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Generic Cost Estimates for the Disposal of Radioactive Wastes

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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 radwastes 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 of the major elements that contribute to the overall costs. They key factors that influence the costs are discussed. Pertinent ranges of values for the key variables are explored and important sensitivities identified. Occupational radiation exposure associated with in-plant handling of the wastes is also discussed.

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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 Cost Analysis Group sponsored this study. Its purpose is to provide an NRC 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 for each type of waste likely to be generated as a result of repairs or modifications at nulcear plants. The estimates are per 1000 ft^3 of as-generated waste and represent conditions consistant 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

Table 1.1 Summary of Total Cost Estimates for the Disposal of Low Level Radioactive Wastes

Cost per 1000 ft^3 of As-Generated Waste

	Total Cost Assuming Typical Waste Activity Level and Most Prevalent Volume Reduction Processes.** ($)
DRY WASTES	
Non-Compactible Trash	
BWR or PWR	200,100*
Compactible Trash	
BWR or PWR	11,500*
WET WASTES	
Ion Exchange Resins	
BWR	134,900*
PWR	119,300*
Concentated Liquids	
BWR	152,700
PWR	80,500
Filter Sludge	
BWR	193,700
PWR	159,300

*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 of 1000 miles.

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 are generally referred to as waste streams. Each stream is relatively distinct in terms of its form (wet or dry, compactible or non-compactible), 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 non-compactible 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.

Non-compactible 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. Non-compactible 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*. This waste stream is amenable to considerable volume reduction.

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*Solid wood pieces are sometimes disposed of as compactible trash.

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 floculating 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 floculating 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
Non-compactible 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 of.

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 of, 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.

1.2 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 non-compactible 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

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 compaction in 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
	BWR/PWR	
CONCLIQ	0.7/0.7	Solidification in cement
	1.9/3.7	Evaporator/crystalizer process, solidification in binder
	2.4/5.4	Mobile evaporator, solidification in binder
	3.8/6.6	Evaporator, grinding of residue, mixing with 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

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

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 non-compactible trash are believed 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 non-compactible wastes generated. From these data, the following ratios can be derived:

$$\text{At PWRs:} \quad \frac{\text{Volume Compactible DAW}}{\text{Volume Non-Compactible DAW}} \cong 0.9$$

$$\text{At BWRs:} \quad \frac{\text{Volume Compactible DAW}}{\text{Volume Non-Compactible DAW}} \cong 2.1$$

Given the estimated volume of non-compactible 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:

$$\frac{\text{As-Generated Volume Compactible DAW}}{\text{As-Generated Volume Non-Compactible DAW}} \cong \frac{0.9x(3.8 + 5.7)}{(0.2 + 0.4)} \cong 14.3$$

At BWRs:

$$\frac{\text{As-Generated Volume Compactible DAW}}{\text{As-Generated Volume Non-Compactible DAW}} \cong \frac{2.1x(3.8 + 5.7)}{(0.2 + 0.4)} \cong 33.3$$

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

Table 1.3 Summary Approach to Waste Volume Estimating*

WASTE STREAM	COMPONENTS	APPROACH	QUANTITATIVE GUIDANCE
Non-Compactible 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 non-compactible DAW:	At PWRs: $\frac{\text{Vol.Comp.DAW}}{\text{Vol.Non-Comp.DAW}} \simeq 0.9$ At BWRs: $\frac{\text{Vol.Comp.DAW}}{\text{Vol.Non-Comp.DAW}} \simeq 2.1$
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 decontaiminated, and the decon solution used.	For LOMI decon solution: ~0.1 ft^3 of waste / gal. decon soln.
Filters	From decontaimination 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)

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

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 cask rental if such casks 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. 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 quantititative 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:

- 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 abritrary, 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, storage, transport, and burial, as well as the total costs, are displayed.

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

- o 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.
- o 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.
- o 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.
- o 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.
- o 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

Table 1.4 Estimated Cost for the Disposal of Low Level Radioactive Wastes

Cost per 1000 ft^3 of As-Generated Waste
BWR Reactor Type

WASTE TYPE	ACTIVITY LEVEL (Ci/ft^3)	VRF	PROCESSING COSTS, $	TRANSPORT** COSTS, $	STORAGE COSTS, $	BURIAL COSTS, $	TOTAL COSTS, $
DRY WASTES							
Non-Compactible Trash							
(BNCTRASH)	LOW to	0.20*	77200	14200	53200	113800	258360
	TYPICAL	0.40*	48700	8900	26600	56900	141000
	(to 0.0013)	0.60	39300	8600	17700	37900	103500
		0.80	34600	8300	13300	28400	84700
	HIGH	0.20	77200	14200	58600	120200	270100
	(0.013)	0.40	48700	8900	29300	60900	147800
		0.60	39300	8600	19500	41800	109200
		0.80	34600	8300	14600	32200	89800
	VERY HIGH	0.20	77200	121900	58600	168700	426400
	(0.13)	0.40	48700	61000	29300	90400	229400
		0.60	39300	40600	19500	91600	191000
		0.80	34600	30500	14600	71700	151500
Compactible Trash							
(BCOTRASH)	LOW to	2.27	6800	1200	4700	10000	22800
	TYPICAL	3.78*	4100	700	2800	6000	13700
	(to 0.0001)	5.67*	2900	500	1900	4000	9300
		8.69	2600	300	1200	2600	6800
		113.40	1600	0	100	300	2100
	HIGH	2.27	6800	2600	5200	11000	25600
	(0.001)	3.78	4100	1600	3100	6600	15400
		5.67	2900	1200	2100	4400	10600
		8.69	2600	1200	1300	3000	8100
		113.40	1600	300	100	500	2600
	VERY HIGH	2.27	6800	10700	5200	15500	38200
	(0.01)	3.78	4100	6400	3100	10000	23600
		5.67	2900	6400	2100	7600	19100
		8.69	2600	4200	1300	5000	13200
		113.40	1600	600	100	1100	3400

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*Typical Conditions
**Based on 1000 mile distance

Table 1.4 (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	PROCESSING COSTS, $	TRANSPORT** COSTS, $	STORAGE COSTS, $	BURIAL COSTS, $	TOTAL COSTS, $
WET WASTES							
<u>Ion-Exchange Resins</u>							
(BIXRESIN)	LOW (0.0176)	0.71	24100	19600	16500	37700	97900
		0.95	16300	13400	12300	27900	69900
		1.40	21400	17400	8400	23200	70400
		2.00	37700	12200	5900	18100	73900
		4.00	26400	6100	2900	9000	44500
	TYPICAL (0.176)	0.71*	24100	51500	16500	61100	153200
		0.95*	16300	38500	12300	49500	116600
		1.40	21400	26100	8400	40500	96300
		2.00	37700	18300	5900	30600	92500
		4 00	26400	18300	2900	22300	70000
	HIGH (1.76)	0.71	24100	103000	16500	146100	289700
		0.95	16300	77000	12300	149600	255200
		1.40	21400	52200	8400	120500	202500
		2.00	37700	42700	5900	111300	197500
		4.00	26400	32000	2900	76400	137700
	VERY HIGH (17.6)	0.71	24100	180300	16500	502900	723800
		0.95	16300	134700	12300	430100	593500
		1.40	21400	91400	8400	292400	413500
		2.00	37700	85300	5900	263400	392300
		4.00	26400	42700	2900	166600	238600
<u>Concentrated Liquids</u>							
(BCONCLIQ)	LOW (0.017)	0.71	23600	17900	16500	37300	95400
		1.90	32700	12800	6200	19000	70700
		2.40	14800	10200	4900	15100	44900
		3.80	21000	6400	3100	9500	40000
		4.50	26400	5400	2600	8400	42800
	TYPICAL (0.17)	0.71*	23600	51500	16500	61100	152700
		1.90	32700	19200	6200	32200	90300
		2.40	14800	15200	4900	25500	60400
		3.80	21000	19200	3100	23500	66800
		4.50	26400	16300	2600	20900	66100

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*Typical Conditions

**Based on 1000 mile distance

Table 1.4 (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	PROCESSING COSTS, $	TRANSPORT** COSTS, $	STORAGE COSTS, $	BURIAL COSTS, $	TOTAL COSTS, $
	HIGH (1.7)	0.71	23600	103000	16500	145100	289200
		1.90	32700	44900	6200	98600	182400
		2.40	14800	35600	4900	92800	148000
		3.80	21000	33700	3100	80400	138200
		4.50	26400	28400	2600	67900	125300
	VERY HIGH (17.0)	0.71	23600	180300	16500	502900	723300
		1.90	32700	89800	6200	277200	405800
		2.40	14800	71100	4900	219700	310500
		3.80	21000	44900	3100	175200	244200
		4.50	26400	37900	2600	148200	215100
<u>Filter Sludge</u>							
(BFSLUDGE)	LOW (0.023)	0.56	30300	24100	20900	47600	122900
		2.00	22500	12200	5900	18100	58600
		4.00	26200	9100	2900	10800	49100
	TYPICAL (0.23)	0.56*	30300	65300	20900	77400	193900
		2.00	22500	18300	5900	30600	77300
		4.00	26200	18300	2900	23500	70900
	HIGH (2.3)	0.56	30300	130600	20900	185200	367000
		2.00	22500	42700	5900	111300	182400
		4.00	26200	32000	2900	89200	150300
	VERY HIGH (23.0)	0.56	30300	228600	20900	637700	917500
		2.00	22500	85300	5900	332200	445900
		4.00	26200	42700	2900	167100	238800

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*Typical Conditions

**Based on 1000 mile distance

Table 1.5. Estimated Cost for the Disposal of Low Level Radioactive Waste

Cost per 1000 ft^3 of As-Generated Waste
PWR Reactor Type

WASTE TYPE	ACTIVITY LEVEL(Ci/ft^3)	VRF	PROCESSING COSTS,$	TRANSPORT** COSTS,$	STORAGE COSTS,$	BURIAL COSTS,$	TOTAL COSTS,$
DRY WASTES							
<u>Non-Compactible Trash</u>							
(PNCTRASH)	LOW to	0.20*	77200	14200	53200	113800	258300
	TYPICAL	0.40*	48700	9600	26600	56900	141800
	(to 0.0027)	0.60	39300	9200	17700	37900	104100
		0.80	34600	9100	13300	28400	85500
	HIGH	0.20	77200	35300	58600	125900	297000
	(0.027)	0.40	48700	32700	29300	66400	177200
		0.60	39300	32300	19500	46700	137800
		0.80	34600	30900	14600	36600	116800
	VERY HIGH	0.20	77200	121900	58600	188400	446100
	(0.27)	0.40	48700	91400	29300	108400	277900
		0.60	39300	61000	19500	109700	229400
		0.80	34600	45700	14600	82200	177200
<u>Compactible Trash</u>							
(PCOTRASH)	LOW TO	3.78*	4100	700	2800	6000	13700
	TYPICAL	5.67*	2900	500	1900	4000	9300
	(TO 0.00019)	8.69	2600	300	1200	2600	6800
		113.40	1600	0	100	300	2100
	HIGH	3.78	4100	1600	3100	6600	15400
	(0.0019)	5.67	2900	1200	2100	4600	10800
		8.69	2600	1200	1300	3100	8300
		113.40	1600	300	100	600	2600
	VERY HIGH	3.78	4100	9700	3100	12100	29000
	(0.019)	5.67	2900	6400	2100	8100	19500
		8.69	2600	4200	1300	5700	13900
		113.40	1600	600	100	1600	4000

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*Typical conditions

**Based on 1000 mile distance

Table 1.5 (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	PROCESSING COSTS, $	TRANSPORT** COSTS, $	STORAGE COSTS, $	BURIAL COSTS, $	TOTAL COSTS, $
WET WASTES							
<u>Ion Exchange Resins</u>							
(PIXRESIN)	LOW (0.011)	0.71	23900	5500	16500	34500	80400
		0.95	16300	9800	12309	27000	65400
		1.40	21000	6900	8400	19200	55500
		2.00	37300	4900	5900	13500	61600
		4.00	26400	6100	2900	9000	44500
	TYPICAL (0.11)	0.71*	23900	34300	16500	51000	125700
		0.95*	16300	38500	12300	45600	112800
		1.40	21000	26100	8400	35300	90800
		2.00	37300	18300	5900	24700	86200
		4.00	26400	9100	2900	15300	53800
	HIGH (1.1)	0.71	23900	103000	16500	125700	269100
		0.95	16300	77000	12300	109200	214800
		1.40	21000	52200	8400	101500	183100
		2.00	37300	36600	5900	84300	164100
		4.00	26400	21300	2900	55700	106400
	VERY HIGH (11.0)	0.71	23900	180300	16500	430200	650900
		0.95	16300	134700	12300	375700	539100
		1.40	21000	91400	8400	255200	376000
		2.00	37300	64000	5900	204500	311700
		4.00	26400	42700	2900	131900	203900
<u>Concentrated Liquids</u>							
(PCONCLIQ)	LOW (0.001)	0.71	24100	5400	15000	32100	76500
		3.70	17000	800	3200	6500	27400
		5.40	7900	500	2200	4500	15000
		6.60	13400	500	1800	3700	19400
		10.40	12900	1300	1100	2600	17800
	TYPICAL (0.01)	0.71*	24100	5400	16500	34500	80500
		3.70	17000	6600	3200	9800	36500
		5.40	7900	4500	2200	6700	21300
		6.60	13400	3700	1800	5500	24400
		10.40	12900	2300	1100	3900	20200

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*Typical conditions

**Based on 1000 mile distance

Table 1.5 (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	PROCESSING COSTS, $	TRANSPORT** COSTS, $	STORAGE COSTS, $	BURIAL COSTS, $	TOTAL COSTS, $
	HIGH (0.1)	0.71	24100	34300	16500	51000	125900
		3.70	17000	9900	3200	16600	46600
		5.40	7900	13500	2200	16500	40100
		6.60	13400	5500	1800	10000	30800
		10.40	12900	7000	1100	10000	31000
	VERY HIGH (1.1)	0.71	24100	51500	16500	106500	198600
		3.70	17000	23100	3200	60200	103300
		5.40	7900	23700	2200	56500	90300
		6.60	13400	12900	1800	38900	67100
		10.40	12900	12300	1100	34300	60600
<u>Filter Sludge</u>							
(PFSLUDGE)	LOW (0.007)	0.56	30300	7000	20900	43800	101900
		2.00	22500	4900	5900	12900	46200
		4.00	26200	6100	2900	8400	43600
	TYPICAL (0.07)	0.56*	30300	43500	20900	64600	159300
		2.00	22500	18300	5900	22900	69500
		4.00	26200	9100	2900	15300	53600
	HIGH (0.7)	0.56	30300	65300	20900	109400	225800
		2.00	22500	36600	5900	61500	126500
		4.00	26200	21300	2900	46800	97300
	VERY HIGH (7.0)	0.56	30300	152400	20900	397600	601100
		2.00	22500	64000	5900	178600	271000
		4.00	26200	42700	2900	131600	203300

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*Typical conditions

**Based on 1000 mile distance

- 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.

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 non-compactible trash is handled and disposed of.

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 non-compactible trash should be in the range of $85,000 to $450,000 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 non-compactible 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 non-compactible 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 non-compactibles. 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 20 to 30%. Therefore, the cost analyst should consult with NRC's Cost Analysis Group staff to determine changes in burial pricing compared to the pricing used herein and the impact on overall disposal costs.

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 evalution 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:

$$E = 1.2V$$

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 any particular waste stream. 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 waste streams.

1.5 SUGGESTED ESTIMATING PROCEDURES

The following listing briefly outlines the major steps which should be taken to effectively utilize 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 1.3 and 1.4 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.

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

$$\frac{\text{actual waste volume (as-generated) ft}^3}{1000\ \text{ft}^3}$$

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), i.e.,

$$\text{Exposure (Person-rem)} = 1.2 \times 10^{-3}\ \frac{\text{person-rem}}{\text{ft}^3} \times \text{Total Volume (As-Shipped, ft}^3\text{)}$$

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 Cost Analysis Group within the USNRC's Office of Reesource Management authorized Science and Engineering Associates, Inc. (SEA) and its subcontractors, S. Cohen and Associates, Inc. (SC&A) and Mathtech, Inc. to perform an assessment of the generic costs of disposing of 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 typical ways in which each type of waste is handled and disposed of,
- 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 two other aspects of estimating the waste disposal costs. The first is, 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. The second concerns the radiation exposure received by workers in the course of handling wastes. A correlation was developed from existing data to estimate this exposure for incorporation in value-impact assessments.

All of the stated objectives have been accomplished.

2.2 APPROACH

The basic approach used in this study was as follows:

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 search 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.

5. Develop a correlation from existing waste volume and radiation exposure data to evaluate the occupational radiation exposure associated with waste handling.

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.

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 specific cases.

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.

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 applied in the present effort.

Section 6.0 presents a detailed assessment of the costs of disposing of each different waste type. 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 presented in this document, 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. This report also includes three appendicies. Appendix A presents the derivation details and supporting data for the occupational radiation exposure correlation. 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.

3.0 LOW-LEVEL RADWASTE CHARACTERISTICS AND VOLUME REDUCTION TECHNOLOGY

This section discusses the physical and radiological characteristic 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 technology 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 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 non-compactible), its chemical makeup, and its radio-nuclide content and concentration. For the purposes of this study the following waste streams have been identified.

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 roughly 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 summarized 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 References 2 and 6. 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 individual isotope concentrations were adjusted to reflect the typical total stream activity as reported in Reference 1. These adjustments were made because the data in Ref. 1 was more broad-based and more current than that from Ref. 2 and 6.

3.1.1 Dry Active Waste Characteristics

3.1.1.1 Non-Compactible Trash (NCTRASH)

Non-compactible trash is the waste stream of primary interest to this study. This is because the non-compactible trash is made up of the hardware and components which are the main object 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. Non-compactible trash typically consists of the following materials, as reported by plants surveyed in the EPRI 1981 study (Reference 1):

Table 3.1.
AS GENERATED (UNTREATED) ISOTOPIC CONCENTRATIONS -- PWR
(Ci/m^3)

	P-IXRESIN	P-CONCLIQ	P-FSLUDGE	P-COTRASH	P-NCTRASH
Total	5.82E-02	1.35E-01	1.43E+00	3.20E-02	7.36E-01
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	2.75E-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*	2.19E-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-00	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	6.52E-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

* Not included in NRC source terms.

Table 3.2.

AS GENERATED (UNTREATED) ISOTOPIC CONCENTRATIONS -- BWR
(Ci/m^3)

	B-IXRESIN	B-CONCLIQ	B-FSLUDGE	B-COTRASH	B-NCTRASH
Total	7.60E+02	3.20E-01	7.97E+00	3.65E-02	5.88E+00
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-02	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	1.19	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-03	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*	2.04	5.10E-02	1.33	7.14E-03	1.15
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	1.23E-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-07	2.53E-09	4.08E-07
Am-241	2.32E-05	9.20E-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-04	2.24E-04	1.49E-06	2.41E-04

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* Not Included In NRC source terms.

- 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 any material that is considered compactible.
- Filter Frames are the wooden or metal frames that surround high efficiency particulate air (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 specifically identified above.

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

Fractional Composition of Non-Compactible 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 Matls.	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 non-compactible wastes was reported to be 0.4 mCi/ft^3 (14.1 mCi/m^3) for PWR's. This average excluded several plants reporting over a factor of 10 greater than this value. The specific activity for BWR non-compactible waste was 0.2 mCi/ft^3 (7.1 mCi/m^3), half that reported for PWR's. These activity levels represent the as-shipped conditions for the waste. The as-generated activity concentrations for this and the other waste streams were noted in Section 1.1.1.

The data presented in the 1981 EPRI utility survey (Ref. 1) indicated that the average density of the packaged non-compactible 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 non-compactible trash do not lend themselves to high packing efficiencies.

For the purposes of this study a VRF of 1.0 for non-compactible 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 non-compactible 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 non-halogenated 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 including most non-rigid 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.

- <u>Metal</u> consists of metallic items that can be compacted such as aerosol cans, paint cans, etc.
- <u>Filters</u> include high efficiency particulate air (HEPA) filters, respirator canisters, etc.
- <u>Glass</u> includes bottles, laboratory glassware, instrument tubing, face plates, view ports, etc.
- <u>Miscellaneous</u> 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

	<u>BWR</u>	<u>PWR</u>
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 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 non-compactible 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 typical 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/or 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 the 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 (Reference 7). 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 apparently going away from this method of treating liquid wastes. Several plants have gone instead to the filter/demineralizer type of system. Nevertheless, a number of plants still employ the evaporator-concentrator system for reprocessing 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 floculating 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 floculating 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., $\$/\text{ft}^3$), 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 of.

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. 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, decontamination and recycle rather than disposal, 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 being employed. Many of these techniques and ideas are discussed in Ref. 1 and Ref. 8.

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 of, while incineration of the resin can substantially decrease the final volume.

The following sections discuss several of the waste processing methods available to nuclear plant operators. These discussions give an overview of representative volume reduction techniques. 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 non-compactible trash, compactible trash, and certain filters used in removing particulates from liquid waste streams. Normally non-compactible 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, non-compactible 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 packing factor of 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 55 gallon (7.5 ft^3) drums.

