600	59,900	-10,480
		3.8	250	5,529	53,732	-8,666
		4.5	250	4,607	57,431	-7,221
	HIGH	0.71	250	28,871	233,289	-45,254
		1.9	250	23,519	170,653	-36,565
		2.4	250	18,550	123,269	-28,840
		3.8	250	11,925	100,354	-18,540

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		4.5	250	9,938	92,926	-15,450
	VERY HIGH	0.71	250	62,275	477,653	-96,820
		1.9	250	23,519	240,372	-36,565
		2.4	250	18,550	178,588	-28,840
		3.8	250	11,925	127,718	-18,540
		4.5	250	9,938	115,989	-15,450
BCONCLIQ	LOW	0.71	500	10,259	136,481	-8,648
		1.9	500	7,725	75,246	-6,289
		2.4	500	6,093	48,418	-4,960
		3.8	500	3,917	43,419	-3,189
		4.5	500	3,264	45,572	-2,657
	TYPICAL	0.71	500	31,691	156,957	-25,649
		1.9	500	11,969	93,958	-9,686
		2.4	500	9,440	62,740	-7,640
		3.8	500	7,997	56,200	-6,197
		4.5	500	5,664	59,488	-5,164
	HIGH	0.71	500	41,763	246,180	-32,363
		1.9	500	34,258	181,392	-25,826
		2.4	500	27,020	131,739	-20,370
		3.8	500	17,370	105,799	-13,095
		4.5	500	14,475	97,464	-10,913
	VERY HIGH	0.71	500	90,710	506,088	-68,385
		1.9	500	34,258	251,111	-25,826
		2.4	500	27,020	187,058	-20,370
		3.8	500	17,370	133,163	-13,095
		4.5	500	14,475	120,52[illegible]	-10,913
BCONCLIQ	LOW	0.71	2000	37,278	163,499	18,370
		1.9	2000	27,267	94,788	13,253
		2.4	2000	21,507	63,832	10,453
		3.8	2000	13,826	53,327	6,720

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		4.5	2000	11,521	53,829	5,600
	TYPICAL	0.71	2000	111,323	236,589	53,983
		1.9	2000	42,042	124,032	20,387
		2.4	2000	33,160	86,460	16,080
		3.8	2000	27,103	75,306	12,909
		4.5	2000	22,586	75,409	10,757
	HIGH	0.71	2000	141,537	345,954	67,411
		1.9	2000	113,511	260,646	53,428
		2.4	2000	89,530	194,249	42,140
		3.8	2000	57,555	145,984	27,090
		4.5	2000	47,963	130,951	22,575
	VERY HIGH	0.71	2000	300,565	715,943	141,470
		1.9	2000	113,511	330,365	53,428
		2.4	2000	89,530	249,568	42,140
		3.8	2000	57,555	173,348	27,090
		4.5	2000	47,963	154,014	22,575
BCONCLIQ	LOW	0.71	3000	55,648	181,869	36,741
		1.9	3000	40,521	108,041	26,507
		2.4	3000	31,960	74,285	20,907
		3.8	3000	20,546	60,047	13,440
		4.5	3000	17,121	59,429	11,200
	TYPICAL	0.71	3000	165,306	290,571	107,966
		1.9	3000	62,429	144,419	40,774
		2.4	3000	49,240	102,540	32,160
		3.8	3000	40,011	88,214	25,817
		4.5	3000	33,343	86,166	21,514
	HIGH	0.71	3000	208,949	413,366	134,823
		1.9	3000	166,939	314,073	106,855
		2.4	3000	131,670	236,389	84,280
		3.8	3000	84,645	173,074	54,180
		4.5	3000	70,538	153,526	45,150

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
	VERY HIGH	0.71	3000	442,035	857,413	282,940
		1.9	3000	166,939	383,792	106,855
		2.4	3000	131,670	291,708	84,280
		3.8	3000	84,645	200,438	54,180
		4.5	3000	70,538	176,589	45,150
BFSLUDGE	LOW	0.56	250	9,490	172,212	-15,254
		2	250	5,105	60,865	-8,120
		4	250	4,007	49,980	-6,363
	TYPICAL	0.56	250	28,168	187,663	-44,727
		2	250	10,289	79,181	-16,128
		4	250	5,221	61,306	-8,184
	HIGH	0.56	250	36,704	296,839	-57,531
		2	250	22,194	168,929	-34,505
		4	250	11,263	109,627	-17,510
	VERY HIGH	0.56	250	79,169	607,652	-123,085
		2	250	22,194	219,094	-34,505
		4	250	11,263	128,087	-17,510
BFSLUDGE	LOW	0.56	500	13,426	176,148	-11,317
		2	500	7,290	63,050	-5,934
		4	500	5,731	51,705	-4,639
	TYPICAL	0.56	500	40,289	199,783	-32,606
		2	500	14,884	83,775	-11,534
		4	500	7,553	63,638	-5,853
	HIGH	0.56	500	53,092	313,228	-41,142
		2	500	32,328	179,062	-24,371
		4	500	16,405	114,770	-12,368

* Differential costs compared to 1000 mile distance case

Table B.1 Transport Costs for BWR Waste Streams (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
	VERY HIGH	0.56	500	115,318	643,801	-86,936
		2	500	32,328	229,228	-24,371
		4	500	16,405	133,230	-12,368
BFSLUDGE	LOW	0.56	2000	48,784	211,506	24,041
		2	2000	25,731	81,491	12,507
		4	2000	20,133	66,106	9,763
	TYPICAL	0.56	2000	141,522	301,017	68,627
		2	2000	50,441	119,333	24,024
		4	2000	25,597	81,682	12,191
	HIGH	0.56	2000	179,933	440,069	85,699
		2	2000	107,116	253,851	50,418
		4	2000	54,358	152,722	25,585
	VERY HIGH	0.56	2000	382,101	910,585	179,848
		2	2000	107,116	304,017	50,418
		4	2000	54,358	171,182	25,585
BFSLUDGE	LOW	0.56	3000	72,825	235,547	48,081
		2	3000	38,238	93,998	25,013
		4	3000	29,896	75,869	19,526
	TYPICAL	0.56	3000	210,149	369,644	137,254
		2	3000	74,466	143,357	48,049
		4	3000	37,789	93,874	24,383
	HIGH	0.56	3000	265,631	525,767	171,397
		2	3000	157,534	304,269	100,835
		4	3000	79,943	178,307	51,170
	VERY HIGH	0.56	3000	561,949	1,090,432	359,695
		2	3000	157,534	354,434	100,835
		4	3000	79,943	196,767	51,170