Contaminated filters can be classed as non-compactible 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 radioactive liquid 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 of. The following volume increase ratios are believed to be typical (Ref. 1,2, & 18).

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 55 gal. 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 X 10^6 (Ref. 2).

It is possible that devices such as the supercompactor could be used with non-compactible 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 non-compactible 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 $\$2.6 \times 10^6$ to more than $\$24 \times 10^6$.

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, ion-exchange resins, 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 x 10^6 to \$9 x 10^6 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 desireable to achieve effective volume reduction for all waste streams. Several combinations of systems were considered in Ref. 2 and 18.

3.2.3 Summary of Volume Reduction Processes

Table 3.3 summarizes the various waste processing systems and associated volume reduction (increase) factors for each waste stream. The different volume reduction techniques were discussed previously. 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 wastes produced by the plants. Most utilities have responded by attacking both the waste generation aspect and the volume reduction aspect. Equipment vendors have

Table 3.3 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 compaction in 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
	BWR/PWR	
CONCLIQ	0.7/0.7	Solidification in cement
	1.9/3.7	Evaporator/crystalizer process, solidification in binder
	2.4/5.4	Mobile evaporator, solidification in binder
	3.8/6.6	Evaporator, grinding of residue, mixing with 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

responded to utility needs by offering more effective volume reduction systems than were available several years ago.

A limited survey of nuclear plant operators was made during this study in order to assess current practices and future trends by operators regarding their waste processing. The survey obtained responses from representatives of 11 BWR units and 15 PWR units. The plants contacted were selected on a random basis. Most of them had startup-dates prior to 1980. Even though the sample size was small, the responses obtained are believed to be reasonably representative. The responses are noted in the following discussions by reactor type and waste type.

3.3.1 BWR Practices & Trends

3.3.1.1 Dry Active Wastes

Almost universally, plant operators stated they were instituting control measures to reduce the amount of dry active waste produced. This was especially true for compactible trash.

At the present time, most BWR operators are using mechanical compaction of compactible trash as the primary volume reduction process. Most of the survey respondants indicated that they are achieving densities of 30 to 40 lb/ft^3 for this waste stream. The corresponding volume reduction factors are in the range of 3.8:1 to 5:1. This is in contrast to the results presented in Ref. 1 which stated that, as of 1982, the nominal volume reduction factor for BWR COTRASH was about 2.3:1.

Only one BWR station surveyed indicated the use of incinerators to reduce the volume of combustible dry active trash.

In terms of future trends, about half of those responding stated they were studying "supercompactor" type equipment. One plant had this equipment on order.

For non-compactible trash there is somewhat of a trend to decontaminate items and recycle them rather than dispose of them as radioactive waste.

3.3.1.2 Wet Wastes

The 1981-82 survey conducted for the Electric Power Research Institute (Ref. 1) indicated that a substantial amount of wet waste in BWRs was generated in the regeneration of ion-exchange resin beds. The radioactive materials removed from the resins were typically processed in evaporator units to produce concentrated liquid effluents. The concentrated liquids were then mixed with cement to solidify and stabilize them. The EPRI survey also indicated that many plants were going away from the practice of regeneration of resins. Instead, the spent resins were disposed of and replaced with fresh resins. At that time, some plants solidified the resins in cement, while others de-watered the spent resins and packaged them in high integrity containers (HIC) for disposal.

The survey conducted for the present study indicated that most BWR operators have reduced the use of resin regeneration with its attendant production of concentrated liquid wastes. The spent resins are disposed of and replaced rather than regenerated. About three-fourths of the BWR respondents stated that they dewatered the spent resins and shipped them for burial in high integrity containers. Two of the stations indicated they stabilized the resins in cement for disposal rather than using the dewatering, HIC option.

Relatively few of the BWR operators indicated any plans to make substantial changes in their processing of wet wastes. One plant was investigating the possibility of incineration of spent resins and filter sludges. Thus, it appears that at the present time, most BWR operators dewater their spent ion-exchange resins and place them in high integrity containers for disposal. This results in a slight increase in the disposal volume compared to the material volume. The volume increase factor is roughly 1.05:1 to 1.1:1. For those plants that solidify the resins in cement, the volume increase factor is about 1.4:1. For filter sludges solidified in cement, the volume increase is about 1.8:1.

3.3.2 <u>PWR Practices & Trends</u>

3.3.2.1 Dry Active Wastes

As with BWRs, PWR plant operators indicated they are instituting control measures and practices aimed at reducing the quantities of dry wastes generated. The current practice in the processing of compactible trash appears to be essentially the same as that for BWRs. Most plants employ mechanical compactors which give a waste density of about 30 to 40 lb/ft^3. One plant surveyed incinerates its combustible dry waste. Of the 16 PWR units surveyed, three had recently purchased improved compaction equipment and a few others were considering such equipment.

Thus, the practices and trends for processing dry active wastes at PWR stations appear to be quite similar to those at BWR stations.

3.3.2.2 Wet Wastes

As with BWR's, the EPRI Survey (Ref. 1) indicated the decreased use of evaporation systems for reducing liquid waste volume and the increased use of resin beds for liquid stream processing. About half of the PWR stations contacted during the present study indicated that the spent resins are dewatered and shipped for burial in high integrity containers. The other half solidifies the resins in cement prior to shipment. The applicable volume increase factors are the same as for BWRs resin wastes.

The plants contacted did not indicate any major trends in terms of changing to alternative wet waste processing methods in the near future.

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 NON-COMPACTIBLE DRY ACTIVE WASTE (DAW)

In general, the primary waste stream for a plant modification is non-compactible 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,

Table 4.1 Summary Approach to Waste Volume Estimating*

WASTE STREAM	COMPONENTS	APPROACH	QUANTITATIVE GUIDANCE
Non-Compactible 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 non-compactible DAW:	At PWRs: $\frac{\text{Vol.Comp.DAW}}{\text{Vol.Non-Comp.DAW}} \simeq 0.9$ At BWRs: $\frac{\text{Vol.Comp.DAW}}{\text{Vol.Non-Comp.DAW}} \simeq 2.1$
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 decontaiminated, and the decon solution used.	For LOMI decon solution: ~0.1 ft^3 of waste / gal. decon soln.
Filters	From decontaimination 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)

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*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 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 (Ref. 8). 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, non-compactible DAW was typically packaged in 98 to 122 ft^3 Low Specific Activity (LSA) boxes (Ref. 1). The dimensions of a 98ft^3 LSA box are 6ft x 4ft x 4ft. 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 non-compactible DAW range from approximately 0.2 to 0.75 (Ref. 9).

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 evaluated the feasibility of cutting 200-ft. of 28" pipe into clam shell segments (Ref. 10). 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 $40/hr (probably high). The cutting speed was estimated to be 3 ft/hr.* 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.

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*For cutting speed estimates, contact Newport News Industrial Corporation.

An option other than disposal is available for some constituents of non-compactible DAW. This is decontamination and recycle, which can be applied to essentially anything metallic; i.e., welding machines, chain falls, lead bricks, cable trays, etc.* 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 (Ref. 11) (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 (DAW)

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

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

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 (man-rem).* 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 non-compactible wastes. From these data, the following ratios can be derived:

$$\text{At PWRs:}\quad \frac{\text{Volume Compactible DAW}}{\text{Volume Non-Compactible DAW}} \cong 0.9$$

$$\text{At BWRs:}\quad \frac{\text{Volume Compactible DAW}}{\text{Volume Non-Compactible DAW}} \cong 2.1$$

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 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:

$$\text{At PWRS:}\quad \frac{\text{As-Generated Volume Compatible DAW}}{\text{As-Generated Volume Non-Compactible DAW}} = \frac{0.9x(3.8 + 5.7)}{(0.2 + 0.4)} = 14.3$$

$$\text{At BWRs:}\quad \frac{\text{As-Generated Volume Compatible DAW}}{\text{As-Generated Volume Non-Compactible DAW}} = \frac{2.1x(3.8 + 5.7)}{(0.2 + 0.4)} = 33.3$$

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*Reference 1 indicates that the amount of compactible DAW generated at PWRs correlates against man-rem, but not at BWRs.

Given the estimated volume of non-compactible 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 1981 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 (Ref. 9). However, the volumes of non-compactible 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 non-compactible volumes derived in 1981 may still be valid.

Data from two nuclear stations provide partial corroboration of this conjecture.* For the PWR visited the ratio of compactible to non-compactible 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 non-compactible 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 non-compactible trash of 1.0 to 2.0 for BWRs.

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*As 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 PWR: $\frac{\text{Volume Compactible DAW}}{\text{Volume Non-compactible DAW}} \cong 1.2$

Visted BWR: $\frac{\text{Volume Compactible DAW}}{\text{Volume Non-compactible DAW}} \cong 0.25\text{-}0.5$

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 (Ref. 12). 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.

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 10^3 to 10^4 gallons of liquid (Ref. 12).

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 (Ref. 12). 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 (Ref. 12). Decontamination of a steam generator channel head takes approximately

100 cubic feet of ion-exchange resin (Ref. 12). All other factors being equal, use of Candecon rather than LOMI as the decontamination solution results in approximately the same waste volume as LOMI (Ref. 13). 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 utility the system used to decontaminate personnel respirators generates roughly 1×10^{-3} ft^3 of waste filters per respirator decontaminated. Approximately one-half of this waste is compactible DAW; the remainder is non-compactible DAW. At this same utility, respirators are worn in approximately one-third of containment entries (Ref. 5).

Many stations, recognizing the high impact of disposable clothing on radwaste volumes, have converted to launderable clothing (Ref. 8). Several use a freon system for laundering the clothing. At one utility, roughly 2×10^{-3} ft^3 of waste filters are generated per dressout (coveralls, shoecovers, hoods, booties) (Ref. 5). 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.

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	3600
Totals	33800	15000

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*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 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 non-compactible 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 VFR= 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:

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

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

Table 5.2 BWR Waste Stream Characteristics

Waste Stream	Volume Reduction Factor	As-Shipped[(a)] Volume, ft^3	As Shipped[(b)] Density, lb/ft^3	Activity Concentration Ci/ft^3 (Ci/m^3)	Surface[(c)] Dose, R/hr
B-COTRASH	2.3	440.3	18.0	2.50E-4 (8.82E-3)	0.02
	3.8	264.7	30.0	4.16E-4 (1.47E-2)	0.03
	5.7	176.4	45.0	6.23E-4 (2.20E-2)	0.03
	8.7	115.1	70.0	9.57E-4 (3.38E-2)	0.03
	113.4	8.8	93.3	12.46E-4 (4.40E-1)	0.32
B-NCTRASH	0.2	5000.0	42.6	2.66E-4 (9.41203)	0.01
	0.4	2500.0	85.2	5.32E-4 (1.88E-2)	0.02
	0.6	1666.7	127.8	7.98E-4 (2.82E-2)	0.02
	0.8	1250.0	170.4	10.66E-4 (3.77E-2)	0.02
B-1XRESIN	0.7	1408.4	93.3	1.25E-1 (4.41)	3.33
	0.95	1052.6	70.9	1.67E-1 (5.90)	4.84
	1.4	714.3	70.8	2.46E-1 (8.70)	8.95
	2.0	500.0	75.3	3.52E-1 (12.43)	12.08
	4.0	250.0	93.3	7.04E-1 (24.86)	19.87
B-CONCLIQ	0.7	1408.4	47.8	1.20E-1 (4.24)	3.61
	1.9	526.3	68.0	3.21E-1 (11.34)	11.43
	2.4	416.7	56.5	4.06E-1 (14.32)	14.77
	3.8	263.2	88.0	6.42E-1 (22.68)	18.95
	4.5	222.2	93.3	7.60E-1 (26.85)	22.44
B-FSLUDGE	0.56	1785.7	96.0	1.30E-1 (4.59)	3.29
	2.0	500.0	69.3	4.64E-1 (16.38)	15.78
	4.0	250.0	69.3	9.28E-1 (32.77)	31.56

NOTES

(a) For 1000 ft^3 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[(a)] Volume, ft^3	As Shipped[(b)] Density, lb/ft^3	Activity Concentration Ci/ft^3 (Ci/m^3)	Surface[(c)] Dose, R/hr
P-COTRASH	3.8	264.7	30.0	7.00E-4 (2.47E-2)	0.06
	5.7	176.4	45.0	10.48E-4 (3.70E-2)	0.07
	8.7	115.1	70.0	18.92E-4 (6.68E-2)	0.07
	113.4	8.8	93.3	20.99E-4 (7.41E02)	0.70
P-NCTRASH	0.2	5000.0	46.6	5.32E-4 (1.88E-2)	0.03
	0.4	2500.0	93.2	10.66E-4 (3.77E-2)	0.03
	0.6	1666.7	139.8	15.98E-4 (5.65E-2)	0.03
	0.8	1250.0	186.4	21.30E-4 (7.53E-2)	0.03
P-1XRESIN	0.7	1408.4	96.0	7.82E-2 (2.76)	1.84
	0.95	1052.6	64.2	10.45E-2 (3.69)	3.55
	1.4	714.3	67.0	15.41E-2 (5.44)	5.03
	2.0	500.0	69.3	20.01E-2 (7.77)	6.97
	4.0	250.0	93.3	44.01E-2 (15.54)	10.64
P-CONCLIQ	0.7	1408.4	91.3	0.71E-2 (0.25)	0.15
	3.7	270.3	76.0	3.74E-2 (1.32)	1.08
	5.4	185.2	74.1	5.47E-2 (1.93)	1.85
	6.6	151.5	93.3	6.68E-2 (2.36)	1.85
	10.4	96.2	93.3	10.54E-2 (3.72)	2.27
P-FSUDGE	0.56	1785.7	96.0	3.94E-2 (1.39)	1.17
	2.0	500.0	69.3	14.05E-2 (4.96)	5.61
	4.0	250.0	69.3	28.09E-2 (9.92)	11.23

<u>NOTES</u>

(a) For 1000 ft^3 of as-generated waste
(b) Including binder where applicable
(c) Based on typical stream activity concentration

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 non-compactible trash. The present 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.

Table 5.5 Waste Processing Unit Cost Components*

Waste Stream	Volume Reduction Factor	Binder Unit Mass, lb/ft^3	Equipment Operator Time, hrs/ft^3	Container Handling Time, hrs/cont	Energy Unit Costs, \$/ft^3	Maintenance Costs, \$/ft^3
COTRASH	2.3	--	0.14	1.0	0.02	3.38
	3.8	--	0.14	1.0	0.03	4.0
	5.7	--	0.15	1.0	0.03	4.0
	8.7	--	0.18	1.5	0.08	6.91
	113.4	26.7	0.27	1.0	119.35	9.30
NCTRASH	0.2	--	0.14	1.0	0.0	3.38
	0.4	--	0.27	1.0	0.0	3.38
	0.6	--	0.41	1.0	0.03	3.38
	0.8	--	0.41	1.0	0.08	6.91
		BWR/PWR				
IXRESIN	0.7	51.3/48.0	0.14	0.8	0.05	3.38
	0.95	0.01/00.0	0.14	1.0	0.05	3.38
	1.4	40.7/36.9	0.33	0.5	1.57	6.65
	2.0	40.7/34.7	0.80	0.5	6.93	29.50
	4.0	26.7/26.7	0.60	1.0	6.93	28.78
B-CONCLIQ	0.7	44.7	0.14	0.8	0.05	3.38
	1.9	26.7	0.22	1.0	0.05	6.47
	2.4	40.8	0.33	0.5	7.08	6.65
	3.8	37.3	0.80	0.5	11.53	29.50
	4.5	26.7	0.52	1.0	28.37	23.44
P-CONCLIQ	0.7	51.3	0.14	0.8	0.05	3.38
	3.7	26.7	0.22	1.0	1.10	6.47
	5.4	29.9	0.33	0.5	15.58	6.65
	6.6	44.0	0.80	0.5	19.71	29.50
	10.4	26.7	0.52	1.0	43.53	23.44
FSLUDGE	0.56	48.0	0.14	0.8	0.05	3.38
	2.0	34.7	0.45	0.5	6.95	12.81
	4.0	34.7	1.15	0.5	6.93	46.12

* Based on the as-shipped conditions of the wastes.

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:

- Container Costs:

No. required =

$$\frac{\text{As-generated Waste volume } (ft^3)}{\text{Container Volume } (ft^3) \times \text{Volume Reduction Factor}}$$

Container Cost =

Container Unit Cost (\$/Container) x No. Required

Based on recent vendor estimates, the cost of 7.5 ft^3 drums is \$26.00 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	0.046
Bitumen	0.127
DOW	1.505

  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 $30.00/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.

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*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 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 ultilized 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 consistant 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.

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 onsite for lengthy periods of time prior to shipment.

8. Transportation fees are based on present day rates charged by licensed radioactive waste carriers (Ref. 3). Where different rates would apply in different parts of the country these rates were averaged and a single rate was used.

9. Shielded 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 (Ref. 3).

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 appears to be that typically not more than 80 7.5 ft^3 drums are hauled on a single truck load (Ref. 3). 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 (Ref. 3). 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.

Table 5.6
Shipping Cask Capabilities

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	200	--
14 Drum Cask	18.0	14	200	--
7 Drum Cask	100.0	7	200	--
6 Drum Cask	160.0	6	200	--
4 Drum Cask	1000.0	4	200	--
3 Drum Cask	>1000.0	3	200	--

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 cask is required it is assumed that the cask must be returned to the plant after the waste is off-loaded at the burial site. The analysis also assumed that rental fees are charged for the deadhead time when the cask is being returned 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 $25 to about $100 per shipment. Only five states require such permits at the present time (Ref. 3). 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 commerical shipper rate schedules effective through at least mid-1985 (Ref. 3). 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.

Table 5.7
Waste Transportation Rates

Maximum One-way Distance, Miles	One-Way Rate, $/Mile	Round-Trip Rate, $/Mile
100	4.83	3.38
250	3.00	2.17
500	2.12	1.52
750	1.91	1.42
1000	1.75	1.42
over 1000	1.70	1.42

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 (Barwell SC; Beatty, NV; and Richland, WA). The milages 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 form 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

Table 5.8 Approximate Distances from Power Plant Sites to Waste Depositories for each NRC Region

NRC Region	Barnwell SC			Beatty, NV			Richland, VA		
	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	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	1030	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:

  $$\text{TIME} = \frac{\text{One-way Distance (mi)} \times \text{RT}}{500\ \text{(mi/day)}} + 1$$

  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

- o 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.

Ref. 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 assesssment. The cost per square foot of storage area varies, depending on the dose rate of the wastes. The capital costs cited in Ref. 2 are as follows:

Surface dose <100 mr/hr	$98.00/ft^2$
Surface dose >100 mr/hr	$108.00/ft^2$

These capital costs were used but were escalated to reflect construction cost changes between 1982 and 1985.

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

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

$$\text{Cost} = \text{Storage area}(\text{ft}^2) \times \text{Unit Cost}(\$/\text{ft}^2)$$

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 commerical 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 Hanford, 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. Thus far this legislation has not resulted in the required development, and amendments to the Low-Level Waste Policy Act of 1980 are currently being considered. This legislation could potentially 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 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 pellets or waste which is in boxes can be handled by a fork lift and the weight surcharges do not apply in most cases (Ref. 4). However, if the waste was shipped in shielded casks

Table 5.9
Average Burial Cost Rates,
Beatty, Nevada and Hanford, Washington

Disposal Charges

Solid Wastes

Steel Drums, Wood Boxes:

R/HR AT CONTAINER SURFACE	PRICE PER CU. FT.
0.00 - 0.20	19.80
0.201 - 1.00	21.39
1.01 - 2.00	23.89
2.01 - 5.00	26.88
5.01 - 10.00	31.55
10.01 - 20.00	40.60
20.01 - 40.00	50.10
40.01 - 60.00	74.16
60.01 - 80.00	88.82
80.01 - 100.00	97.88

Disposal Liners Removed from Shield: (Greater than 12.0 cu. ft. each)

R/HR AT CONTAINER SURFACE	SURCHARGE PER LINER	PRICE=PER CU. FT.
0.00 - 0.20	No Charge	19.80
0.201 - 1.00	236.5	19.80
1.01 - 2.00	581.15	19.80
2.01 - 5.00	816.9	19.80
5.01 - 10.00	1181.2	19.80
10.01 - 20.00	1507.6	19.80
20.01 - 40.00	1872.8	19.80
40.01 - 60.00	2220.8	19.80
60.01 - 80.00	2562.9	19.80
80.01 - 100.00	2910.9	

SURCHARGE FOR HEAVY OBJECTS:

Less than 10,000 pounds	No Charge
10,000 pounds to Capacity of Site Equipment	$179.35 plus $.09 per lb. above 10,000 lbs.

SURCHARGE FOR CURIES (Per Load):

Less than 100 Curies	No Charge
100 - 300 Curies	$1304.00 plus $.17/Ci above 100 Ci
301 - License Limits	By Request

MINIMUM CHARGE PER SHIPMENT	$403.50
CASK HANDLING FEE:	$664.00

Table 5.10
Barnwell, SC, Rate Schedule for Burial of Low-Level Radioactive Wastes

1. BASE DISPOSAL CHARGES (Not including Surcharges and Barnwell County Business License Tax)

A.	Standard Waste	$25.11/ft^3
B.	Biological Waste	$26.11/ft^3
C.	Special Nuclear Material plus $1.75 per Gram SNM	$25.11/ft^3

Note: Minimum charge per shipment, excluding Surcharges and specific Other Charges is $500.00.

2. SURCHARGES

A. Weight Surcharges (Crane Load Only)

Weight of Container	Surcharge Per Container
0 - 1,000 Lbs.	No Surcharge
1,001 - 5,000 Lbs.	$ 275
5,001 - 10,000 Lbs.	$ 550
10,001 - 20,000 Lbs.	$ 825
20,001 - 30,000 Lbs.	$1,100
30,001 - 40,000 Lbs	$1,650
40,001 - 50,000 Lbs	$2,200
Greater than 50,000	By Special Request

Table 5.10 (continued)

B. Curie Surcharge

Curie Content Per Shipment	Surcharge Per Shipment
0 - 1	No Surcharge
1.1 - 5	$ 1,500
5.1 - 15	$ 2,250
15.1 - 25	$ 3,000
25.1 - 50	$ 4,500
50.1 - 75	$ 5,500
75.1 - 100	$ 7,450
100.1 - 150	$ 8,900
150.1 - 250	$ 12,000
250.1 - 500	$ 15,000
500.1 -1,000	$ 18,000
1,000.1 -5,000	$ 24,000
Greater than 5,000	By Special Request

3. <u>OTHER CHARGES</u>

A. Cask Handling Fee	$600.00 per cask, minimum
B. Barnwell Country Business License Tax	2.4% of total

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 primarily due to the higher Curie charges 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:

- Burial at U.S. Ecology Sites

  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.

Check container weight againt 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

Total Costs = Weight Charges + Basic Burial Charges + Curie Charges + Cask Handling Charges

- Burial at Barnwell, SC

Basic charge =rate($/ft^3) x No. of containers per 1000 ft^3 of unprocessed waste x container volume(ft^3)

Check if a cask is used for waste transport. If yes, determine applicate 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.

Total Cost= Weight Charge + Basic Burial Charge + Cask Handling Charge + Curie Charge

Tax is applied to get the overall cost.

- Average burial cost:

Average= Barnwell Burial Cost + U.S. Ecology Burial Cost x 0.5

As noted previously, burial costs have been rising rapidly in the past few years. Users of this document should consult with NCR's Cost Analysis Group staff to determine the up-to-date 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 Legislation Potentialy Impacting Low-Level Waste Burial Costs

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 have been formed since the 1980 legislation, no new burial sites have been developed as was intended.

As this document is being written, Congress is considering amendments to the Low-Level Waste Policy Act of 1980. The House and Senate versions are somewhat different, but the key aspects of the pending 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 (LLW) 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 may add a provision for rebate of surcharges for waste generators in compacts meeting milestones for establishing their own waste disposal sites.

Thus, the pending legislation is likely to extend 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 basic disposal charges may rise from about $20 per cubic foot to about $80 per cubic foot (Ref. 26). This is a possible near-term impact which many utilities will have to face.

In the longer term the legislation promotes the development of regional disposal facilities. The increase in the number of sites and the regional control of these sites should tend to stabilize burial costs. Studies of the costs of developing and operating new low-level waste burial sites indicate that burial costs at such sites could reasonably be expected to be on the same order as present day charges at existing sites (Ref. 2, Vol. 4).

Another potential impact of the pending legislation is that transport distances from generators to burial sites should be reduced as new burial sites are developed and put into operation. These new sites, on average, should be located closer to nuclear plants than is presently the case. This reduced transport distance should translate into reduced waste transportation costs.

In summary, the impacts of the pending low-level waste legislation would appear to be:

- Keep open the option for nuclear plant operators to dispose of their low-level wastes at the three existing LLW burial sites.
- For the near term, allow for surcharges for out-of-region waste generators. This may substantially increase burial costs for such generators.
- In the longer term, promote the development of regional burial sites which should stabilize burial costs.
- Reduce transport distances, and thus transport costs, as new disposal sites become operational closer to waste generators.

Users of this document must factor in these impacts as appropriate once the final legislation is enacted by Congress.

The foregoing methods for calculating costs for processing, storage, transportation, and burial of low level radwastes as discussed in Sections 5.2.1 through 5.2.4 were programmed for use on a personal 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:

- o Reactor type (BWR and PWR)
- o Waste type (NCTRASH, COTRASH, IXRESIN, CONCLIQ and FSLUDGE
- o Activity level (Low, Typical, High, and Very High)
- o 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 other than this can readily be estimated using linear scaling. None of the cost elements appear to be sensitive to volume throughput, and thus, the linear scaling with volume should give reasonable results.

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 115. 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 proportional to the volume reduction achieved. For the lowest volume reduction factor, ~0.2, over 666 7.5 ft^3 drums are needed. At the other end of the spectrum the VRF of ~115 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.

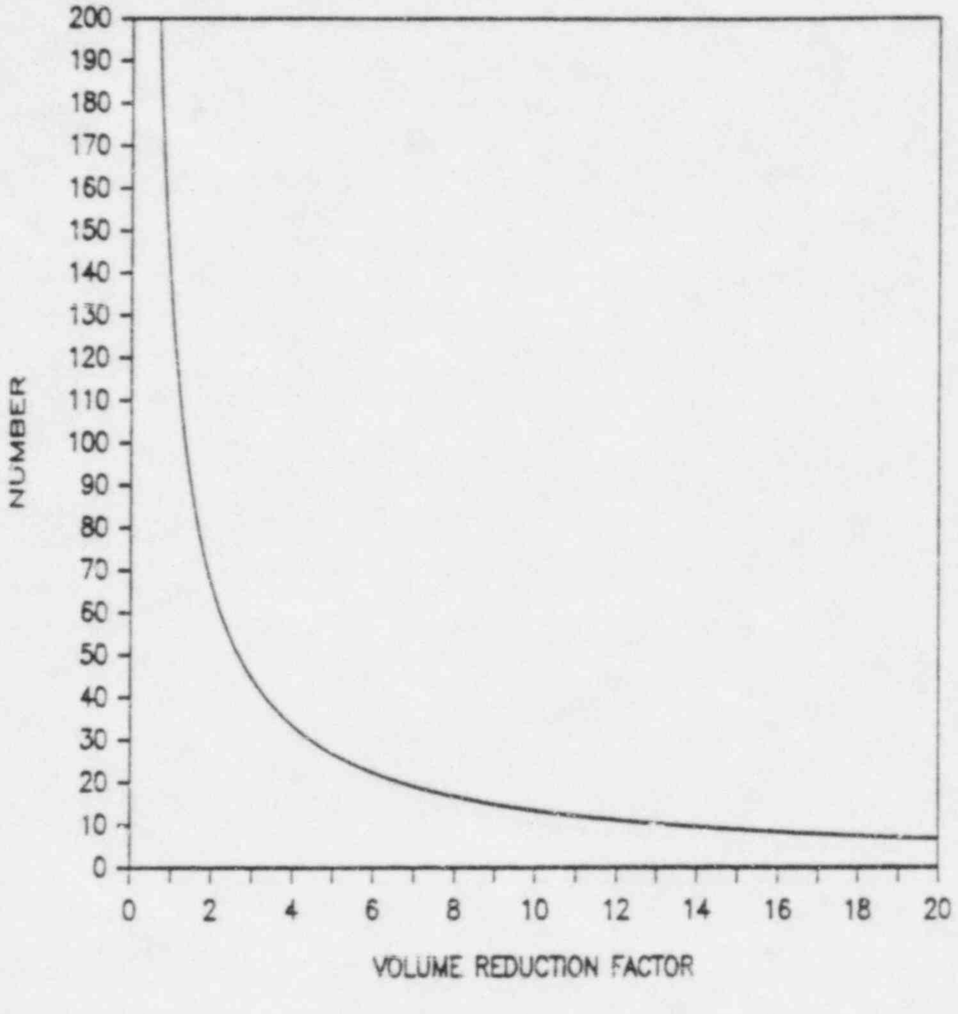

Figure 6.1. Number of 7.5 ft^3 Containers Needed to Hold 100 ft^3 of Unprocessed Waste as a Function of Volume Reduction Factor.

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 WASTE 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 is 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.

Figure 6.2 displays the total waste disposal costs for BWR and PWR non-compactible trash. 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 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 $260,000 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

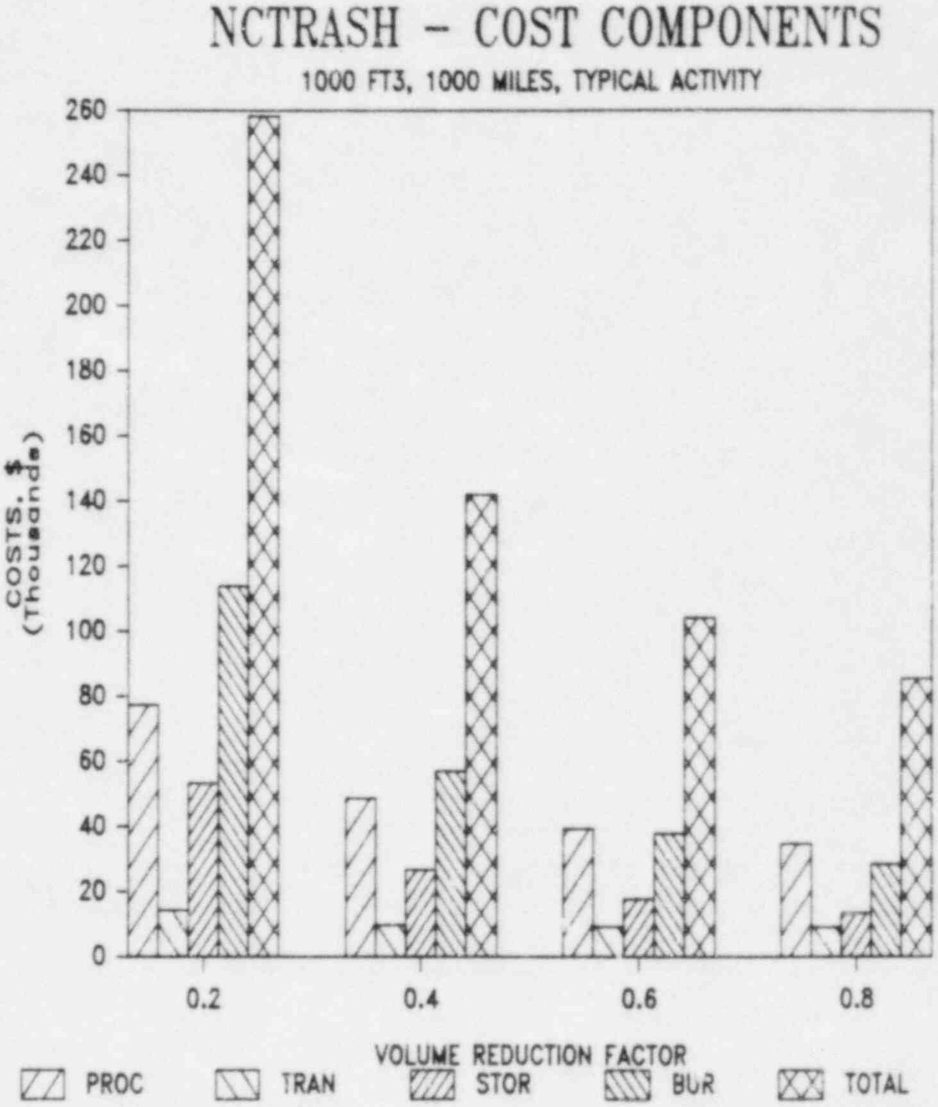

Figure 6.2. Disposal Costs for Non-Compactible Trash.

roughly roughly a factor of 3 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 more costly as greater volume reduction is achieved. The burial costs displayed in Figure 6.2 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 $4,000 to $15,000 higher than shown per 1000 cubic feet of waste if the burial site is Barnwell. Conversely, the values would be $4,000 to $15,000 lower if U.S. Ecology burial sites are used. Site-specific burial cost adjustments for all costs 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 (act = 1.33E-4 Ci/ft^3) low to the high cases. An increase in the activity level to the very high case (act = 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.

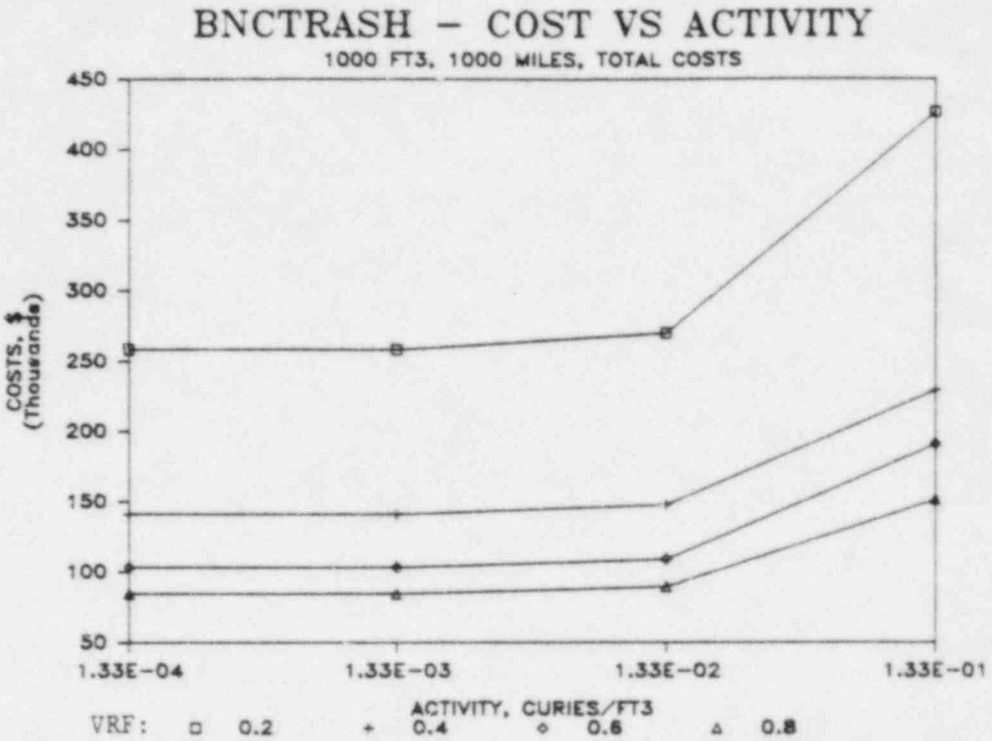

Figure 6.3.(a) Cost Sensitivity of BWR Non-Compactible Trash to Activity Level.

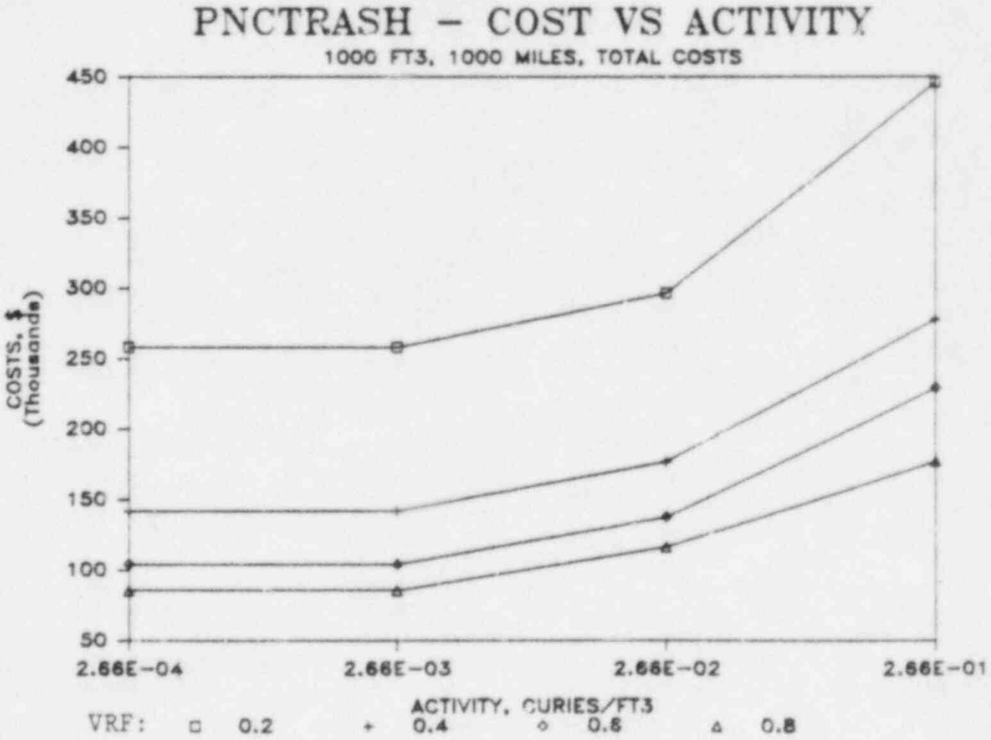

Figure 6.3.(b) Cost Sensitivity of PWR Non-Compactible Trash to Activity Level.

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. The costs are not very sensitive to reactor type. Increased volume reduction reduces each of the cost components. 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, transported and buried. 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 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.

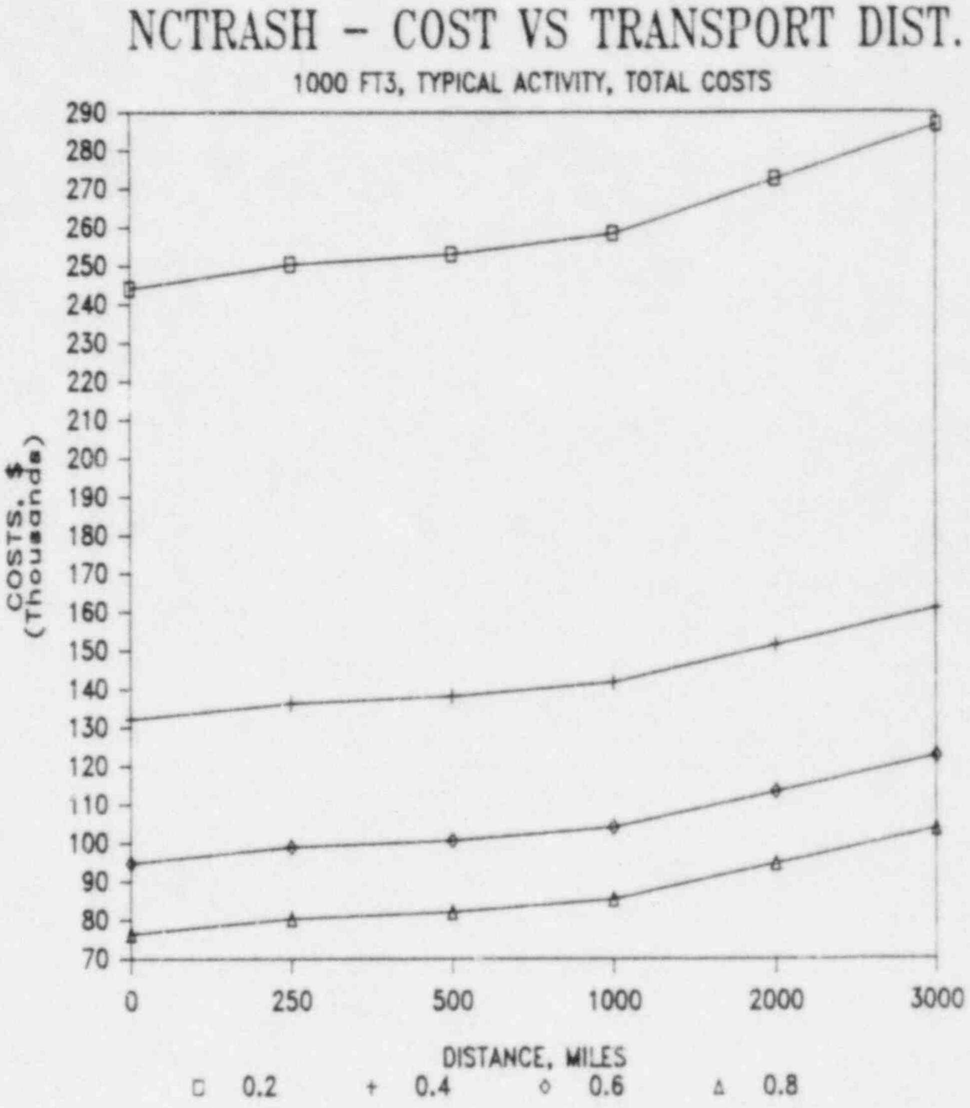

Figure 6.4. Variation of Non-Compactible Trash Disposal Cost with Transport Distance.

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/ft^3 and for PWRs it is 0.000185 Ci/ft^3, both in the as-generated condition (Ref. 1).