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
PNCTRASH	LOW	0.2	250	6,618	330,518	-7,973
		0.4	250	4,419	190,515	-5,323
		0.6	250	4,317	198,319	-5,201
		0.8	250	4,276	167,538	-5,151
	TYPICAL	0.2	250	6,618	330,518	-7,973
		0.4	250	4,419	190,515	-5,323
		0.6	250	4,317	198,319	-5,201
		0.8	250	4,276	167,538	-5,151
	HIGH	0.2	250	14,070	375,572	-22,615
		0.4	250	12,883	250,849	-20,708
		0.6	250	12,544	256,076	-20,165
		0.8	250	12,525	225,225	-20,133
	VERY HIGH	0.2	250	78,611	550,063	-124,824
		0.4	250	39,354	297,522	-62,506
		0.6	250	26,282	267,573	-41,733
		0.8	250	19,682	205,908	-31,253
PNCTRASH	LOW	0.2	500	9,380	333,280	-5,211
		0.4	500	6,263	192,359	-3,479
		0.6	500	6,119	200,121	-3,399
		0.8	500	6,060	169,322	-3,367
	TYPICAL	0.2	500	9,380	333,280	-5,211
		0.4	500	6,263	192,359	-3,479
		0.6	500	6,119	200,121	-3,399
		0.8	500	6,060	169,322	-3,367
	HIGH	0.2	500	19,906	381,409	-16,779
		0.4	500	18,227	256,193	-15,364
		0.6	500	17,747	261,279	-14,960
		0.8	500	17,721	230,421	-14,937
	VERY HIGH	0.2	500	112,437	583,890	-90,998
		0.4	500	56,303	314,460	-45,567

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		0.6	500	37,591	278,882	-30,424
		0.8	500	28,151	214,378	-22,784
PNCTRASH	LOW	0.2	2000	29,181	353,081	14,591
		0.4	2000	19,483	205,580	9,742
		0.6	2000	19,037	213,038	9,518
		0.8	2000	18,855	182,116	9,427
	TYPICAL	0.2	2000	29,181	353,081	14,591
		0.4	2000	19,483	205,580	9,742
		0.6	2000	19,037	213,038	9,518
		0.8	2000	18,855	182,116	9,427
	HIGH	0.2	2000	72,328	433,831	35,643
		0.4	2000	66,227	304,194	32,637
		0.6	2000	64,484	308,016	31,778
		0.8	2000	64,388	277,088	31,730
	VERY HIGH	0.2	2000	394,959	866,412	191,524
		0.4	2000	197,776	455,933	95,906
		0.6	2000	132,048	373,339	64,033
		0.8	2000	98,888	285,114	47,953
PNCTRASH	LOW	0.2	3000	43,772	367,672	29,181
		0.4	3000	29,225	215,321	19,483
		0.6	3000	28,555	222,557	19,037
		0.8	3000	28,282	191,544	18,855
	TYPICAL	0.2	3000	43,772	367,672	29,181
		0.4	3000	29,225	215,321	19,483
		0.6	3000	28,555	222,557	19,037
		0.8	3000	28,282	191,544	18,855
	HIGH	0.2	3000	107,971	469,474	71,286
		0.4	3000	98,864	336,830	65,273

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		0.6	3000	96,262	339,794	63,555
		0.8	3000	96,118	308,818	63,460
	VERY HIGH	0.2	3000	586,484	1,057,936	383,049
		0.4	3000	293,681	551,839	191,811
		0.6	3000	196,081	437,371	128,066
		0.8	3000	146,841	333,067	95,906
PCOTRASH	LOW	3.78	250	357	17,576	-430
		5.67	250	238	11,925	-287
		8.69	250	165	8,774	-199
		113.4	250	26	3,629	-32
	TYPICAL	3.78	250	357	17,576	-430
		5.67	250	238	11,925	-287
		8.69	250	165	8,774	-199
		113.4	250	77	3,969	-124
	HIGH	3.78	250	648	18,920	-1,042
		5.67	250	491	13,377	-789
		8.69	250	480	10,971	-772
		113.4	250	236	4,118	-374
	VERY HIGH	3.78	250	4,243	28,352	-6,737
		5.67	250	2,829	19,109	-4,491
		8.69	250	1,886	14,032	-2,994
		113.4	250	307	5,031	-481
PCOTRASH	LOW	3.78	500	506	17,725	-281
		5.67	500	338	12,024	-188
		8.69	500	234	8,843	-130
		113.4	500	38	3,640	-21
	TYPICAL	3.78	500	506	17,725	-281
		5.67	500	338	12,024	-188

* Differential costs compared to 1000 mile distance case

Table B.2 Transport Costs for PWR Waste Streams (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		8.69	500	234	8,843	-130
		113.4	500	109	4,001	-92
	HIGH	3.78	500	917	19,189	-773
		5.67	500	695	13,581	-565
		8.69	500	679	11,170	-572
		113.4	500	337	4,219	-273
	VERY HIGH	3.78	500	6,069	30,178	-4,911
		5.67	500	4,046	20,326	-3,274
		8.69	500	2,697	14,843	-2,183
		113.4	500	444	5,168	-344
PCOTRASH	LOW	3.78	2000	1,575	18,793	788
		5.67	2000	1,050	12,737	525
		8.69	2000	727	9,336	364
		113.4	2000	117	3,720	58
	TYPICAL	3.78	2000	1,575	18,793	788
		5.67	2000	1,050	12,737	525
		8.69	2000	727	9,336	364
		113.4	2000	397	4,289	195
	HIGH	3.78	2000	3,332	21,603	1,642
		5.67	2000	2,524	15,410	1,244
		8.69	2000	2,468	12,958	1,216
		113.4	2000	1,184	5,066	574
	VERY HIGH	3.78	2000	21,317	45,427	10,337
		5.67	2000	14,211	30,492	6,891
		8.69	2000	9,474	21,620	4,594
		113.4	2000	1,506	6,230	717
PCOTRASH	LOW	3.78	3000	2,363	19,581	1,575
		5.67	3000	1,575	13,262	1,050
		8.65	3000	1,091	9,700	727