Figure 6.5(a) covers one additional VRF (VRF=2.3) 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 \$25,000 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

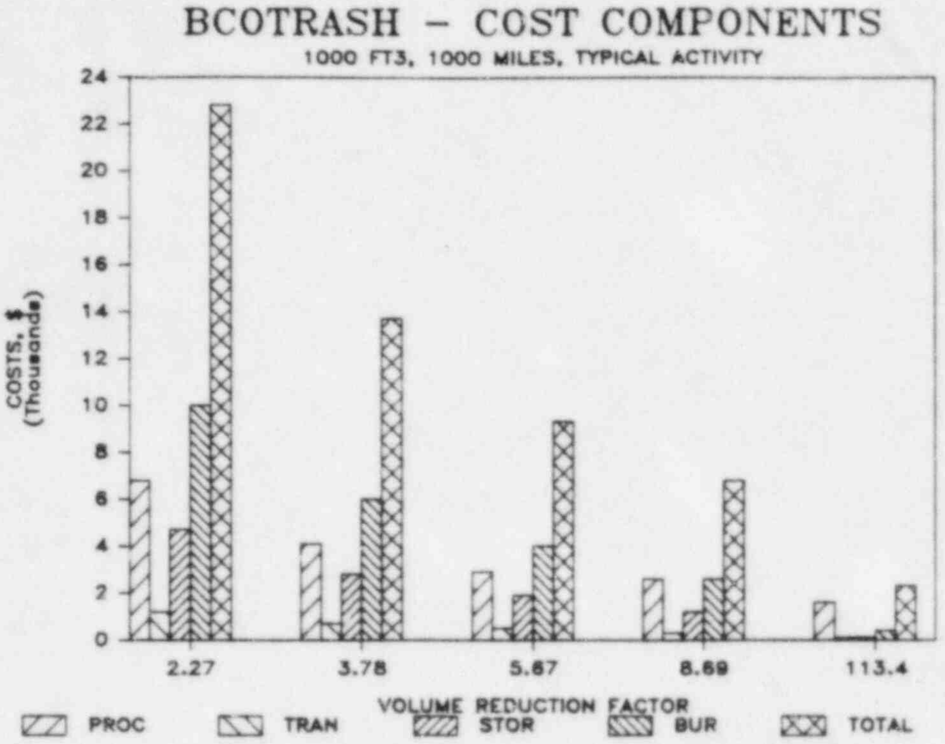

Figure 6.5.(a) Disposal Costs for BWR Compactible Trash.

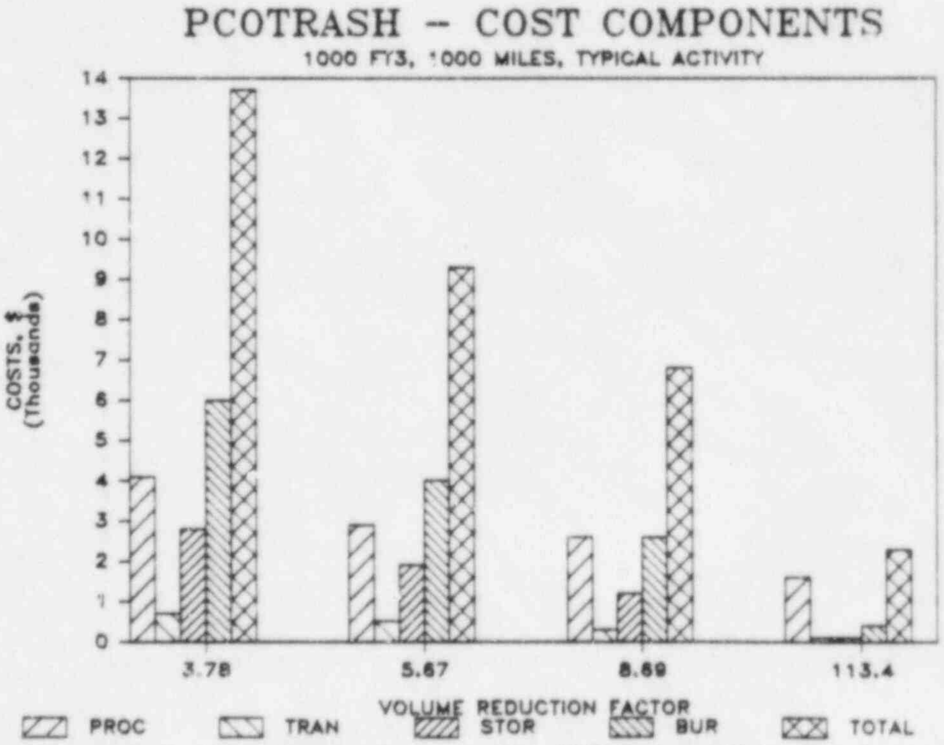

Figure 6.5.(b) Disposal Costs for PWR Compactible Trash

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 volume reduction factors from 3.8 to 113.4. The lower compaction case for BWRs (VRF = 2.3) 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 of. 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 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).

Figure 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.

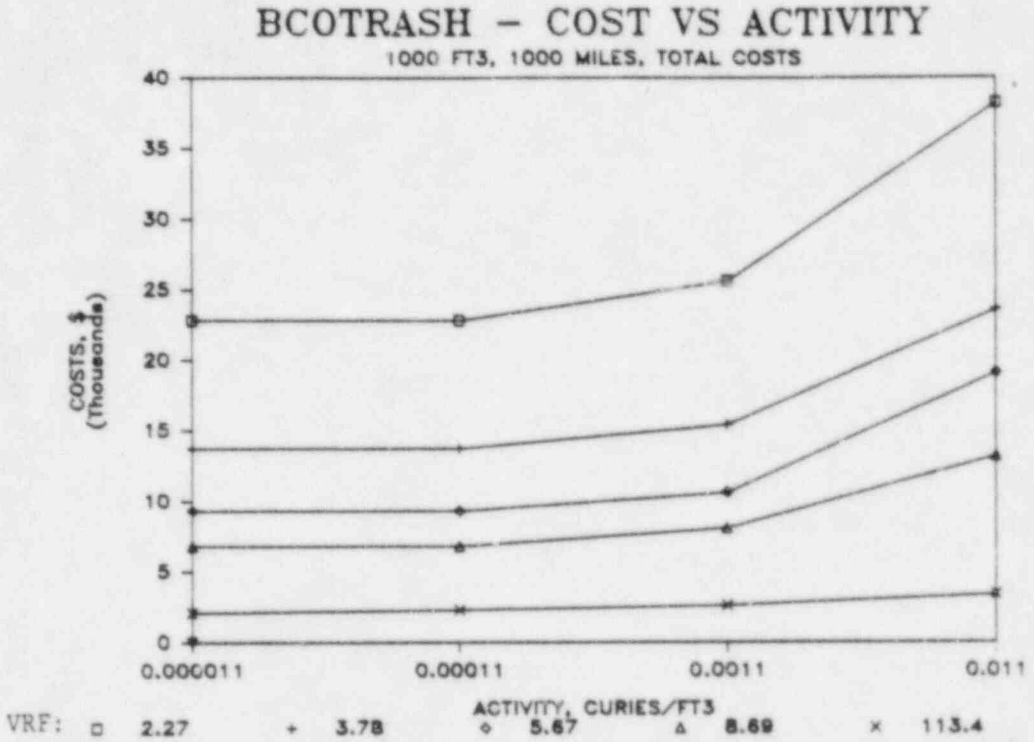

Figure 6.6.(a) Cost Sensitivity of BWR Compactible Trash to Activity Level.

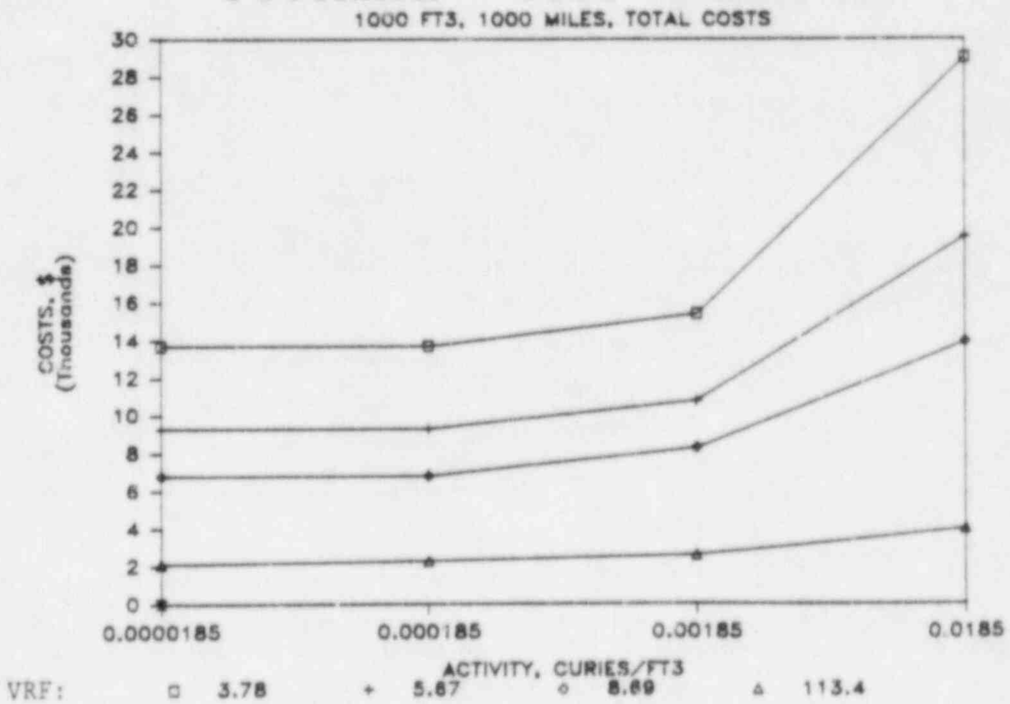

Figure 6.6.(b) Cost Sensitivity of PWR Compactible Trash to Activity Level.

Figure 6.7 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 and dissolved solids from liquid steams. Liquids that must be processed may be generated as a result of cleanup, washing, or decontamination of radioactive sytems. 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. 5)

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 COTRASH. Disposal costs for IXRESINs are roughly 30 to 50% higher than for NCTRASH if comparable volume reduction cases are considered (i.e. VRF = 0.6 for NCTRASH and 0.7 for IXRESIN). These higher costs are due to the higher activity levels typical of ion-exchange resins.

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

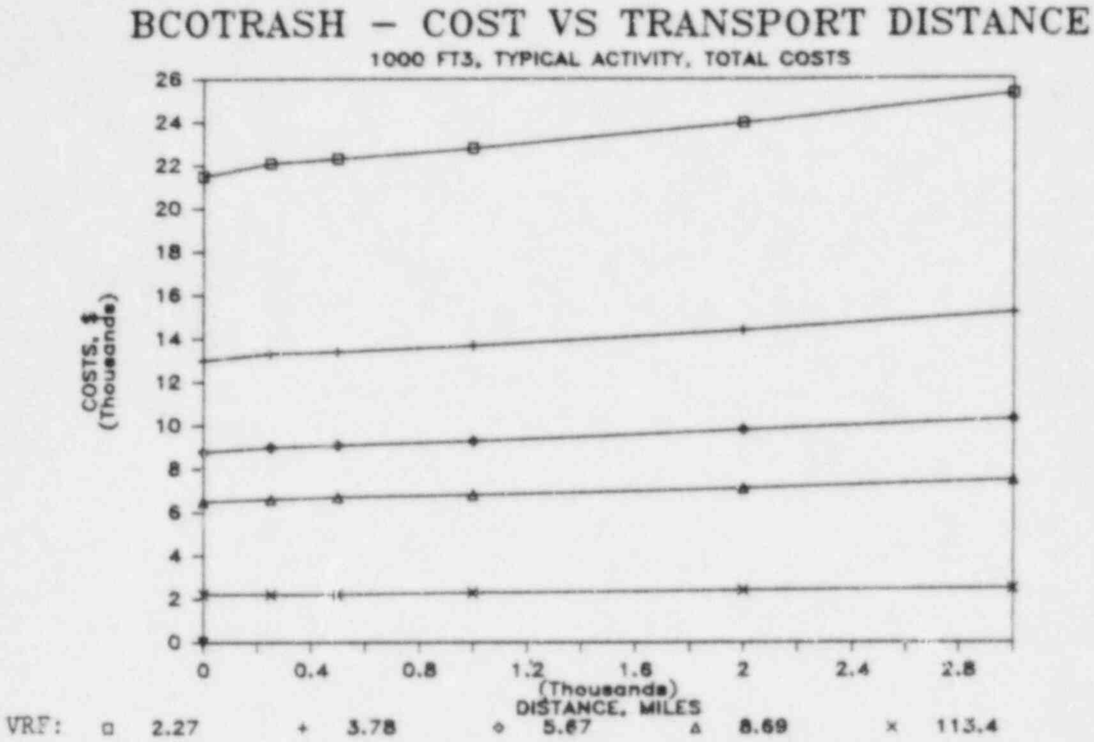

Figure 6.7.(a) Variation in BWR Compactible Trash Disposal Costs with Transport Distance.

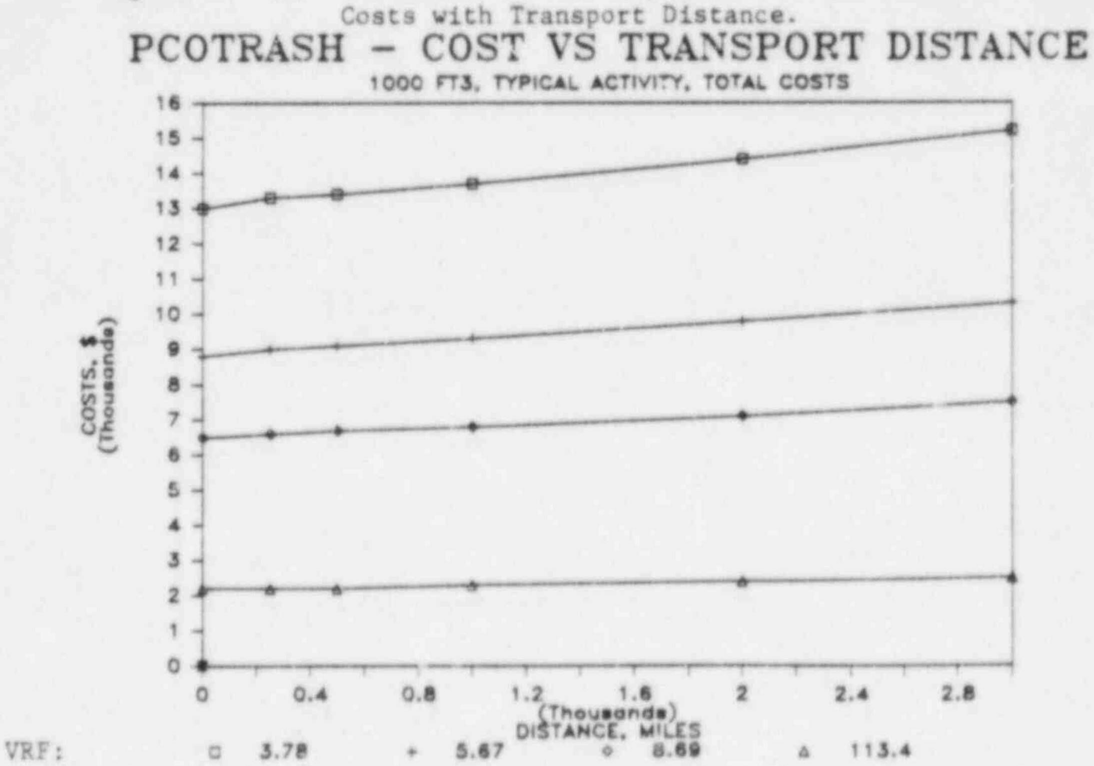

Figure 6.7.(b) Variation in PWR Compactible Trash Disposal Costs with Transport Distance.

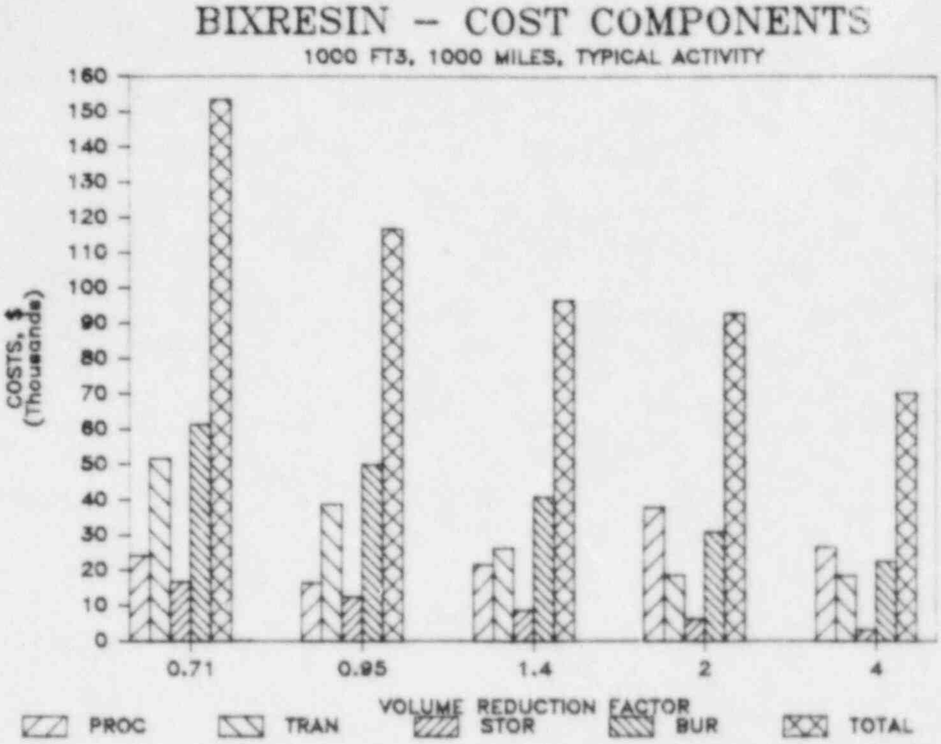

Figure 6.8.(a) Disposal Costs for BWR Ion-Exchange Resins.

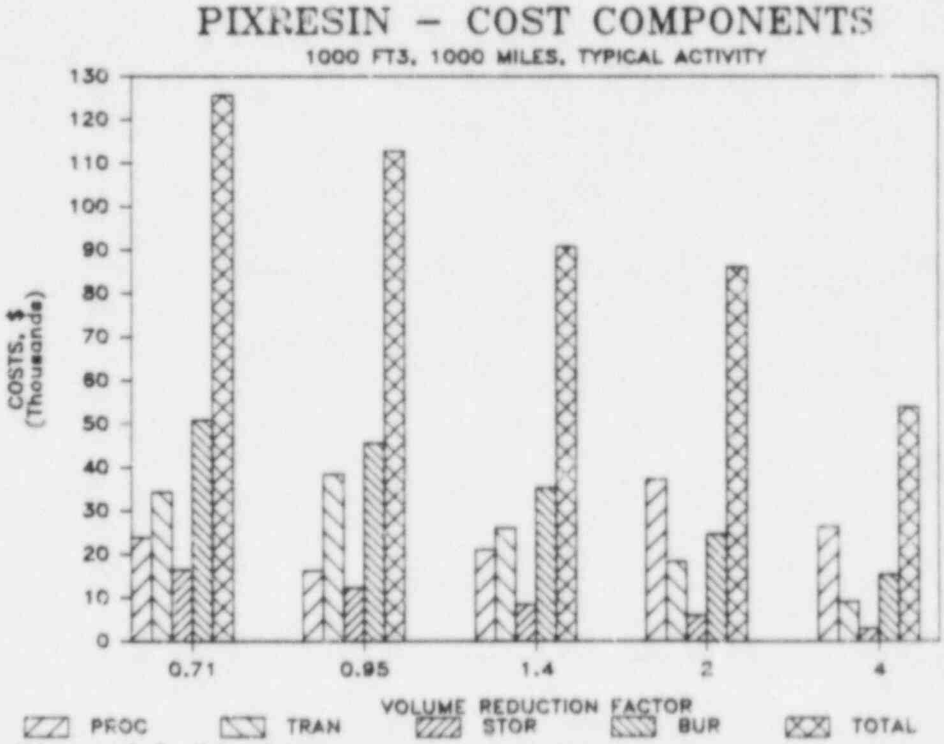

Figure 6.8.(b) Disposal Costs for PWR Ion-Exchange Resins.