* Differential costs compared to 1000 mile distance case

Table B.2 Transport Costs for PWR Waste Streams (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		113.4	3000	175	3,778	117
	TYPICAL	3.78	3000	2,363	19,581	1,575
		5.67	3000	1,575	13,262	1,050
		8.69	3000	1,091	9,700	727
		113.4	3000	592	4,484	391
	HIGH	3.78	3000	4,973	23,245	3,283
		5.67	3000	3,767	16,653	2,487
		8.69	3000	3,684	14,174	2,432
		113.4	3000	1,759	5,640	1,149
	VERY HIGH	3.78	3000	31,654	55,764	20,674
		5.67	3000	21,103	37,384	13,783
		8.69	3000	14,069	26,215	9,189
		113.4	3000	2,223	6,947	1,434
PIXRESIN	LOW	0.71	250	2,665	105,624	-3,210
		0.95	250	5,288	97,419	-8,499
		1.4	250	2,880	71,428	-4,629
		2	250	2,154	75,296	-3,462
		4	250	2,590	46,770	-4,120
	TYPICAL	0.71	250	14,324	129,073	-22,784
		0.95	250	16,618	109,154	-26,387
		1.4	250	11,314	88,046	-17,966
		2	250	7,896	86,494	-12,539
		4	250	4,007	54,851	-6,363
	HIGH	0.71	250	28,871	206,132	-45,254
		0.95	250	21,654	173,536	-33,941
		1.4	250	14,743	142,344	-23,109
		2	250	22,194	152,364	-34,505
		4	250	11,263	101,601	-17,510
	VERY HIGH	0.71	250	62,275	432,983	-96,820

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		0.95	250	46,706	356,655	-72,615
		1.4	250	31,800	254,003	-49,440
		2	250	22,194	233,993	-34,505
		4	250	11,263	126,987	-17,510
PIXRESIN	LOW	0.71	500	3,777	106,736	-2,098
		0.95	500	7,481	99,612	-6,306
		1.4	500	4,075	72,622	-3,435
		2	500	3,047	76,190	-2,568
		4	500	3,700	47,879	-3,011
	TYPICAL	0.71	500	20,456	135,205	-16,651
		0.95	500	23,769	116,305	-19,236
		1.4	500	16,183	92,915	-13,097
		2	500	11,294	89,891	-9,141
		4	500	5,731	56,575	-4,639
	HIGH	0.71	500	41,763	219,023	-32,363
		0.95	500	31,322	183,205	-24,272
		1.4	500	21,326	148,927	-16,526
		2	500	32,328	162,498	-24,371
		4	500	16,405	106,743	-12,368
	VERY HIGH	0.71	500	90,710	461,418	-68,385
		0.95	500	68,033	377,981	-51,289
		1.4	500	46,320	268,523	-34,920
		2	500	32,328	244,127	-24,371
		4	500	16,405	132,129	-12,368
PIXRESIN	LOW	0.71	2000	11,750	114,710	5,875
		0.95	2000	27,182	119,313	13,395
		1.4	2000	14,805	83,353	7,296
		2	2000	11,071	84,214	5,456
		4	2000	13,058	57,238	6,347
	TYPICAL	0.71	2000	72,201	186,950	35,093

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		0.95	2000	83,492	176,028	40,487
		1.4	2000	56,846	133,578	27,566
		2	2000	39,674	118,271	19,239
		4	2000	20,133	70,976	9,763
	HIGH	0.71	2000	141,537	318,797	67,411
		0.95	2000	106,153	258,035	50,559
		1.4	2000	72,274	199,876	34,423
		2	2000	107,116	237,286	50,418
		4	2000	54,358	144,6[illegible]6	25,585
	VERY HIGH	0.71	2000	300,565	671,273	141,470
		0.95	2000	225,424	535,372	106,103
		1.4	2000	153,480	375,683	72,240
		2	2000	107,116	318,915	50,418
		4	2000	54,358	170,082	25,585
PIXRESIN	LOW	0.71	3000	17,[illegible]25	120,585	11,750
		0.95	3000	40,5[illegible]7	132,708	26,790
		1.4	3000	22,101	90,649	14,592
		2	3000	16,527	89,670	10,911
		4	3000	19,404	63,584	12,693
	TYPICAL	0.71	3000	107,294	222,043	70,187
		0.95	3000	123,979	216,515	80,974
		1.4	3000	84,411	161,143	55,131
		2	3000	58,912	137,509	38,477
		4	3000	29,896	80,739	19,526
	HIGH	0.71	3000	208,949	386,209	134,823
		0.95	3000	156,711	308,594	101,117
		1.4	3000	106,697	[illegible]34,299	68,846
		2	3000	157,534	287,704	100,835
		4	3000	79,943	170,281	51,170
	VERY HIGH	0.71	3000	442,035	812,743	282,940
		0.95	3000	331,526	641,475	212,205

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		1.4	3000	225,720	447,923	144,480
		2	3000	157,534	369,333	100,835
		4	3000	79,943	195,667	51,170
CONCLIQ	LOW	0.71	250	2,529	102,496	-3,047
		3.7	250	372	31,882	-448
		5.4	250	625	19,966	-1,005
		6.6	250	265	22,974	-319
		10.4	250	501	21,154	-806
	TYPICAL	0.71	250	2,529	103,958	-3,047
		3.7	250	2,819	38,420	-4,484
		5.4	250	1,905	22,309	-3,030
		6.6	250	1,600	26,025	-2,545
		10.4	250	990	21,182	-1,575
	HIGH	0.71	250	14,324	129,299	-22,784
		3.7	250	4,361	47,213	-6,924
		5.4	250	3,839	30,767	-6,018
		6.6	250	3,225	32,726	-5,055
		10.4	250	1,996	28,055	-3,129
	VERY HIGH	0.71	250	28,871	206,132	-45,254
		3.7	250	12,256	89,071	-19,055
		5.4	250	8,281	62,546	-12,875
		6.6	250	6,956	59,925	-10,815
		10.4	250	4,306	44,938	-6,695
CONCLIQ	LOW	0.71	500	3,585	103,552	-1,992
		3.7	500	527	32,037	-293
		5.4	500	884	20,225	-745
		6.6	500	375	23,084	-208
		10.4	500	709	21,362	-598
	TYPICAL	0.71	500	3,585	105,013	-1,992

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		3.7	500	4,026	39,627	-3,277
		5.4	500	2,720	23,124	-2,214
		6.6	500	2,285	26,710	-1,860
		10.4	500	1,415	21,606	-1,151
	HIGH	0.71	500	20,456	135,432	-16,651
		3.7	500	6,237	49,089	-5,048
		5.4	500	5,554	32,481	-4,304
		6.6	500	4,665	34,166	-3,615
		10.4	500	2,888	28,946	-2,238
	VERY HIGH	0.71	500	41,763	219,023	-32,363
		3.7	500	17,853	94,667	-13,459
		5.4	500	12,063	66,327	-9,094
		6.6	500	10,133	63,101	-7,639
		10.4	500	6,273	46,904	-4,729
CONCLIQ	LOW	0.71	2000	11,153	111,119	5,576
		3.7	2000	1,639	33,150	820
		5.4	2000	3,213	22,554	1,583
		6.6	2000	1,167	23,876	583
		10.4	2000	2,578	23,231	1,270
	TYPICAL	0.71	2000	11,153	112,581	5,576
		3.7	2000	14,210	49,810	6,907
		5.4	2000	9,601	30,005	4,667
		6.6	2000	8,065	32,490	3,920
		10.4	2000	4,993	25,184	2,427
	HIGH	0.71	2000	72,201	187,176	35,093
		3.7	2000	21,909	64,761	10,624
		5.4	2000	18,821	45,749	8,964
		6.6	2000	15,810	45,311	7,530
		10.4	2000	9,787	35,846	4,661
	VERY HIGH	0.71	2000	141,537	318,797	67,411
		3.7	2000	59,154	135,968	27,843

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
		5.4	2000	39,969	94,233	18,813
		6.6	2000	33,574	86,543	15,803
		10.4	2000	20,784	61,416	9,783
CONCLIQ	LOW	0.71	3000	16,729	116,696	11,153
		3.7	3000	2,459	33,969	1,639
		5.4	3000	4,796	24,137	3,167
		6.6	3000	1,750	24,459	1,167
		10.4	3000	3,848	24,501	2,541
	TYPICAL	0.71	3000	16,729	118,157	11,153
		3.7	3000	21,116	56,717	13,813
		5.4	3000	14,268	34,672	9,333
		6.6	3000	11,985	36,410	7,840
		10.4	3000	7,419	27,610	4,853
	HIGH	0.71	3000	107,294	222,270	70,187
		3.7	3000	32,534	75,386	21,249
		5.4	3000	27,786	54,713	17,929
		6.6	3000	23,340	52,841	15,060
		10.4	3000	14,449	40,507	9,323
	VERY HIGH	0.71	3000	208,949	386,209	134,823
		3.7	3000	86,996	163,811	55,685
		5.4	3000	58,781	113,046	37,625
		6.6	3000	49,376	102,345	31,605
		10.4	3000	30,566	71,198	19,565
PFSLUDGE	LOW	0.56	250	3,271	132,512	-3,940
		2	250	2,010	57,672	-3,231
		4	250	2,590	46,355	-4,120
	TYPICAL	0.56	250	18,210	164,046	-28,965
		2	250	7,896	68,454	-12,539
		4	250	4,007	54,701	-6,363

* Differential costs compared to 1000 mile distance case

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
	HIGH	0.56	250	28,168	220,846	-44,727
		2	250	22,194	121,712	-34,505
		4	250	11,263	93,141	-17,510
	VERY HIGH	0.56	250	79,169	491,274	-123,085
		2	250	22,194	185,272	-34,505
		4	250	11,263	126,429	-17,510
PFSLUDGE	LOW	0.56	500	4,636	133,877	-2,575
		2	500	2,844	58,506	-2,397
		4	500	3,700	47,464	-3,011
	TYPICAL	0.56	500	26,005	171,842	-21,169
		2	500	11,294	71,852	-9,141
		4	500	5,731	56,425	-4,639
	HIGH	0.56	500	40,289	232,966	-32,606
		2	500	32,328	131,845	-24,371
		4	500	16,405	98,284	-12,368
	VERY HIGH	0.56	500	115,318	527,423	-86,936
		2	500	32,328	195,406	-24,371
		4	500	16,405	131,572	-12,368
PFSLUDGE	LOW	0.56	2000	14,422	143,664	7,211
		2	2000	10,333	65,995	5,092
		4	2000	13,058	56,823	6,347
	TYPICAL	0.56	2000	91,787	237,624	44,613
		2	2000	39,674	100,232	19,239
		4	2000	20,133	70,827	9,763
	HIGH	0.56	2000	141,522	334,200	68,627
		2	2000	107,116	206,634	50,418
		4	2000	54,358	136,236	25,585