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. This is sufficiently higher that the BWR wastes 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 2.3 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

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 bar graphs indicate that a factor of 10 reduction in stream activity, compared to the average, will reduce disposal costs about 20 to 40%, while a waste activity which is a factor of 10 higher than average will increase the total costs by about a factor of 2. Activity levels 100 times greater than average result in costs 3 to 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

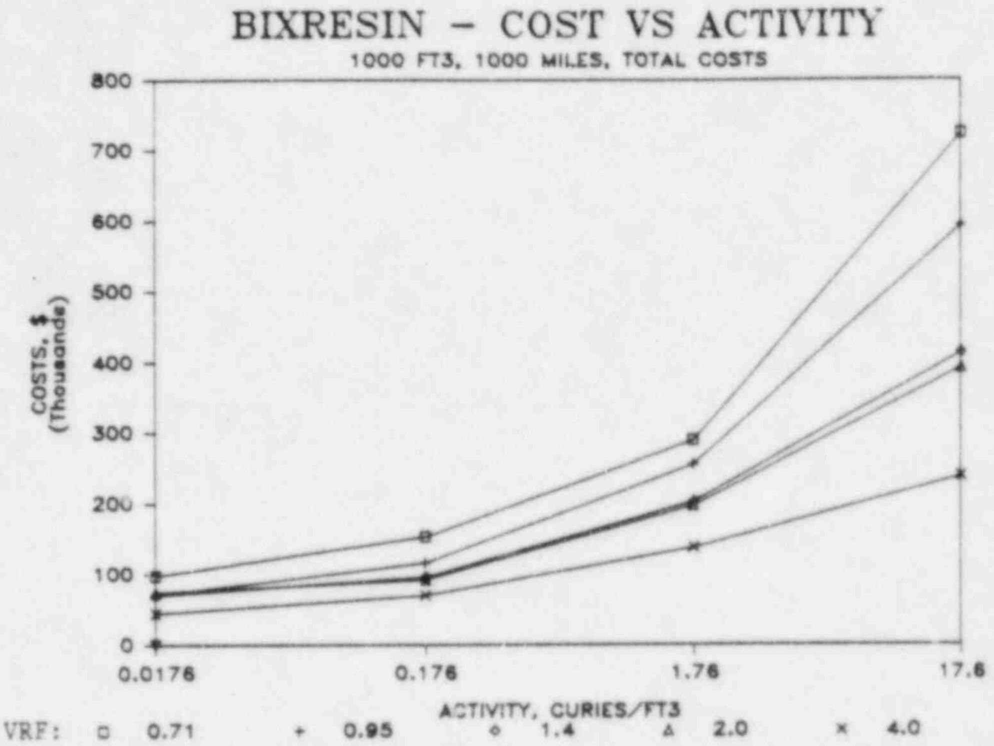

Figure 6.9.(a) Cost Sensitivity of BWR Ion-Exchange Resins to Activity Level.

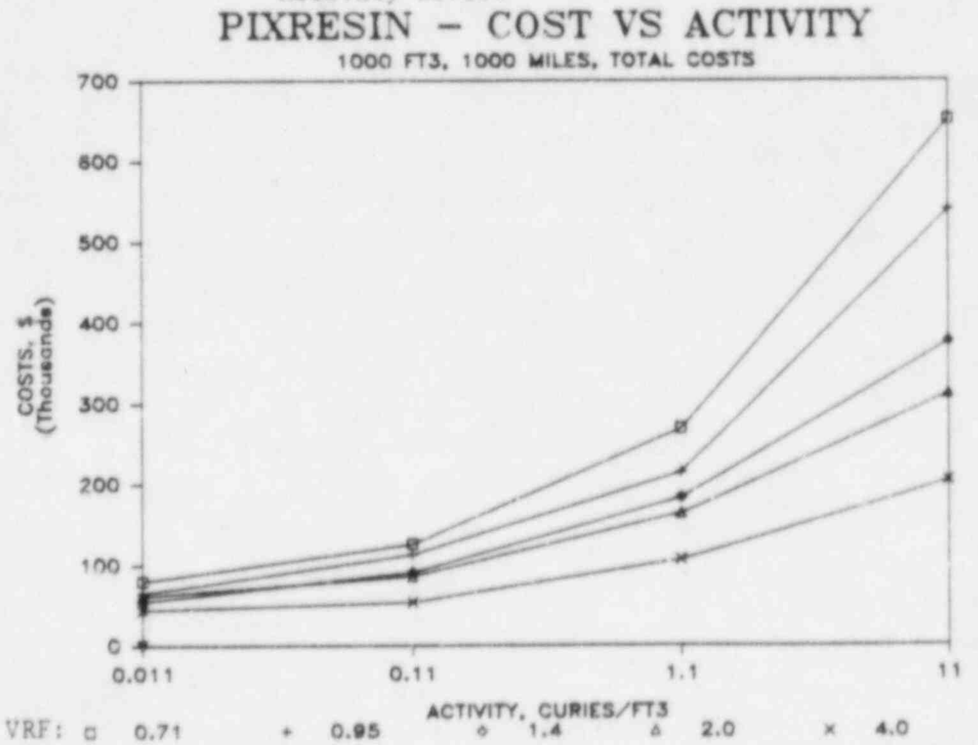

Figure 6.9.(b) Cost Sensitivity of PWR Ion-Exchange Resins to Activity Level.

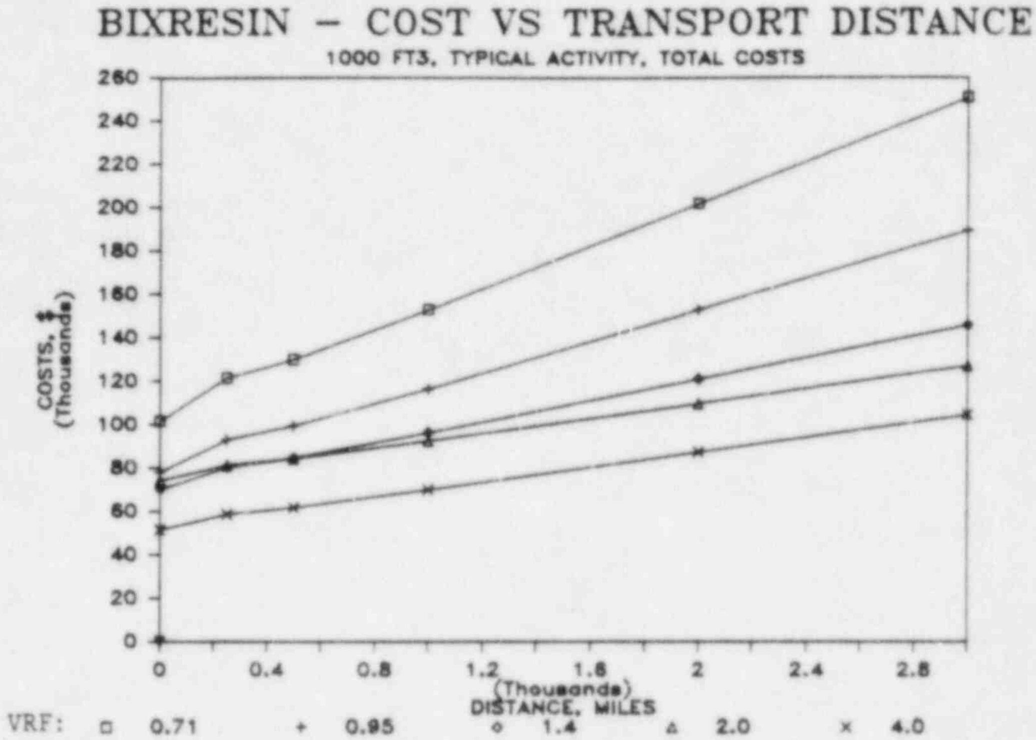

Figure 6.10.(a) Variation in BWR Ion-Exchange Resin Disposal Costs with Transport Distance.

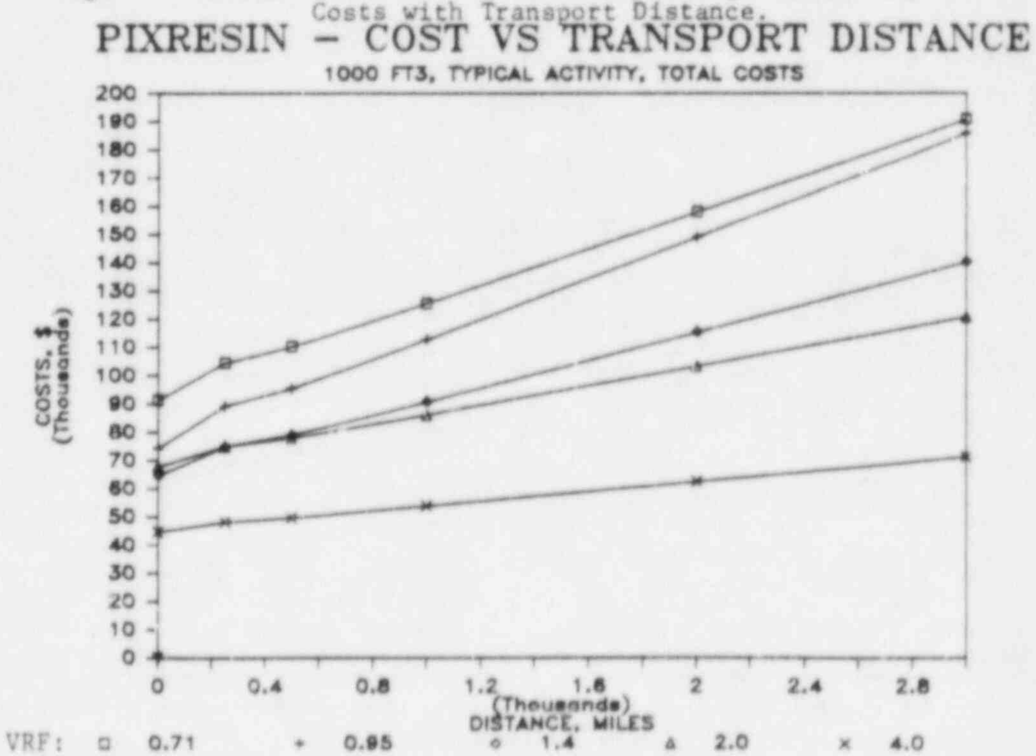

Figure 6.10.(b) Variation in PWR Ion-Exchange Resin Disposal Costs with Transport Distance.

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.

CONCLIQ Volume Reduction Processes

	Volume Reduction Factor	
Process	BWR	PWR
Solidification in Cement	0.7	0.7
Evaporator/Crystalizer, 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 [illegible]

The costs in Figure 6.11 indicate that it [illegible] costly to dispose of BWR concentrated liquids than [illegible] concentrated liquids. There are two primary reasons f[illegible]s. 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 $150,000 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 $80,000 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 $80,000 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 $35,000 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 roughly one-third 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

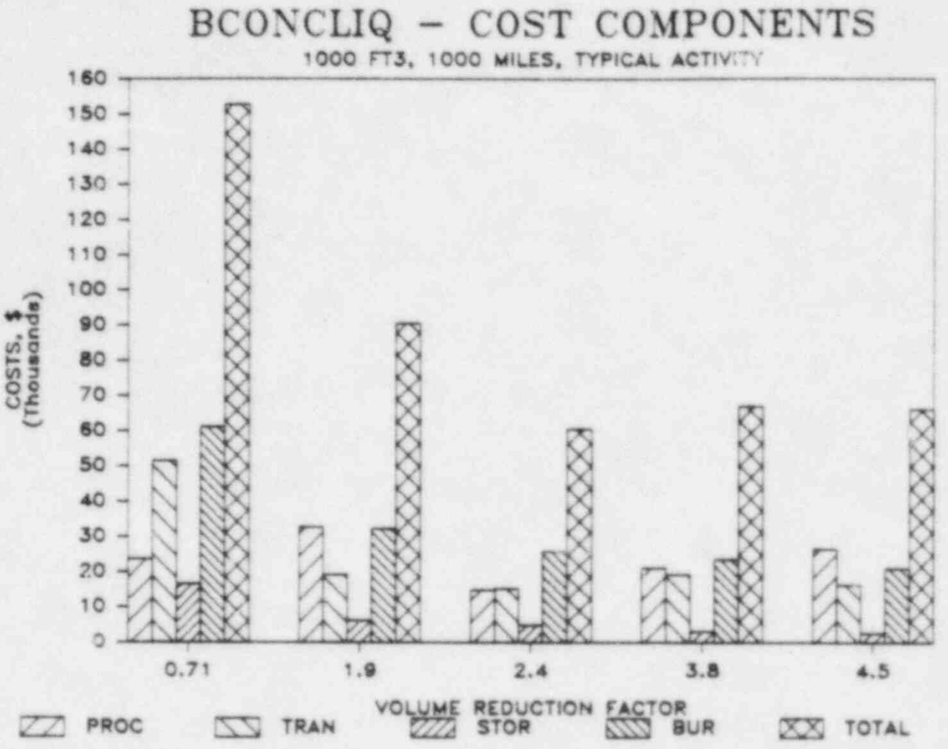

Figure 6.11.(a) Disposal Costs for BWR Concentrated Liquids.

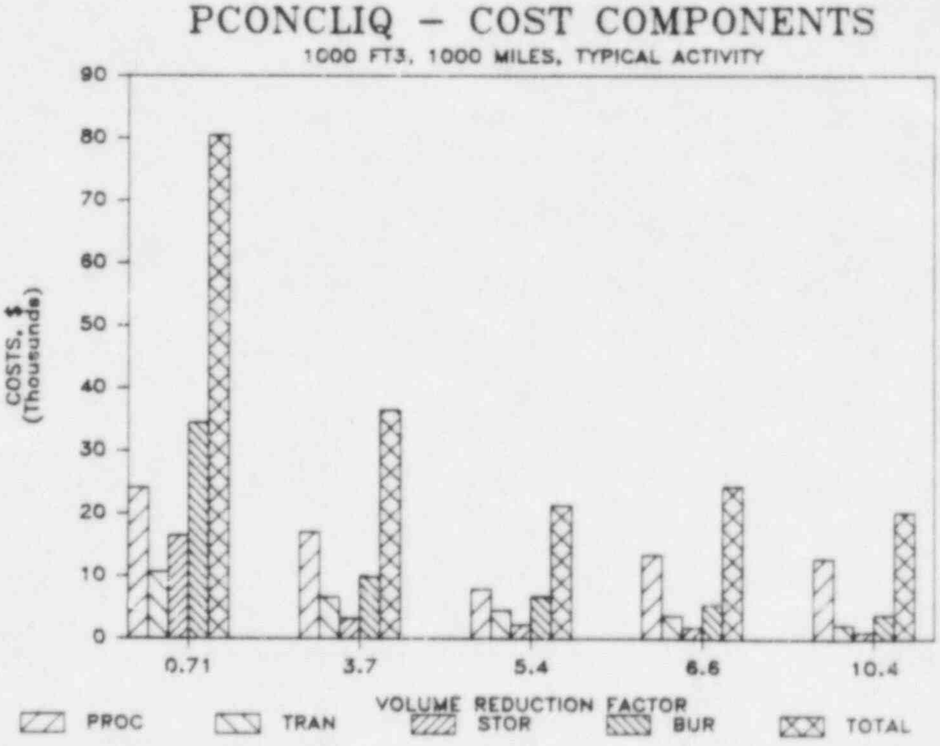

Figure 6.11.(b) Disposal Costs for PWR Concentrated Liquids.

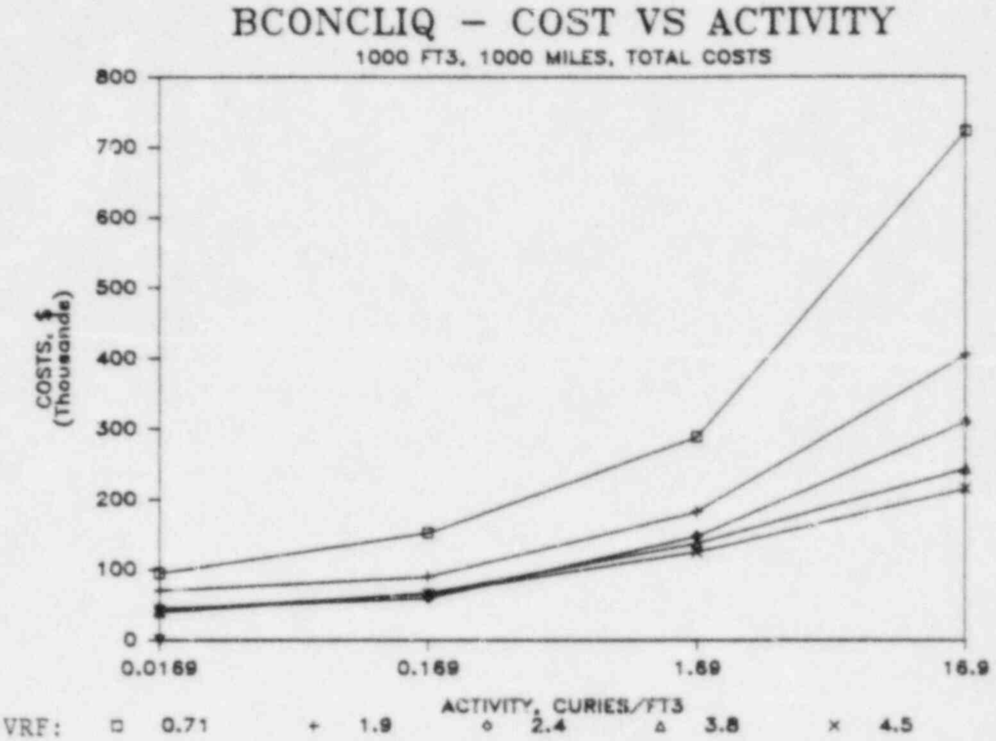

Figure 6.12.(a) Cost Sensitivity of BWR Concentrated Liquids to Activity Level.

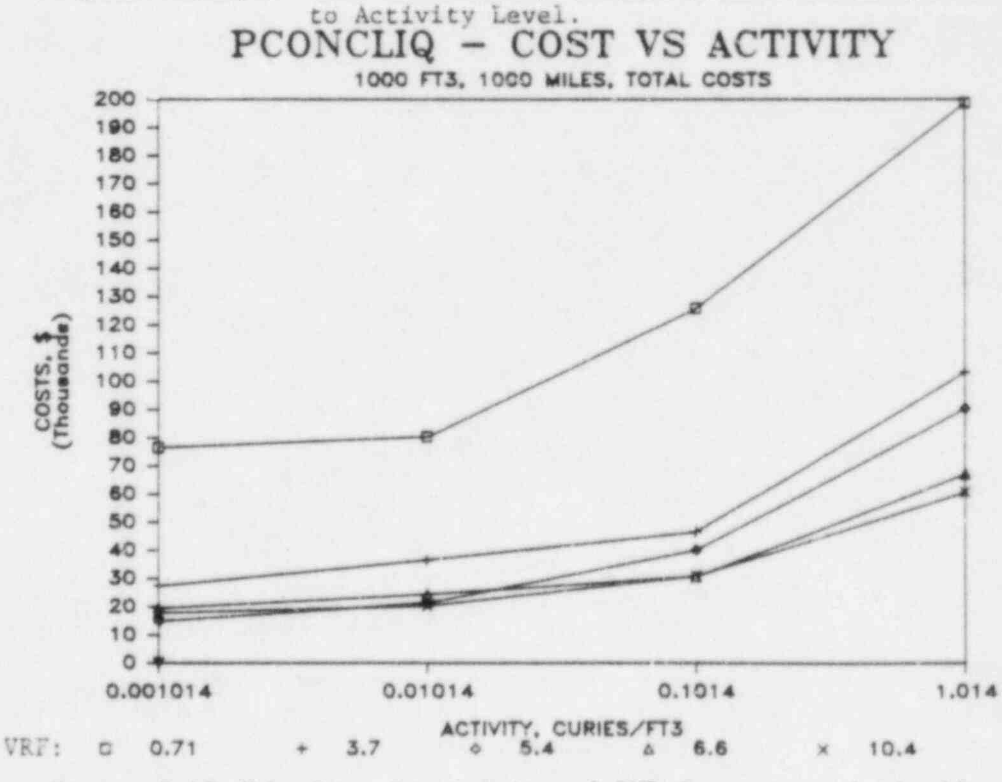

Figure 6.12.(b) Cost Sensitivity of PWR Concentrated Liquids to Activity Level.

higher than typical activity essentially doubles the disposal costs, while a factor of 100 higher activity increases costs by about a factor of 5. For PWR concentrated wastes, a factor of 10 lower activity will reduce costs by 10 to 20 percent. A factor of 10 higher activity will increase costs from about 20 percent to almost a factor of 2, depending on the extent of volume reduction achieved.