* Differential costs compared to 1000 mile distance case

Table B.2 Transport Costs for PWR Waste Streams (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL * TRANSP COSTS, $
	VERY HIGH	0.56	2000	382,101	794,206	179,848
		2	2000	107,116	270,194	50,418
		4	2000	54,358	169,524	25,585
PFSLUDGE	LOW	0.56	3000	21,634	150,875	14,422
		2	3000	15,425	71,087	10,184
		4	3000	19,404	63,169	12,693
	TYPICAL	0.56	3000	136,401	282,237	89,227
		2	3000	58,912	119,470	38,477
		4	3000	29,896	80,589	19,526
	HIGH	0.56	3000	210,149	402,827	137,254
		2	3000	157,534	257,052	100,835
		4	3000	79,943	161,821	51,170
	VERY HIGH	0.56	3000	561,949	974,054	359,695
		2	3000	157,534	320,612	100,835
		4	3000	79,943	195,109	51,170

* Differential costs compared to 1000 mile distance case

APPENDIX C

SITE-SPECIFIC BURIAL COSTS

Tables C.1 and C.2 present burial costs for BWR and PWR low-level radwastes, respectively. Burial costs are shown based on two rate schedules. The costs for burial at sites operated by U.S. Ecology, Inc. (Beatty, NV and Hanford, WA) are based on the average rates charged between these two sites. The costs for burial at the Barnwell, SC site, are based on a rate schedule for that site supplied by Chem-Nuclear Systems, Inc., the site operator. The "Average Burial Costs" tabulated are a linear average of the U.S. Ecology and Barnwell costs.

The differential cost columns simply show the site specific burial costs minus the average burial costs. These differentials should allow the user to adjust the total disposal costs for particular wastes to reflect burial at a specific burial site.

Table C.1 Site - Specific Burial Costs for BWR Wastes (1988 dollars)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS, $	BARNWELL BUR COSTS, $	AVERAGE BUR COSTS, $	DIFFERENTIAL * U.S. ECO - AVG, $	DIFFERENTIAL ** BNWL - AVG, $
BNCTRASH	LOW	0.2	144,972	180,929	162,951	-17,978	17,978
		0.4	72,595	90,600	81,597	-9,003	9,003
		0.6	48,469	152,973	100,721	-52,252	52,252
		0.8	36,297	114,558	75,428	-39,130	39,130
	TYPICAL	0.2	144,972	180,929	162,951	-17,978	17,978
		0.4	72,595	90,600	81,597	-9,003	9,003
		0.6	48,469	152,973	100,721	-52,252	52,252
		0.8	36,297	114,558	75,428	-39,130	39,130
	HIGH	0.2	144,972	180,929	162,951	-17,978	17,978
		0.4	72,595	90,600	81,597	-9,003	9,003
		0.6	48,469	152,973	100,721	-52,252	52,252
		0.8	36,297	114,558	75,428	-39,130	39,130
	VERY HIGH	0.2	174,673	294,763	234,718	-60,045	60,045
		0.4	87,467	152,814	120,141	-32,674	32,674
		0.6	58,399	194,511	126,455	-68,056	68,056
		0.8	43,734	153,239	98,486	-54,753	54,753
BCOTRASH	LOW	2.27	12,824	16,004	14,414	-1,590	1,590
		3.78	7,825	9,765	8,795	-970	970
		5.67	5,216	6,510	5,863	-647	647
		8.69	3,478	4,340	3,909	-431	431
		113.4	435	543	489	-54	54
	TYPICAL	2.27	12,824	16,004	14,414	-1,590	1,590
		3.78	7,825	9,765	8,795	-970	970
		5.67	5,216	6,510	5,863	-647	647
		8.69	3,478	4,340	3,909	-431	431
		113.4	435	543	489	-54	54
	HIGH	2.27	13,319	16,018	15,669	-2,349	2,349
		3.78	8,127	10,994	9,561	-1,434	1,434
		5.67	5,418	7,441	6,430	-1,012	1,012
		8.69	3,612	5,250	4,431	-819	819
		113.4	524	915	719	-196	196

* U.S. *Ecology* site burial costs minus average burial costs

** Barnwell, SC site burial costs minus average burial costs

Table C.1 Site - Specific Burial Costs for BWR Wastes (1988 dollars) (cont.) 7/88

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS, $	BARNWELL BUR COSTS, $	AVERAGE BUR COSTS, $	DIFFERENTIAL * U.S. ECO - AVG, $	DIFFERENTIAL ** BNWL - AVG, $
	VERY HIGH	2.27	15,926	26,074	21,000	-5,074	5,074
		3.78	9,718	16,471	13,094	-3,377	3,377
		5.67	6,479	10,981	8,730	-2,251	2,251
		8.69	4,529	8,811	6,670	-2,141	2,141
		113.4	707	2,057	1,382	-675	675
BIXRESIN	LOW	0.71	45,574	65,581	55,578	-10,003	10,003
		0.95	33,985	48,274	41,129	-7,145	7,145
		1.4	24,186	42,425	33,306	-9,119	9,119
		2	17,546	30,654	24,100	-6,554	6,554
		4	8,904	15,556	12,230	-3,326	3,326
	TYPICAL	0.71	53,211	103,525	78,368	-25,157	25,157
		0.95	44,006	87,235	65,620	-21,614	21,614
		1.4	29,961	72,735	51,348	-21,387	21,387
		2	23,699	50,763	37,231	-13,532	13,532
		4	12,027	28,869	20,448	-8,421	8,421
	HIGH	0.71	96,296	218,757	157,527	-61,230	61,230
		0.95	72,312	203,258	137,785	-65,473	65,473
		1.4	60,103	175,954	118,029	-57,926	57,926
		2	42,056	155,390	98,723	-56,667	56,667
		4	21,519	95,392	58,456	-36,936	36,936
	VERY HIGH	0.71	120,603	616,500	368,552	-247,949	247,949
		0.95	91,354	462,375	276,865	-185,511	185,511
		1.4	63,350	406,969	235,159	-171,809	171,809
		2	45,303	284,030	164,667	-119,364	119,364
		4	24,767	144,135	84,451	-59,684	59,684
BCONCLIQ	LOW	0.71	42,441	64,747	53,594	-11,153	11,153
		1.9	18,593	31,377	24,985	-6,392	6,392
		2.4	14,665	25,622	20,143	-5,478	5,478
		3.3	9,428	16,471	12,949	-3,522	3,522
		4.5	8,098	13,726	10,912	-2,814	2,814