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, necesitates 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

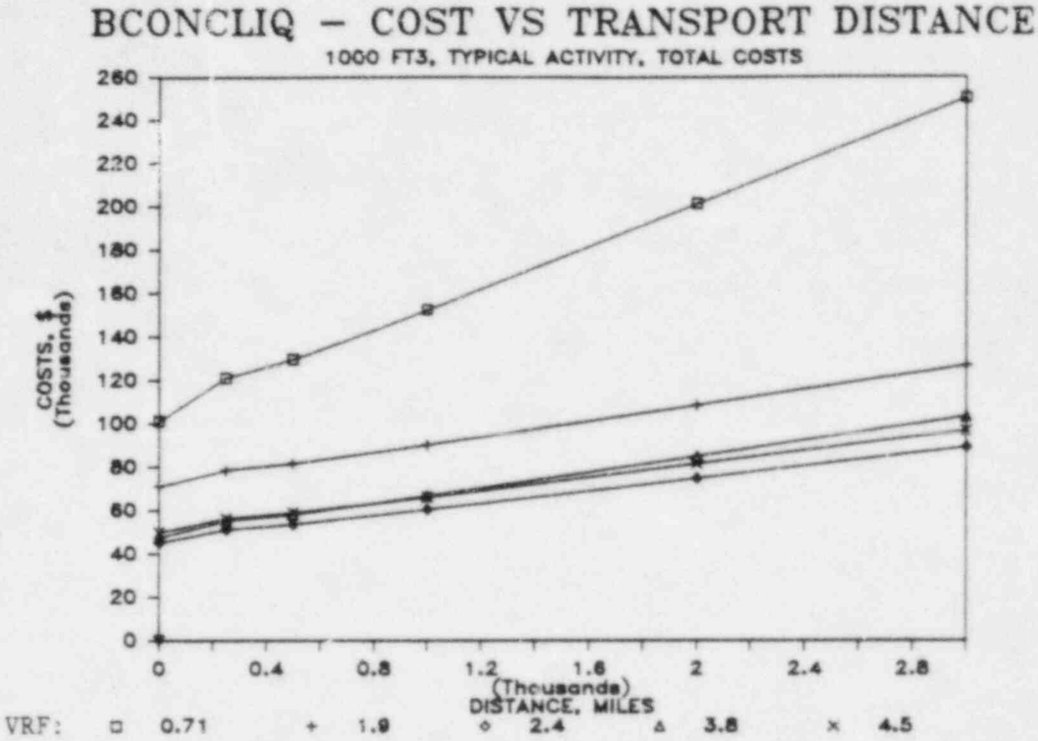

Figure 6.13.(a) Variation in BWR Concentrated Liquids Disposal Costs with Transport Distance.

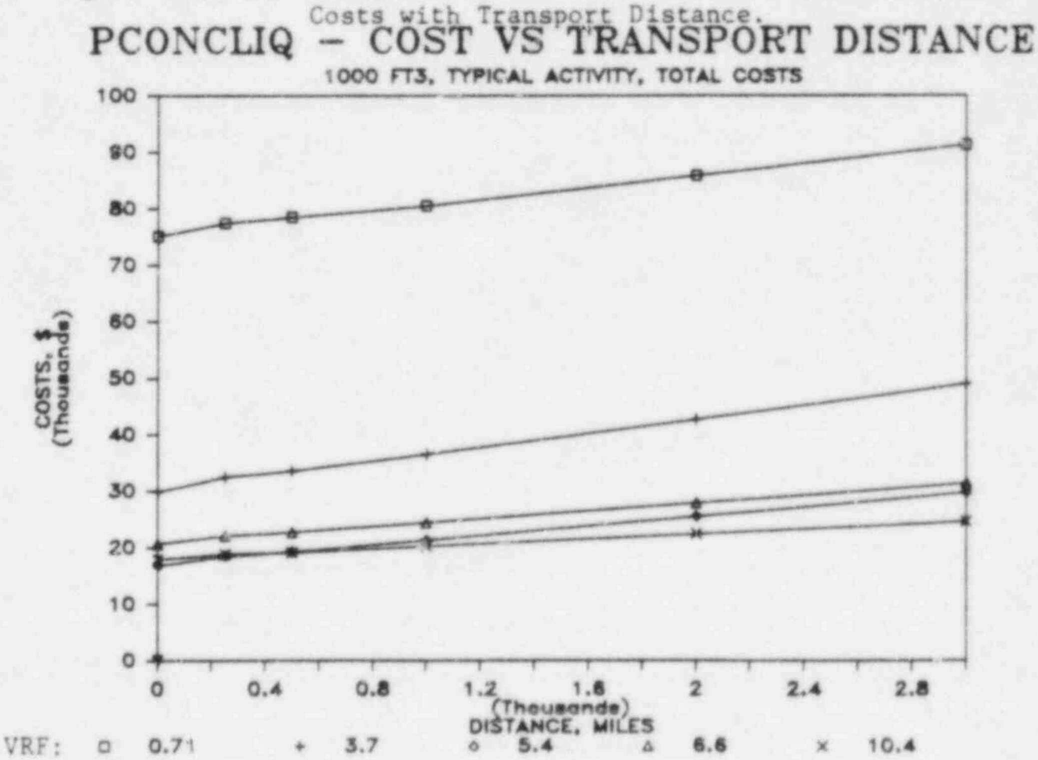

Figure 6.13.(b) Variation in PWR Concentrated Liquids Disposal Costs with Transport Distance.

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 increases costs by more than a factor of 5. 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 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 35 percent.

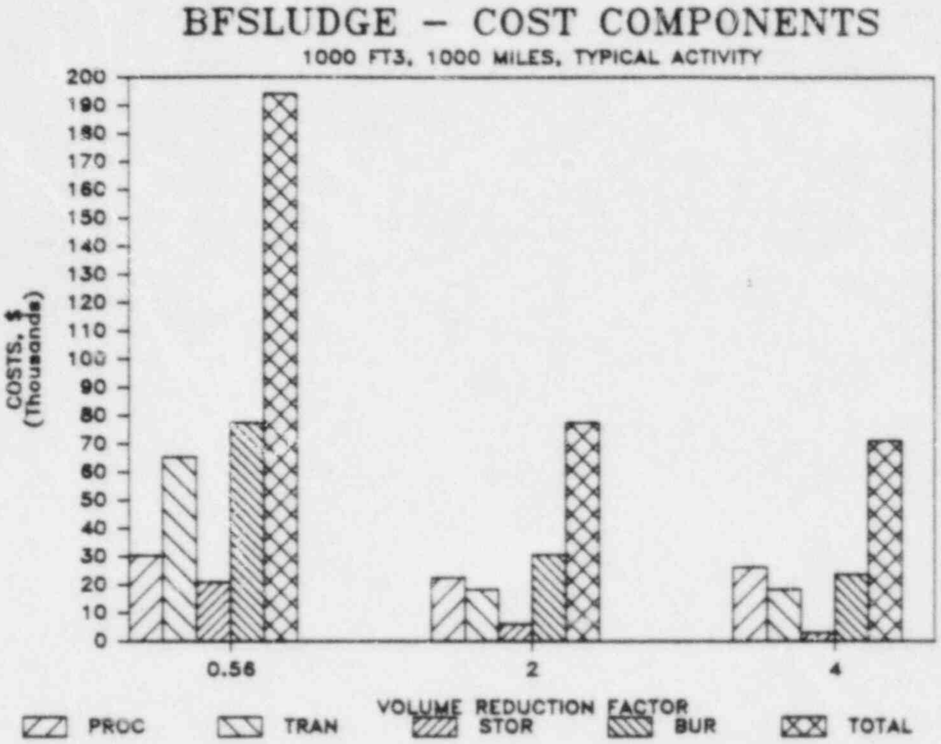

Figure 6.14.(a) Disposal Costs for BWR Filter Sludge.

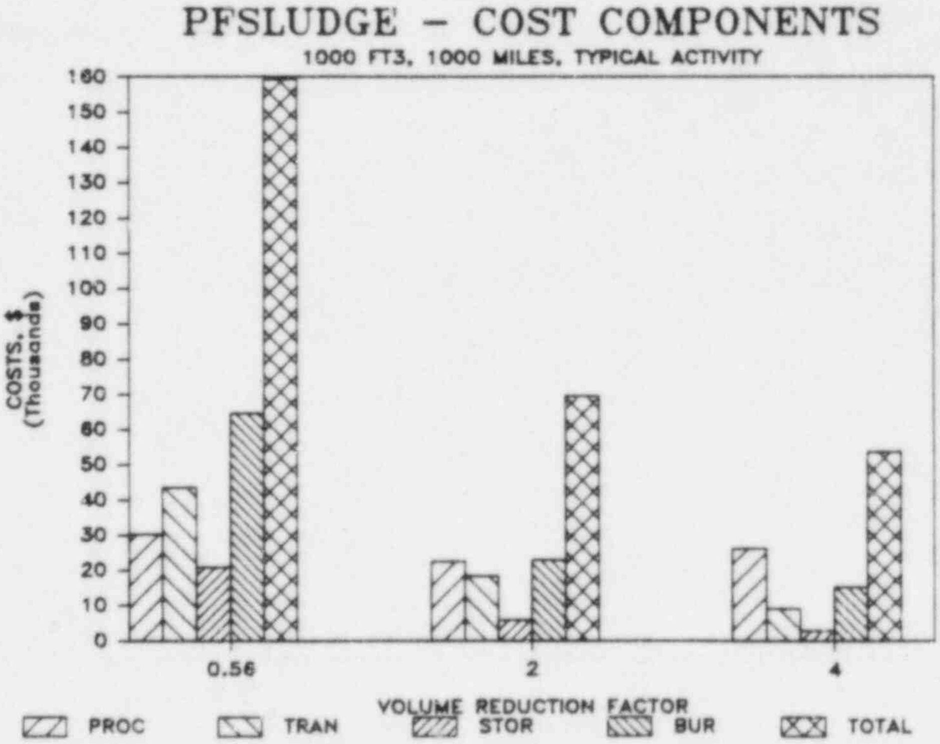

Figure 6.14.(b) Disposal Costs for PWR Filter Sludge.

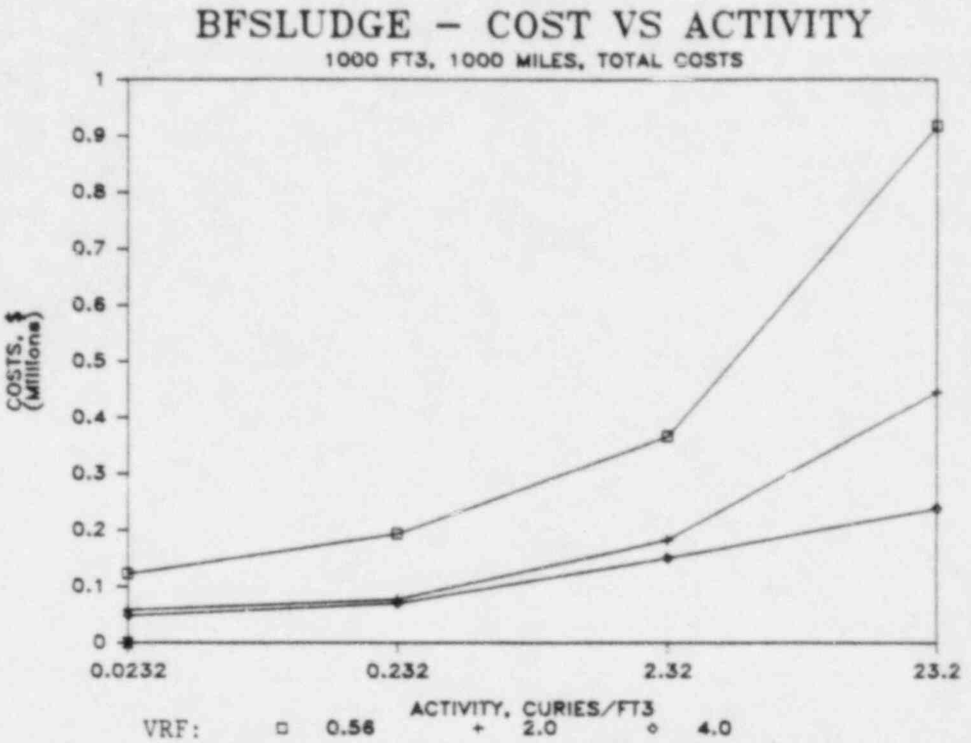

Figure 6.15.(a) Cost Sensitivity of BWR Filter Sludge to Activity Level.

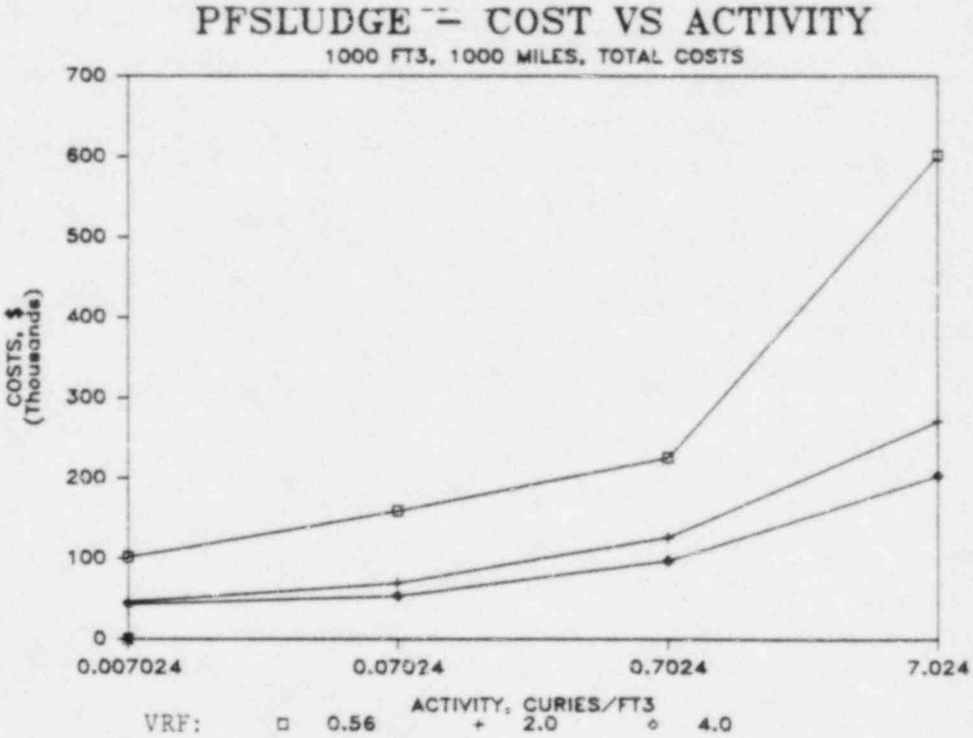

Figure 6.15.(b) Cost Sensitivity of PWR Filter Sludge to Activity Level.

Figure 6.16 shows 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 transport distance increases the total costs by $40,000 to $80,000, 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.

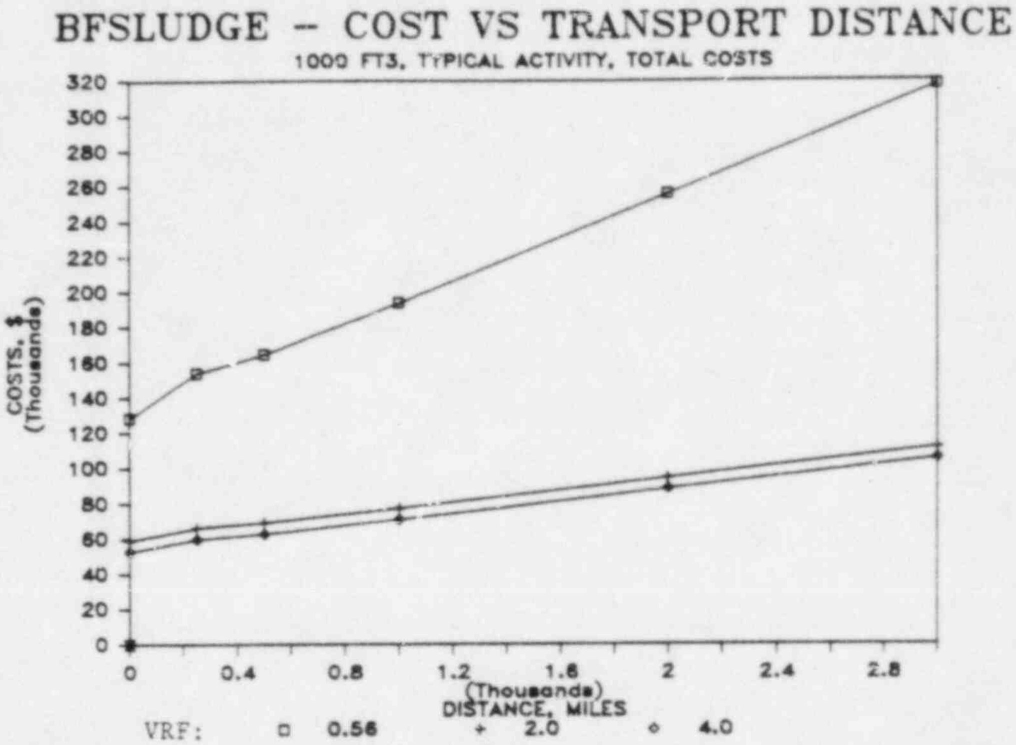

Figure 6.16.(a) Variation in BWR Filter Sludge Disposal Costs with Transport Distance.

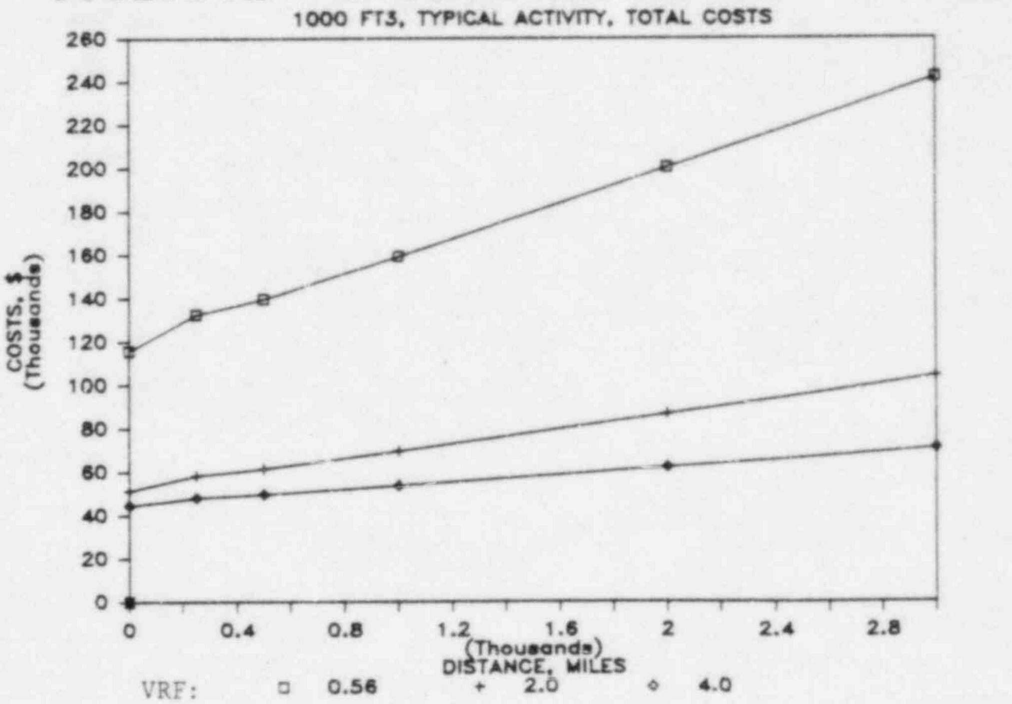

Figure 6.16.(b) Variation in PWR Filter Sludge Disposal Costs with Transport Distance.

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 appendicies 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 few nuclear plants 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. Aspects such as extent of volume reduction achieved, volume reduction process employed, type of shipping container used, and activity concentration or surface dose rate were needed. Those interviewed gave the desired information in most cases, although data ranges were generally given rather than single point values.

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 BWR COTRASH. The ratio of generic estimated costs to actual costs was only 0.70. On the other hand, COTRASH from another utility (mixed BWR and PWR wastes at this site) had an estimated vs actual cost ratio of 0.97.

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

Waste Type	Stated or Implied VRF	Surface Dose, R/Hr	Quoted Disposal Cost,*$/1000 ft^3	Generic Est. Cost,*$/1000 ft^3	Ratio $\frac{\text{Generic Cost}}{\text{Actual}}$
BCOTRASH	4.8	<.200	9,400	6,600	0.70
NCTRASH	0.75	0-.15	48,300	45,400	0.94
COTRASH	3.7	0-.15	8,800	8,500	0.97
BIXRESIN	0.71	50-75	410,000	379,600	0.93
BCONCLIQ	0.71	1-5	141,300	134,800	0.95
BFSLUDGE	0.82	5-10	152,500	151,700	0.99
PIXRESIN	<0.8	25-50	393,700	350,100	0.89

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

7.1 BWR COMPACTIBLE TRASH (BCOTRASH) DISPOSAL COSTS

Figure 7.1 presents the details of the cost comparison for BWR compactible trash. The disposal cost quoted by the utility for this type of waste was $\$45/\text{ft}^3$ (as-shipped). The stated volume reduction factor was about 4.8, and the container surface dose rate was quoted as being considerably less than 200 mr/hr. The actual disposal cost is about $\$9400$ 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. For BCOTRASH, generic costs were calculated for volume reduction factors which bracket the stated VRF of 4.8. Therefore, generic estimates based on VRF = 3.8 and VRF = 5.7 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 = 4.8.

The surface dose rate for the utility waste was stated to be less than 200 mr/hr. Table 5.2 gives approximate surface dose rates for the various BWR waste streams. For typical activity concentrations for BCOTRASH 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 less than .2 R/hr (how much less is not clear), the typical activity case was chosen for the generic estimate basis.