* U.S. Ecology site burial costs minus average burial costs

** Barnwell, SC site burial costs minus average burial costs

Table C.1 Site - Specific Burial Costs for BWR Wastes (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS, $	BARNWELL BUR COSTS, $	AVERAGE BUR COSTS, $	DIFFERENTIAL * U.S. ECO - AVG, $	DIFFERENTIAL ** BNWL - AVG, $
	TYPICAL	0.71	53,211	103,525	78,368	-25,157	25,157
		1.9	25,114	53,794	39,454	-14,340	14,340
		2.4	19,809	42,429	31,119	-11,310	11,310
		3.8	12,734	30,567	21,651	-8,917	8,917
		4.5	12,007	30,849	21,428	-9,421	9,421
	HIGH	0.71	96,282	218,757	157,519	-61,238	61,238
		1.9	44,531	164,667	104,599	-60,068	60,068
		2.4	35,196	129,878	82,537	-47,341	47,341
		3.8	22,750	101,004	61,877	-39,127	39,127
		4.5	19,016	84,170	51,593	-32,577	32,577
	VERY HIGH	0.71	120,459	616,500	368,480	-248,021	248,021
		1.9	47,649	360,987	174,318	-126,669	126,669
		2.4	38,314	237,398	137,856	-99,542	99,542
		3.8	25,868	152,613	89,241	-63,373	63,373
		4.5	22,134	127,178	74,656	-52,522	52,522
BFSLUDGE	LOW	0.56	53,954	82,826	68,390	-14,436	14,436
		2	17,546	30,654	24,100	-6,554	6,554
		4	9,623	18,723	14,173	-4,550	4,550
	TYPICAL	0.56	67,646	131,609	99,627	-31,981	31,981
		2	23,699	50,763	37,231	-13,532	13,532
		4	13,608	34,962	24,285	-10,677	10,677
	HIGH	0.56	122,436	278,101	200,268	-77,832	77,832
		2	42,171	187,979	115,075	-72,904	72,904
		4	21,634	111,495	66,564	-44,930	44,930
	VERY HIGH	0.56	153,489	783,743	468,616	-315,127	315,127
		2	46,451	284,030	165,241	-118,790	118,790
		4	25,915	144,135	85,025	-59,110	59,110

* U.S. Ecology site burial costs minus average burial costs

** Barnwell, SC site burial costs minus average burial costs

Table C.2 Site - Specific Burial Costs for PWR Wastes (1988 dollars)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS, $	BARNWELL BUR COSTS, $	AVERAGE BUR COSTS, $	DIFFERENTIAL * U.S. ECO - AVG, $	DIFFERENTIAL ** BNWL - AVG, $
PNCTRASH	LOW	0.2	144,972	180,929	162,951	-17,978	17,978
		0.4	72,595	90,600	81,597	-9,003	9,003
		0.6	48,469	152,973	100,721	-52,252	52,252
		0.8	36,297	114,558	75,428	-39,130	39,130
	TYPICAL	0.2	144,972	180,929	162,951	-17,978	17,978
		0.4	72,595	90,600	81,597	-9,003	9,003
		0.6	48,469	152,973	100,721	-52,252	52,252
		0.8	36,297	114,558	75,428	-39,130	39,130
	HIGH	0.2	150,575	211,024	180,800	-30,224	30,224
		0.4	75,401	118,157	96,779	-21,378	21,378
		0.6	50,342	179,[illegible]4	115,073	-64,731	64,731
		0.8	37,700	141,350	89,525	-51,825	51,825
	VERY HIGH	0.2	256,360	367,292	311,826	-55,466	55,466
		0.4	128,372	206,641	167,507	-39,134	39,134
		0.6	85,710	261,440	173,575	-87,865	87,865
		0.8	64,186	195,787	129,987	-65,800	65,800
PCOTRASH	LOW	3.78	7,825	9,765	8,795	-970	970
		5.67	5,216	6,510	5,863	-647	647
		8.69	3,478	4,340	3,909	-431	431
		113.4	435	543	489	-54	54
	TYPICAL	3.78	7,825	9,765	8,795	-970	970
		5.67	5,216	6,510	5,863	-647	647
		8.69	3,478	4,340	3,909	-431	431
		113.4	452	689	570	-119	119
	HIGH	3.78	8,127	10,994	9,561	-1,434	1,434
		5.67	5,418	7,560	6,489	-1,071	1,071
		8.69	3,612	5,367	4,489	-877	877
		113.4	566	1,101	834	-268	268
	VERY HIGH	3.78	11,236	19,824	15,530	-4,294	4,294
		5.67	7,490	13,216	10,353	-2,863	2,863