To determine the base cost for the generic estimate Table B.1 was used. The estimated distance from the plant to the Barnwell burial site is 250 miles. Therefore, base estimates are chosen for the cases of distance = 250 miles, typical activity level, and VRFs of 3.76 and 5.67. Table B.1 presents the total costs for these conditions.

Actual Cost

Waste Type: BWR Compactible trash (BCOTRASH)

Plant: NRC Region II BWR

Container type used: 98 ft^3 boxes

Surface dose rate, R/hr: <.20

Volume reduction factor: ~4.8

Quoted disposal costs: \$45/ft^3 as-shipped

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

Distance to burial site: ~5 hrs (250 mi assumed)

Actual costs (per 1000 ft^3 of as-generated waste)

$(45 \times 1/4.8) \times 1000 = \$9400/1000ft^3$

Generic Estimates

Waste Type: BCOTRASH

Case VRF:	3.8	5.7
Surface dose (R/hr) (Table 5.2), typical activity	.03	.03
Total Cost (@250 mi, Table B-1)	13300	9000
Adjustments:		
In-Plant handling costs:	(-)3200	(-)2300
Interim Storage costs: (Table 1.4)	(-)2800	(-)1900
Burial at Barnwell (Table C-1)	800	500
Generic estimates (adjusted)	\$8100	\$5300

Linear interpolation to VRF = 4.8, Cost = \$6600/1000 ft^3

Ratio: $\frac{\text{Generic Est}}{\text{Actual}} \quad \frac{6600}{9400} = 0.70$

Figure 7.1 Cost Comparison for BWR Compactible Trash

The total estimated costs from Table B.1 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 1.4. The final adjustment to the estimated costs is that for burial at Barnwell, SC. Table C.1 presents the differential cost for burial at Barnwell compared to the average site burial costs.

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)*
> Container handling time: 1.0 (hrs/container)
> Maintenance unit costs: 4.0 ($\$/ft^3$)*

- Number of containers:

$$\text{No.} = \frac{1000\ (ft^3)}{7.5\ (ft^3/\text{cont})\times 3.78} = 35.27\quad (\text{cont.}/10^3\ ft^3)$$

- Container handling labor cost:
  Hand. Cost = 1.0 (hrs/cont) x
  35.27 (cont) x 30 ($/hr) = $1058.1

- Equipment Operating Labor:
  Op. cost = 0.14 (hrs/ft^3) x 35.27 (cont)
  x 7.5 (ft^3/cont) x 30 ($/hr) = $1111.1

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*Based on as-shipped conditions.

- o Maintenance cost:
  Maint. Cost = 4.0(\$/ft^3) x
  35.27 (cont) x 7.5 (ft^3/cont) = <u>\$1058.1</u>

Total in-plant labor cost (per 1000 ft^3 of as-generated waste) = \$3227.3

This total labor cost figure is rounded to \$3200 per 10^3 ft^3, and 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 \$8100/1000 ft^3 and \$5300/1000 ft^3 for VRFs of 3.8 and 5.7, respectively. Linear interpolation to a VRF of 4.8 gives a generic estimate of \$6600/1000 ft^3. The actual cost quoted by the utility was \$9400/1000 ft^3. Thus, the generic estimate is about 30% less than the actual cost for this particular case.

7.2 NON-COMPACTIBLE 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 in the range of 0 - .15 R/hr. The VRF was not given, so a value of 0.2 was assumed. 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 non-compactible trash from both a BWR and a PWR. The average surface dose of the actual waste is taken to be about 0.08 R/hr. From Table 5.2 this is very close to the predicted surface dose of BNCTRASH with a "high" activity concentration (i.e., a factor of 10 higher than typical) and with a VRF of 0.2. Therefore, BNCTRASH generic costs were used based on these conditions. The specific generic cost base used was that from Table 1.4 for high activity wastes with a VRF of 0.20. This gave a total cost, prior to adjustments, of \$270100/1000 ft^3, which is applicable to the 1000 mile transport distance appropriate for this comparison.

Actual Cost

Waste Type: Non-Compactible Trash (NCTRASH)
Plant: BWR & PWR, NRC Region I
Container type used: 87 ft^3 boxes
Surface dose rate, R/hr: 0 -.15
Volume reduction factor: ~0.2
Quoted disposal costs: $3151/container
(excludes costs for in-plant handling and interim storage)
Distance to burial site: ~1000 mi

Actual costs (per 1000 ft^3 of as-generated waste)

$$3151/(87 \times .2) \times 10^3 = \$181100/1000ft^3$$

Generic Estimates

Waste type: BNCTRASH

Case VRF:	.2
Surface dose (R/hr) (Table 5.2)	
High Activity	.1
Total Cost:	270100
Adjustments:	
In-Plant handling costs:	(-) 59900
Interim Storage costs: (Table 1.4)	(-) 58600
Burial at Barnwell (Table C-1)	21200
Generic estimates (adjusted)	$172800

$$\text{Ratio:} \quad \frac{\text{Generic Est}}{\text{Actual}} \quad \frac{\$172800}{\$181100} = 0.95$$

Figure 7.2 Cost Comparison for Mixed BWR and PWR Non-compactible Trash

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 agrees quite well with the actual cost.

7.3 MIXED BWR AND PWR COMPACTIBLE TRASH (COTRASH) DISPOSAL COSTS

The utility providing this cost input stated that the BWR and PWR compactible trash from this site was mixed and processed in common. This waste is disposed of in 7.5 ft^3 drums. The as-generated waste volume placed in each drum was stated to be 27.5 ft^3. This gives a volume reduction factor of about 3.7. The utility contact stated that the disposal costs were $243 per drum, and that the surface dose rate was in the range of 0 - 0.15 R/hr.

Figure 7.3 presents the actual versus generic cost comparison. The waste stream conditions chosen for the generic estimate are those for PWR compactible trash, typical activity level (SDR ~ 0.062) and a volume reduction factor of 3.78. Total disposal costs for the 1000 mile transport distance case are taken from Table 1.5. Figure 7.3 shows the adjustments made to the generic estimate and the subsequent comparison to the actual costs. The generic estimate compares quite favorably to the actual costs quoted by the utility.

Note that the generic estimate could have been based on BWR COTRASH rather than PWR COTRASH. Costs for disposal of compactible trash are quite insensitive to reactor type. Similarly, they are only mildly dependent on the activity level of the wastes.

Actual Cost

Waste Type: Mixed BWR & PWR Compactible Trash (COTRASH)

Plant: NRC Region I, BWR & PWR

Container type used: 7.5 ft^3 drum

Surface dose rate, R/hr: 0 - .15

Volume reduction factor: ~3.7 (27.5 ft^3 of as-generated waste per container)

Quoted disposal costs: $243/drum
(excludes costs for in-plant handling and interim storage)

Distance to burial site: ~1000 miles

Actual costs (per 1000 ft^3 of as-generated waste)

$(243/27.5) \times 1000 = \$8800/1000\ ft^3$

Generic Estimates

Waste type: PCOTRASH, typical activity case

Case VRF: 3.78

Surface dose (R/hr (Table 5.3)	0.062	
Total Cost (Table 1.5):		$13700
Adjustments:		
In-Plant handling costs:		(-) 3200
Interim Storage costs: (Table 1.5)		(-) 2800
Burial at Barnwell (Table C-2)		800
Generic estimates (adjusted)		$8500/1000 ft^3

$$\text{Ratio:} \quad \frac{\text{Generic Est}}{\text{Actual}} \quad \frac{8500}{8800} = 0.97$$

Figure 7.3 Cost Comparison for Mixed BWR and PWR Compactible Trash

7.4 BWR ION-EXCHANGE RESINS (BIXRESIN) DISPOSAL COSTS

Figure 7.4 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 84 cubic foot containers and that 60 cubic feet of actual waste are put in each container. This gives a VRF of 0.71. The quoted disposal costs are quite high, giving the equivalent of \$410000 per 1000 ft^3 of as-generated waste. The surface dose rate of the IXRESIN wastes was stated to be between 50 and 75 R/hr. A mean value of about 62 R/hr is used. Generic estimates for this waste are shown in Table 1.4 for VRF = 0.71 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 0.7 have an estimated surface dose of about 3.3 R/hr. The high and very high activity level cases would have surface doses which are factors of 10(i.e., 33.0 R/hr) and 100 (330 R/hr) higher than the typical case, respectively. The surface doses for the high and very high cases bracket the actual case surface dose conditions. Therefore, generic estimates are produced for these two conditions. Linear interpolation based on surface dose was then used to estimate the generic costs for a case corresponding to the surface dose rate of 62 R/hr. The resulting generic disposal costs are 93% of the actual disposal costs reported by the utility.

Actual Cost

Waste Type: BWR Ion-Exchange Resin (BIXRESIN)

Plant: NRC Region I BWR

Container type used: 84 ft^3

Surface dose rate, R/hr: 50-75

Volume reduction factor: ~0.71 (actual waste/container = 60 ft^3)

Quoted disposal costs: $24600/container

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

Distance to burial site: ~1000 miles

Actual costs (per 1000 ft^3 of as-generated waste)

($24600/60) x 1000 = $410000/1000 ft^3

Generic Estimates

Waste type: BIXRESIN

Case VRF: 0.71	High act.	Very High act.
Surface dose (R/Hr) (Table 5.2)	33	330
Total Cost	$289700	723800
Adjustments:		
In-Plant handling costs:	(-)15700	(-)15700
Interim Storage costs: (Table 1.4)	(-)16500	(-)16500
Burial at Barnwell (Table C-1) (BNWL-Ave)	57700	283300
Generic estimates (adjusted)	$315200	$974900

Linear interpolation to surface dose condition of ~62 R/hr gives adjusted generic estimates of $379600/1000 ft^3

Ratio: $\frac{\text{Generic Est}}{\text{Actual}} \quad \frac{379600}{410000} = 0.93$

Figure 7.4 Cost Comparison for BWR Ion-Exchange Resins

7.5 BWR CONCENTRATED LIQUID (BCONCLIQ) DISPOSAL COSTS

Figure 7.5 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 comparision. As noted in Figure 7.5, the generic estimates for this waste stream compare quite favorably with the reported actual disposal costs.

7.6 BWR FILTER SLUDGE (BFSLUDGE) DISPOSAL COSTS

The actual conditions cited by the utility for their BWR filter sludge lies between the specific cases covered by the generic estimates. Specifically, the VRF given by the utility for this waste was about 0.82, whereas the generic estimates were calculated for cases of VRF = 0.52 and 2.0. Since the waste disposal costs for this stream vary considerably in the VRF range between 0.56 and 2.0, cost interpolation was used to arrive at the generic estimate corresponding to a case with a volume reduction factor of about 0.8.

Figure 7.6 shows the details of the cost comparison for BWR filter sludge. The costs derived from the generic estimates compare very favorably with the actual disposal costs reported by the utility.

If the generic estimate had been based on the case with VRF = 0.56, (the nearest VRF to that reported by the utility), the resulting estimated disposal cost would be \$171200/1000 ft^3. This is about 13% higher than the actual reported cost. Thus, even the less precise estimate based on VRF = 0.56 rather than 0.8 is still reasonably close to the actual reported cost.

The data in Table 1.4 indicates that the disposal costs for BFSLUDGE are fairly sensitive to activity level in the waste. The generic estimates noted above are based on a typical activity concentration which gives an estimated surface dose (SDR) of about 3.5 R/hr for the case with VRF = 0.56. The utility stated

Actual Cost

Waste Type: BWR Concentrated Liquids (BCONCLIQ)

Plant: NRC Region I BWR

Container type used: 195 ft^3 liners

Surface dose rate, R/hr: 1-5 R/hr

Volume reduction factor: ~0.71 (138 ft^3 actual waste vol. per container)

Quoted disposal costs: $19500/liner (excludes costs for in-plant handling and interim storage)

Distance to burial site: ~ 1000 miles

Actual costs (per 1000 ft^3 of as-generated waste)

(19800/138) x 1000 = $141300/1000 ft^3

Generic Estimates

Waste type: BCONCLIQ, typical activity case

Case VRF: 0.71

Surface dose (R/hr) (Table 5.2)	3.6
Total Cost (Table 1.4)	$152700
Adjustments:	
In-Plant handling costs:	(-) 15700
Interim Storage costs: (Table 1.4)	(-) 16500
Burial at Barnwell (Table C-1)	14300
Generic estimates (adjusted)	$134800

$$\text{Ratio:} \quad \frac{\text{Generic Est}}{\text{Actual}} \quad \frac{134800}{141300} = 0.95$$

Figure 7.5 Cost Comparison for BWR Concentrated Liquids

Actual Cost

Waste Type: BWR Filter Sludge (BFSLUDGE)

Plant: NRC Region I BWR

Container type used: 195 ft^3 liner

Surface dose rate, R/hr: 5-10

Volume reduction factor: ~0.8 (160 ft^3 of actual waste per container)

Quoted disposal costs: $24400/container
(excludes costs for in-plant handling and interim storage)

Distance to burial site: ~1000 miles

Actual costs (per 1000 ft^3 of as-generated waste)
24400/160 x 1000 = $152500/1000 ft^3

Generic Estimates

Waste type:

Case VRF:	0.52	2.0
Surface dose (R/hr (Table 5.3):	3.3	15.8
Total Cost	$193900	$77300
Adjustments:		
In-Plant handling costs:	(-)19900	(-)15100
Interim Storage costs: (Table 1.4)	(-)20900	(-) 5900
Burial at Barnwell (Table C-1)	18100	7100
Generic estimates (adjusted)	$171200	$63400

Linear interpolation to VRF = 0.8 gives an adjusted generic estimate of $151700 per 1000 ft^3 of as-generated waste.

Ratio: $\frac{\text{Generic Est}}{\text{Actual}} \quad \frac{151700}{152500} = 0.99$

Figure 7.6 Cost Comparison for BWR Filter Sludge their BFSLUDGE had an SDR which was generally in the range of 5 to 10 R/hr. A further adjustment of the generic estimate to correspond to a condition with an SDR of ~7.5 R/hr would give an adjusted cost of roughly $175000 per 1000 ft^3 of as-generated waste. This is about 14% higher than the stated actual costs.

7.7 PWR ION-EXCHANGE RESIN (PIXRESIN) DISPOSAL COSTS

Figure 7.7 presents the comparison of actual versus generic estimated disposal costs for PWR IXRESINS. The utility supplying the cost data stated that 121 ft^3 containers were used for the disposal of this waste, and that as much as 95 ft^3 of waste could be disposed in each. Thus, the applicable VRF is about 0.8 or less. The implication is that typically, a VRF of less than 0.8 is achieved. Therefore, the generic estimates were chosen corresponding to a volume reduction factor of 0.71.

The reported surface dose rates for the actual wastes is in the range of 25 to 50 R/hr. This range lies between the doses applicable to the high (SDR ~ 18 R/hr) and the very high (SDR ~ 184 R/hr) generic estimate cases for a volume reduction factor of 0.71. Costs for this waste stream are fairly sensitive to surface dose rate. Therefore, a cost interpolation was made to obtain the estimate applicable to the reported dose range of 25 to 50 R/hr. Figure 7.7 displays the results. The generic estimated is about 11% less than the actual disposal costs reported by the utility.

Waste Type: PWR Ion-Exchange Resins (PIXRESIN)

Actual Cost

Plant: NRC Region I PWR

Container type used: 121 ft^3 liner

Surface dose rate, R/hr: 25-50

Volume reduction factor: 0.8 or less (max: waste volume per container is 95 ft^3)

Quoted disposal costs: $37400/container
(excludes costs for in-plant handling and interim storage)

Distance to burial site: ~1000 miles

Actual costs (per 1000 ft^3 of as-generated waste)
(37400/95) x 1000 = $393700

Generic Estimates

Waste type: PIXRESIN

Case VRF: Use 0.71

	High	Very High
Surface dose (R/hr) (Table 5.3)	18.4	184
Total Cost	$269100	$650900
Adjustments:		
In-Plant handling costs:	(-)15700	(-)15700
Interim Storage costs: (Table 1.5)	(-)16500	(-)16500
Burial at Barnwell (Table C-2)	50600	211800
Generic estimates (adjusted)	$287500	$830500

Interpolation to a condition with a surface dose rate of 37.5 R/hr gives an estimated cost of $350100 per 1000 ft^3 of waste.

Comparison

Ratio: $\frac{\text{Generic Est}}{\text{Actual}} \quad \frac{350100}{293700} = 0.89$

Figure 7.7 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 filed by the utilities pursuant to Regulatory Guide 1.21 (Ref. 27) do not correspond to the waste streams of interest. Moreover, the Occupational Radiation Exposure Reports filed pursuant to Regulatory Guide 1.16 (Ref. 28) 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 overestimate the exposures incurred in handling dry active waste, and to underestimate the exposures associated with handling and processing wet and irradiated waste streams.

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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 and NUREG-0713 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 Table A-1.

In order to determine whether the data from the three years could be treated as a single data set, a variance analysis was perfomed 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, $\bar{x}$=3.73E-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.=6.69E-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, 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 waste shipped were significantly higher at the BWRs, exposure per unit volume shipped (person-rem/m^3) was then computed for all stations (see Table A-1). Over the three year period, the 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 regession analysis of the exposure and waste volume data was performed. Again, the data in Table A-1 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.

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*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.

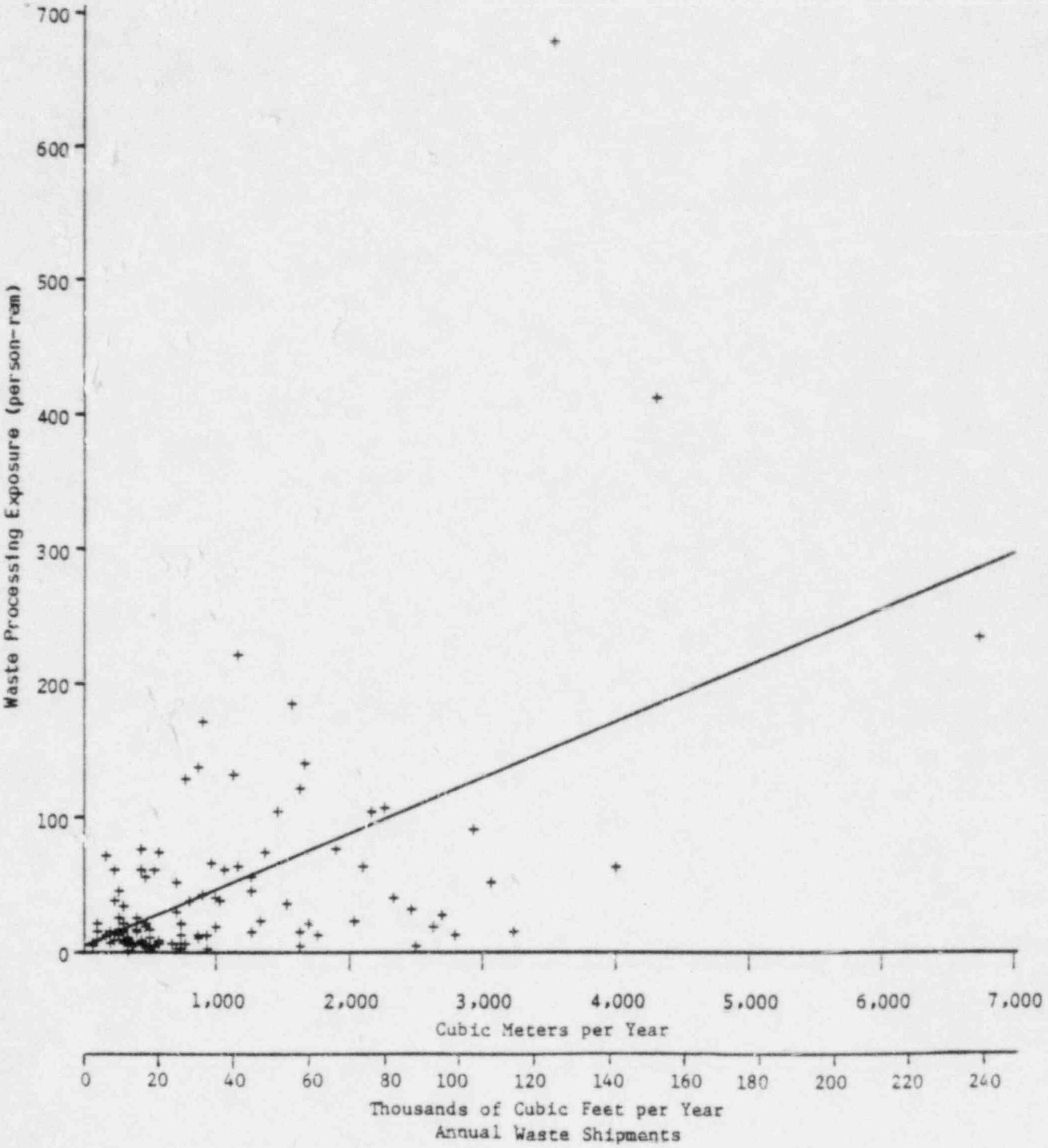

Figure A-1 Plot of Waste Processing Exposure & Waste Volumes Shipped At Commercial Reactors 1980-82

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-1 (continued)

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-1 (continued)

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-1 (continued)

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-1 (continued)

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-1 (continued)

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.