* U.S. Ecology site burial costs minus average burial costs

** Barnwell, SC site burial costs minus average burial costs

Table C.2 Site - Specific Burial Costs for PWR Wastes (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS, $	BARNWELL BUR COSTS, $	AVERAGE BUR COSTS, $	DIFFERENTIAL * U.S. ECO - AVG, $	DIFFERENTIAL ** BNWL - AVG, $
		8.69	4,994	9,893	7,446	-2,453	2,453
		113.4	1,024	2,327	1,676	-651	651
PIXRESIN	LOW	0.71	40,862	50,996	45,929	-5,067	5,067
		0.95	31,831	48,274	40,052	-8,222	8,222
		1.4	21,672	32,201	26,937	-5,265	5,265
		2	15,125	22,781	18,953	-3,828	3,828
		4	8,904	15,556	12,230	-3,326	3,326
	TYPICAL	0.71	49,233	86,015	67,624	-18,391	18,391
		0.95	39,908	77,644	58,776	-18,868	18,868
		1.4	27,171	59,394	43,283	-16,111	16,111
		2	20,911	41,452	31,181	-10,271	10,271
		4	12,027	25,760	18,893	-6,867	6,867
	HIGH	0.71	66,500	193,318	129,909	-63,409	63,409
		0.95	72,177	164,068	118,122	-45,945	45,945
		1.4	49,214	138,388	93,801	-44,587	44,587
		2	41,920	122,801	82,361	-40,441	40,441
		4	21,384	95,392	58,388	-37,004	37,004
	VERY HIGH	0.71	119,250	527,464	323,357	-204,107	204,107
		0.95	90,001	462,375	276,188	-186,187	186,187
		1.4	61,997	314,809	188,403	-126,406	126,406
		2	43,950	284,030	163,990	-120,040	120,040
		4	23,414	144,135	83,774	-60,361	60,361
PCONCLIQ	LOW	0.71	40,862	50,996	45,929	-5,067	5,067
		3.7	8,042	10,037	9,039	-997	997
		5.4	5,644	7,967	6,805	-1,161	1,161
		6.6	4,564	5,696	5,130	-566	566
		10.4	2,935	4,477	3,706	-771	771
	TYPICAL	0.71	40,862	50,996	45,929	-5,067	5,067
		3.7	9,689	16,929	13,309	-3,620	3,620
		5.4	6,749	11,438	9,093	-2,345	2,345

* U.S. Ecology site burial costs minus average burial costs

** Barnwell, SC site burial costs minus average burial costs

Table C.2 Site - Specific Burial Costs for PWR Wastes (1988 dollars) (cont.)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS, $	BARNWELL BUR COSTS, $	AVERAGE BUR COSTS, $	DIFFERENTIAL * U.S. ECO - AVG, $	DIFFERENTIAL ** BNWL - AVG, $
		6.6	5,499	9,608	7,554	-2,054	2,054
		10.4	3,509	6,537	5,023	-1,514	1,514
	HIGH	0.71	49,233	86,015	67,624	-18,391	18,391
		3.7	13,088	28,033	20,561	-7,473	7,473
		5.4	10,006	21,227	15,616	-5,611	5,611
		6.6	7,428	17,831	12,629	-5,201	5,201
		10.4	6,655	15,127	10,891	-4,236	4,236
	VERY HIGH	0.71	66,500	193,318	129,909	-63,409	63,409
		3.7	23,233	85,813	54,523	-31,290	31,290
		5.4	15,766	70,141	42,954	-27,188	27,188
		6.6	13,276	58,919	36,098	-22,821	22,821
		10.4	8,298	42,630	25,464	-17,166	17,166
PFSLUDGE	LOW	0.56	51,947	64,831	58,389	-6,442	6,442
		2	15,125	21,986	18,556	-3,430	3,430
		4	8,904	15,025	11,965	-3,061	3,061
	TYPICAL	0.56	62,589	109,349	85,969	-23,380	23,380
		2	20,911	36,894	28,903	-7,992	7,992
		4	12,027	25,760	18,893	-6,867	6,867
	HIGH	0.56	84,540	181,080	132,810	-48,270	48,270
		2	28,789	106,936	67,862	-39,073	39,073
		4	21,303	78,855	50,079	-28,776	28,776
	VERY HIGH	0.56	150,173	554,303	352,238	-202,065	202,065
		2	43,135	219,710	131,423	-88,288	88,288
		4	22,599	144,135	83,367	-60,768	60,768

* U.S. Ecology site burial costs minus average burial costs

** Barnwell, SC site burial costs minus average burial costs

APPENDIX D

LOCATION OF NUCLEAR POWER PLANTS WITHIN REGIONAL COMPACTS

Table D.1 lists all low-level waste generating commercial nuclear power plants in the United States. The plants are categorized by membership in regional compact and location (by state).[1] Information regarding whether the plant is a BWR or PWR is also included. Applicable 1988 and 1989 Surcharge Costs for each state are pesentd. Fifty of eighty PWR units (63%) are not in a sited compact. For BWR plants, 28 of 37 units (76%) are not located in a sited compact.

Note: Compliance with the national low-level waste disposal facility policy by states and compacts is subject to change as congressionally mandated schedules are met or not met. The analyst should ensure he is working with the most current information when making an assessment based on compact membership.

[1] Source: *Nuclear News*, American Nuclear Society, La Grange Park, IL, March 1988.

TABLE D.1. U.S. NUCLEAR POWER PLANTS BY COMPACT MEMBERSHIP

Compact	State	Plant Name	Plant Type	Applicable Surcharges
APPALACHIAN	Pennsylvania	Beaver Valley 1 & 2	PWR	$20/cu ft
		Limerick 1 & 2	BWR	$20/cu ft
		Peach Bottom 2 & 3	BWR	$20/cu ft
		Susquehanna 1 & 2	BWR	$20/cu ft
		Three Mile Island 1	PWR	$20/cu ft
	Maryland	Calvert Cliffs 1 & 2	PWR	$20/cu ft
	Delaware	No Nuclear Plants		$20/cu ft
	West Virginia	No Nuclear Plants		$20/cu ft
CENTRAL MIDWEST	Illinois	Braidwood 1 & 2	PWR	$20/cu ft
		Byron 1 & 2	PWR	$20/cu ft
		Clinton 1	BWR	$20/cu ft
		Dresden 2 & 3	BWR	$20/cu ft
		La Salle 1 & 2	[illegible]VR	$20/cu ft
		Quad Cities 1 & 2	[illegible]	$20/cu ft
		Zion 1 & 2	PWR	$20/cu ft
	Kentucky	No Nuclear Plants		$20/cu ft
CENTRAL STATES	Arkansas	Nuclear One 1 & 2	PWR	$20/cu ft
	Kansas	Wolf Creek	PWR	$20/cu ft
	Louisiana	River Bend 1	BWR	$20/cu ft
		Waterford [illegible]	PWR	$20/cu ft
	Nebraska	Cooper	BWR	$20/cu ft
		Fort Calhoun 1	PWR	$20/cu ft
	Oklahoma	No Nuclear Plants		$20/cu ft
MIDWEST	Iowa	Duane Arnold	BWR	$20/cu ft
	Michigan	Big Rock Point	BWR	$20/cu ft
		Donald C. Cook 1 & 2	PWR	$20/cu ft
		Fermi 2	BWR	$20/cu ft
		Palisades	PWR	$20/cu ft
	Minnesota	Monticello	BWR	$20/cu ft
		Prairie Island 1 & 2	PWR	$20/cu ft
	Missouri	Callaway 1	PWR	$20/cu ft
	Ohio	Davis-Besse 1	PWR	$20/cu ft
		Perry 1	BWR	$20/cu ft
	Wisconsin	Kewaunee	PWR	$20/cu ft
		Point Beach 1 & 2	PWR	$20/cu ft

TABLE D.1. U.S. NUCLEAR POWER PLANTS BY COMPACT MEMBERSHIP (cont.)

Compact	State	Plant Name	Plant Type	Applicable Surcharges
	Indiana	No Nuclear Plants		$20/cu ft
NORTHEAST	Connecticut	Haddam Neck	PWR	$20/cu ft
		Millstone 1	BWR	$20/cu ft
		Millstone 2 & 3	PWR	$20/cu ft
	New Jersey	Hope Creek 1	BWR	$20/cu ft
		Oyster Creek 1	BWR	$20/cu ft
		Salem 1 & 2	PWR	$20/cu ft
NORTHWEST	Oregon	Trojan	PWR	none
	Washington	WNP-2	BWR	none
	Idaho	No Nuclear Plants		none
	Utah	No Nuclear Plants		none
	Montana	No Nuclear Plants		none
	Alaska	No Nuclear Plants		none
	Hawaii	No Nuclear Plants		none
ROCKY MOUNTAIN	Colorado	Fort St. Vrain	HTGR	none
	New Mexico	No Nuclear Plants		none
	Nevada	No Nuclear Plants		none
	Wyoming	No Nuclear Plants		none
	Rhode Island	No Nuclear Plants		none
SOUTHEAST	Alabama	Bellefonte 1 & 2	PWR	none
		Browns Ferry 1, 2 & 3	BWR	none
		Joseph M. Farley 1 & 2	PWR	none
		Watts Bar 1 & 2	PWR	none
	Florida	Crystal River 3	PWR	none
		St. Lucie 1 & 2	PWR	none
		Turkey Point 3 & 4	PWR	none
	Georgia	Edwin I. Hatch 1 & 2	BWR	none
		Vogtle 1 & 2	PWR	none
	Mississippi	Grand Gulf 1	BWR	none
	North Carolina	Brunswick 1 & 2	BWR	none
		Mc Guire 1 & 2	PWR	none
		Shearon Harris 1	PWR	none

TABLE D.1. U.S. NUCLEAR POWER PLANTS BY COMPACT MEMBERSHIP (cont.)

Compact	State	Plant Name	Plant Type	Applicable Surcharges
	South Carolina	Catawba 1 & 2	PWR	none
		Oconee 1, 2 & 3	PWR	none
		Robinson 2	PWR	none
		Virgil C. Summer 1	PWR	none
	Tennessee	Sequoyah 1 & 2	PWR	none
	Virginia	North Anna 1 & 2	PWR	none
		Surry 1 & 2	PWR	none
"GO-IT-ALONE" STATES	California	Diablo Canyon 1 & 2	PWR	$20/cu ft
		Rancho Seco	PWR	$20/cu ft
		San Onofre 1, 2 & 3	PWR	$20/cu ft
	Massachusetts	Pilgrim 1	BWR	$20/cu ft
		Yankee	PWR	$20/cu ft
	New York	Indian Point 2 & 3	PWR	$20/cu ft
		James A. FitzPatrick	BWR	$20/cu ft
		Nine Mile Point 1 & 2	BWR	$20/cu ft
		Robert E. Ginna	PWR	$20/cu ft
	Texas	Comanche Peak 1 & 2	PWR	$20/cu ft
		South Texas Project 1 & 2	PWR	$20/cu ft
UNDECIDED	Arizona	Palo Verde 1, 2 & 3	PWR	$20/cu ft
	Maine	Maine Yankee	PWR	$20/cu ft
	South Dakota	No Nuclear Plants		$20/cu ft
	New Hampshire	Seabrook 1	PWR	$80/cu ft *
	Vermont	Vermont Yankee	BWR	$80/cu ft *
	North Dakota	No Nuclear Plants		$80/cu ft *
	Puerto Rico	No Nuclear Plants		$80/cu ft *
	District of Columbia	No Nuclear Plants		**
	US Territories	No Nuclear Plants		**

* 1988 Penalty surcharges. After January 1, 1989 these states can be denied access to a disposal facility if 1986 legislative milestones are not met.

** Status unknown. Seeking arrangements with sited compacts.

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NRC regulatory impact analyses address the costs and benefits associated with proposed regulatory requirements. Many of these requirements will result in physical modifications to existing structures and systems at nuc'ear power plants.

This report provides a methodology and data needed to estimate the generic costs of disposing of radioactive wastes that may be generated as a result of NRC regulations requiring modifications or repairs to nuclear facilities. Also presented are descriptions of typical low-level radioactive wastes generated at nuclear power plants and the various processes used to treat the wastes in preparation for shipment and burial. The waste disposal cost estimates included in this report cover all the major elements that contribute to the overall costs. The key factors that influence the costs are discussed. Pertinent ranges c. values for the key variables are explored and important sensitivities identified. The cost implications of the burial surcharges authorized by the Low-Level Radioactive Waste Policy Amendments Act of 1985 are covered. Occupational radiation exposure associated with in-plant handling of the wastes is also discussed.

This report updates and revise: .nformation presented in NUREG/CR-4555.

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