APPENDIX B

VARIATION IN TRANSPORT COSTS WITH TRANSPORT DISTANCE

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 \$8700 per 1000 ft^3 of as-generated waste.

Table B.1. Transport Costs for BWR Waste Streams

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
BNCTRASH	LOW TO HIGH	0.20	250	6300	250400	-7900
		0.40	250	3900	136100	-4900
		0.60	250	3800	98700	-4800
		0.80	250	3700	80000	-4700
	VERY HIGH	0.20	250	47100	351600	-74800
		0.40	250	23600	192000	-37400
		0.60	250	15700	166100	-24900
		0.80	250	11800	132800	-18700
BNCTRASH	LOW TO HIGH	0.20	500	8800	253000	-5300
		0.40	500	5500	137700	-3300
		0.60	500	5400	100300	-3200
		0.80	500	5200	81600	-3100
	VERY HIGH	0.20	500	67300	371800	-54600
		0.40	500	33700	202100	-27300
		0.60	500	22400	172800	-18200
		0.80	500	16800	137800	-13700
BNCTRASH	LOW TO HIGH	0.20	2000	28300	272500	14200
		0.40	2000	17700	149900	8900
		0.60	2000	17200	112100	8600
		0.80	2000	16700	93000	8300
	VERY HIGH	0.20	2000	237500	541900	115600
		0.40	2000	118700	287200	57800
		0.60	2000	79200	229500	38500
		0.80	2000	59400	180400	28900
BNCTRASH	LOW TO HIGH	0.20	3000	42500	286600	28300
		0.40	3000	26600	158700	17700
		0.60	3000	25800	120700	17200
		0.80	3000	25000	101400	16700

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BNCTRASH	VERY HIGH	0.20	3000	353000	657500	231100
		0.40	3000	176500	345000	115600
		0.60	3000	117700	268100	77000
		0.80	3000	88300	209300	57800
BCOTRASH	LOW	2.27	250	600	22100	-700
		3.78	250	300	13300	-400
		5.67	250	200	9000	-300
		8.69	250	100	6600	-200
		113.40	250	0	2100	0
	TYPICAL	2.27	250	600	22100	-700
		3.78	250	300	13300	-400
		5.67	250	200	9000	-300
		8.69	250	100	6600	-200
		113.40	250	0	2200	-100
	HIGH	2.27	250	1000	24000	-1600
		3.78	250	600	14400	-1000
		5.67	250	500	9900	-700
		8.69	250	400	7400	-700
		113.40	250	100	2400	-200
	VERY HIGH	2.27	250	4200	31700	-6600
		3.78	250	2500	19700	-4000
		5.67	250	2500	15100	-4000
		8.69	250	1600	10600	-2600
		113.40	250	200	3000	-400
BCOTRASH	LOW	2.27	500	800	22300	-500
		3.78	500	500	13400	-300
		5.67	500	300	9100	-200
		8.69	500	200	6700	-100
		113.40	500	0	2100	0

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BCOTRASH	TYPICAL	2.27	500	800	22300	-500
		3.78	500	500	13400	-300
		5.67	500	300	9100	-200
		8.69	500	200	6700	-100
		113.40	500	100	2200	-100
	HIGH	2.27	500	1400	24400	-1200
		3.78	500	900	14600	-700
		5.67	500	700	10100	-500
		8.69	500	600	7600	-500
		113.40	500	200	2400	-100
	VERY HIGH	2.27	500	5900	33400	-4800
		3.78	500	3600	20700	-2900
		5.67	500	3600	16200	-2900
		8.69	500	2300	11300	-1900
		113.40	500	400	3200	-300
BCOTRASH	LOW	2.27	2000	2500	24000	1200
		3.78	2000	1500	14400	700
		5.67	2000	1000	9800	500
		8.69	2000	700	7100	300
		113.40	2000	100	2100	0
	TYPICAL	2.27	2000	2500	24000	1200
		3.78	2000	1500	14400	700
		5.67	2000	1000	9800	500
		8.69	2000	700	7100	300
		113.40	2000	200	2300	100
	HIGH	2.27	2000	5200	28100	2500
		3.78	2000	3100	16900	1500
		5.67	2000	2400	11800	1200
		8.69	2000	2300	9200	1100
		113.40	2000	600	2900	300
	VERY HIGH	2.27	2000	20900	48400	10200
		3.78	2000	12600	29700	6100
		5.67	2000	12600	25200	6100
		8.69	2000	8200	17200	4000
		113.40	2000	1300	4100	600

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BCOTRASH	LOW	2.27	3000	3700	25300	2500
		3.78	3000	2200	15200	1500
		5.67	3000	1500	10300	1000
		8.69	3000	1000	7500	700
		113.40	3000	100	2200	100
	TYPICAL	2.27	3000	3700	25300	2500
		3.78	3000	2200	15200	1500
		5.67	3000	1500	10300	1000
		8.69	3000	1000	7500	700
		113.40	3000	300	2500	200
	HIGH	2.27	3000	7700	30600	5100
		3.78	3000	4600	18400	3000
		5.67	3000	3600	13000	2300
		8.69	3000	3400	10400	2300
		113.40	3000	900	3200	600
	VERY HIGH	2.27	3000	31100	58600	20400
		3.78	3000	18700	35800	12200
		5.67	3000	18700	31300	12200
		8.69	3000	12200	21200	8000
		113.40	3000	1900	4700	1200
BIXRESIN	LOW	0.71	250	7500	85800	-12100
		0.95	250	5200	61700	-8200
		1.40	250	6700	59700	-10700
		2.00	250	4700	66400	-7500
		4.00	250	2400	40800	-3700
	TYPICAL	0.71	250	19900	121600	-31600
		0.95	250	14900	93000	-23600
		1.40	250	10100	80300	-16000
		2.00	250	7100	81300	-11200
		4.00	250	7100	58700	-11200
	HIGH	0.71	250	39800	226500	-63200
		0.95	250	29800	208000	-47200
		1.40	250	20200	170400	-32000
		2.00	250	16500	171400	-26200
		4.00	250	12400	118100	-19600

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
	VERY HIGH	0.71	250	69700	613200	-110600
		0.95	250	52100	510900	-82600
		1.40	250	35400	357400	-56100
		2.00	250	33000	340000	-52300
		4.00	250	16500	212500	-26200
BIXRESIN	LOW	0.71	500	10700	88900	-8900
		0.95	500	7300	63800	-6100
		1.40	500	9600	62600	-7800
		2.00	500	6700	68400	-5500
		4.00	500	3400	41800	-2700
	TYPICAL	0.71	500	28400	130100	-23100
		0.95	500	21300	99400	-17200
		1.40	500	14400	84600	-11700
		2.00	500	10100	84300	-8200
		4.00	500	10100	61800	-8200
	HIGH	0.71	500	56900	243500	-46100
		0.95	500	42500	220700	-34500
		1.40	500	28800	179100	-23400
		2.00	500	23600	178400	-19100
		4.00	500	17700	123400	-14300
	VERY HIGH	0.71	500	99500	643000	-80800
		0.95	500	74400	533200	-60400
		1.40	500	50500	372600	-41000
		2.00	500	47100	354100	-38200
		4.00	500	23600	219500	-19100
BIXRESIN	LOW	0.71	2000	38600	116900	19000
		0.95	2000	26400	82900	13000
		1.40	2000	33900	86900	16500
		2.00	2000	23700	85400	11600
		4.00	2000	11900	50300	5800

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*Differential costs compared to 1000 mile distance case

Table B.1..(Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BIXRESIN	TYPICAL	0.71	2000	100300	202000	48800
		0.95	2000	75000	153100	36500
		1.40	2000	50900	121100	24800
		2.00	2000	35600	109800	17300
		4.00	2000	35600	87300	17300
	HIGH	0.71	2000	200700	387300	97700
		0.95	2000	150000	328200	73000
		1.40	2000	101800	252000	49500
		2.00	2000	83100	238000	40400
		4.00	2000	62300	168000	30300
	VERY HIGH	0.71	2000	351200	894700	170900
		0.95	2000	262500	721200	127700
		1.40	2000	178100	500200	86700
		2.00	2000	166200	473200	80900
		4.00	2000	83100	279100	40400
BIXRESIN	LOW	0.71	3000	57600	135900	38000
		0.95	3000	39400	95900	26000
		1.40	3000	50400	103400	33000
		2.00	3000	35300	97000	23100
		4.00	3000	17700	56100	11600
	TYPICAL	0.71	3000	149200	250800	97700
		0.95	3000	111500	189600	73000
		1.40	3000	75600	145900	49500
		2.00	3000	53000	127200	34700
		4.00	3000	53000	104600	34700
	HIGH	0.71	3000	298300	485000	195300
		0.95	3000	223000	401200	146000
		1.40	3000	151300	301500	99000
		2.00	3000	123600	278400	80900
		4.00	3000	92700	198400	60700

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BIXRESIN	VERY HIGH	0.71	3000	522100	1065600	341800
		0.95	3000	390200	848900	255400
		1.40	3000	264800	586900	173300
		2.00	3000	247100	554100	161800
		4.00	3000	123600	319500	80900
BCONCLIQ	LOW	0.71	250	6900	84300	-11000
		1.90	250	5000	62800	-7900
		2.40	250	3900	38600	-6200
		3.80	250	2500	36000	-3900
		4.50	250	2100	39400	-3300
	TYPICAL	0.71	250	19900	121100	-31600
		1.90	250	7400	78500	-11800
		2.40	250	5900	51100	-9300
		3.80	250	7400	55000	-11800
		4.50	250	6300	56100	-10000
	HIGH	0.71	250	39800	226100	-63200
		1.90	250	17400	154800	-27500
		2.40	250	13800	126200	-21800
		3.80	250	13000	117400	-20700
		4.50	250	11000	107800	-17400
	VERY HIGH	0.71	250	69700	612700	-110600
		1.90	250	34700	350700	-55100
		2.40	250	27500	266900	-43600
		3.80	250	17400	216600	-27500
		4.50	250	14700	191800	-23300
BCONCLIQ	LOW	0.71	500	9800	87200	-8200
		1.90	500	7100	65000	-5700
		2.40	500	5600	40300	-4600
		3.80	500	3500	37100	-2900
		4.50	500	3000	40300	-2400

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BCONCLIQ	TYPICAL	0.71	500	28400	129700	-23100
		1.90	500	10600	81700	-8600
		2.40	500	8400	53600	-6800
		3.80	500	10600	58200	-8600
		4.50	500	9000	58800	-7300
	HIGH	0.71	500	56900	243100	-46100
		1.90	500	24800	162200	-20100
		2.40	500	19600	132000	-15900
		3.80	500	18600	123000	-15100
		4.50	500	15700	112600	-12700
	VERY HIGH	0.71	500	99500	642500	-80800
		1.90	500	49600	365600	-40200
		2.40	500	39300	278600	-31900
		3.80	500	24800	224100	-20100
		4.50	500	20900	198100	-17000
BCONCLIQ	LOW	0.71	2000	35300	112700	17400
		1.90	2000	25000	82900	12200
		2.40	2000	19800	54500	9600
		3.80	2000	12500	46100	6100
		4.50	2000	10600	47900	5100
	TYPICAL	0.71	2000	100300	201600	48800
		1.90	2000	37500	108600	18200
		2.40	2000	29700	74800	14400
		3.80	2000	37500	85000	18200
		4.50	2000	31700	81500	15400
	HIGH	0.71	2000	200700	386900	97700
		1.90	2000	87500	224900	42600
		2.40	2000	69300	181700	33700
		3.80	2000	65600	170000	31900
		4.50	2000	55400	152300	27000

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BCONCLIQ	VERY HIGH	0.71	2000	351200	894200	170900
		1.90	2000	175000	491000	85100
		2.40	2000	138500	377900	67400
		3.80	2000	87500	266700	42600
		4.50	2000	73900	251000	36000
BCONCLIQ	LOW	0.71	3000	52700	130100	34800
		1.90	3000	37200	95000	24300
		2.40	3000	29400	64100	19300
		3.80	3000	18600	52100	12200
		4.50	3000	15700	53000	10300
	TYPICAL	0.71	3000	149200	250400	97700
		1.90	3000	55700	126800	36500
		2.40	3000	44100	89300	28900
		3.80	3000	55700	103300	36500
		4.50	3000	47100	96900	30800
	HIGH	0.71	3000	298300	484500	195300
		1.90	3000	130100	267500	85100
		2.40	3000	103000	215400	67400
		3.80	3000	97500	201900	63900
		4.50	3000	82400	179200	53900
	VERY HIGH	0.71	3000	522100	1065100	341800
		1.90	3000	260100	576100	170300
		2.40	3000	205900	445300	134800
		3.80	3000	130100	329300	85100
		4.50	3000	109800	287000	71900
BFSLUDGE	LOW	0.56	250	9300	108000	-14800
		2.00	250	4700	51200	-7500
		4.00	250	3500	43500	-5600
	TYPICAL	0.56	250	25300	153900	-40100
		2.00	250	7100	66100	-11200
		4.00	250	7100	59700	-11200

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*Differential costs compared to 1000 mile distance case

Table B.1. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
BFSLUDGE	HIGH	0.56	250	50500	286900	-80100
		2.00	250	16500	156200	-26200
		4.00	250	12400	130700	-19600
	VERY HIGH	0.56	250	88400	777300	-140200
		2.00	250	33000	393500	-52300
		4.00	250	16500	212700	-26200
BFSLUDGE	LOW	0.56	500	13100	111900	-11000
		2.00	500	6700	53200	-5500
		4.00	500	5000	45000	-4100
	TYPICAL	0.56	500	36100	164700	-29300
		2.00	500	10100	69100	-8200
		4.00	500	10100	62700	-8200
	HIGH	0.56	500	72100	308500	-58500
		2.00	500	23600	163300	-19100
		4.00	500	17700	136000	-14300
	VERY HIGH	0.56	500	126200	815100	-102400
		2.00	500	47100	407600	-38200
		4.00	500	23600	219700	-19100
BFSLUDGE	LOW	0.56	2000	47500	146300	23400
		2.00	2000	23700	70200	11600
		4.00	2000	17800	57800	8700
	TYPICAL	0.56	2000	127200	255800	61900
		2.00	2000	35600	94600	17300
		4.00	2000	35600	88200	17300
	HIGH	0.56	2000	254400	490800	123800
		2.00	2000	83100	222800	40400
		4.00	2000	62300	180600	30300

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*Differential costs compared to 1000 mile distance case

Table B.1..(Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
BFSLUDGE	VERY HIGH	0.56	2000	445200	1134100	216700
		2.00	2000	166200	526800	80900
		4.00	2000	83100	279300	40400
BFSLUDGE	LOW	0.56	3000	70900	169600	46800
		2.00	3000	35300	81800	23100
		4.00	3000	26500	66400	17300
	TYPICAL	0.56	3000	189100	317700	123800
		2.00	3000	53000	111900	34700
		4.00	3000	53000	105500	34700
	HIGH	0.56	3000	378200	614600	247600
		2.00	3000	123600	263300	80900
		4.00	3000	92700	211000	60700
	VERY HIGH	0.56	3000	661900	1350800	433300
		2.00	3000	247100	607600	161800
		4.00	3000	123600	319700	80900

Table B.2. Transport Costs for PWR Waste Streams

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PNCTRASH	LOW TO TYPICAL	0.20	250	6300	250400	-7900
		0.40	250	4200	136400	-5400
		0.60	250	4100	99000	-5100
		0.80	250	4000	80400	-5100
	HIGH	0.20	250	13600	275300	-21700
		0.40	250	12600	157000	-20100
		0.60	250	12400	117900	-19900
		0.80	250	11900	97700	-19000
	VERY HIGH	0.20	250	47100	371300	-74800
		0.40	250	35400	221800	-56100
		0.60	250	23600	192000	-37400
		0.80	250	17700	149200	-28000
PNCTRASH	LOW TO TYPICAL	0.20	500	8800	253000	-5300
		0.40	500	6000	138200	-3600
		0.60	500	5700	100700	-3500
		0.80	500	5700	82100	-3400
	HIGH	0.20	500	19300	280900	-16100
		0.40	500	17800	162300	-14900
		0.60	500	17600	123100	-14700
		0.80	500	16900	102700	-14100
	VERY HIGH	0.20	500	67300	391500	-54600
		0.40	500	50500	236900	-41000
		0.60	500	33700	202100	-27300
		0.80	500	25200	156800	-20500
PNCTRASH	LOW TO TYPICAL	0.20	2000	28300	272500	14200
		0.40	2000	19200	151400	9600
		0.60	2000	18400	113400	9200
		0.80	2000	18300	94700	9100

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*Differential costs compared to 1000 mile distance costs

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PNCTRASH	HIGH	0.20	2000	69600	331300	34300
		0.40	2000	64500	208900	31800
		0.60	2000	63600	169100	31300
		0.80	2000	60900	146800	30000
	VERY HIGH	0.20	2000	237500	561600	115600
		0.40	2000	178100	364500	86700
		0.60	2000	118700	287200	57800
		0.80	2000	89000	220600	43300
PNCTRASH	LOW TO TYPICAL	0.20	3000	42500	286600	28300
		0.40	3000	28800	161000	19200
		0.60	3000	27600	122600	18400
		0.80	3000	27400	103800	18300
	HIGH	0.20	3000	103900	365600	68600
		0.40	3000	96300	240700	63500
		0.60	3000	94900	200400	62600
		0.80	3000	90900	176800	60000
	VERY HIGH	0.20	3000	353000	677200	231100
		0.40	3000	264800	451200	173300
		0.60	3000	176500	345000	115600
		0.80	3000	132400	263900	86700
PCOTRASH	LOW	3.78	250	300	13300	-400
		5.67	250	200	9000	-300
		8.69	250	100	6600	-200
		113.40	250	0	2100	0
	TYPICAL	3.78	250	300	13300	-400
		5.67	250	200	9000	-300
		8.69	250	100	6600	-200
		113.40	250	0	2200	-100

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*Differential costs compared to 1000 mile distance case

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PCOTRASH	HIGH	3.78	250	600	14400	-1000
		5.67	250	500	10000	-700
		8.69	250	400	7500	-700
		113.40	250	100	2400	-200
	VERY HIGH	3.78	250	3700	23000	-5900
		5.67	250	2500	15500	-4000
		8.69	250	1600	11300	-2600
		113.40	250	200	3600	-400
PCOTRASH	LOW	3.78	500	500	13400	-300
		5.67	500	300	9100	-200
		8.69	500	200	6700	-100
		113.40	500	0	2100	0
	TYPICAL	3.78	500	500	13400	-300
		5.67	500	300	9100	-200
		8.69	500	200	6700	-100
		113.40	500	100	2200	-100
	HIGH	3.78	500	900	14600	-700
		5.67	500	700	10200	-500
		8.69	500	600	7700	-500
		113.40	500	200	2500	-100
	VERY HIGH	3.78	500	5300	24600	-4300
		5.67	500	3600	16600	-2900
		8.69	500	2300	12000	-1900
		113.40	500	400	3700	-300
PCOTRASH	LOW	3.78	2000	1500	14400	700
		5.67	2000	1000	9800	500
		8.69	2000	700	7100	300
		113.40	2000	100	2100	0

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*Differential costs compared to 1000 mile distance case

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PCOTRASH	TYPICAL	3.78	2000	1500	14400	700
		5.67	2000	1000	9800	500
		8.69	2000	700	7100	300
		113.40	2000	200	2400	100
	HIGH	3.78	2000	3100	16900	1500
		5.67	2000	2400	11900	1200
		8.69	2000	2300	9400	1100
		113.40	2000	600	2900	300
	VERY HIGH	3.78	2000	18800	38100	9200
		5.67	2000	12600	25600	6100
		8.69	2000	8200	17900	4000
		113.40	2000	1300	4600	600
PCOTRASH	LOW	3.78	3000	2200	15200	1500
		5.67	3000	1500	10300	1000
		8.69	3000	1000	7500	700
		113.40	3000	100	2200	100
	TYPICAL	3.78	3000	2200	15200	1500
		5.67	3000	1500	10300	1000
		8.69	3000	1000	7500	700
		113.40	3000	300	2500	200
	HIGH	3.78	3000	4600	18400	3000
		5.67	3000	3600	13100	2300
		8.69	3000	3400	10500	2300
		113.40	3000	900	3300	600
	VERY HIGH	3.78	3000	28000	47300	18300
		5.67	3000	18700	31700	12200
		8.69	3000	12200	21800	8000
		113.40	3000	1900	5200	1200

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*Differential costs compared to 1000 mile distance case

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PIXRESIN	LOW	0.71	250	2400	77300	-3100
		0.95	250	3800	59400	-6000
		1.40	250	2700	51300	-4300
		2.00	250	1900	58600	-3000
		4.00	250	2400	40800	-3700
	TYPICAL	0.71	250	13300	104600	-21100
		0.95	250	14900	89200	-23600
		1.40	250	10100	74800	-16000
		2.00	250	7100	75000	-11200
		4.00	250	3500	48200	-5600
	HIGH	0.71	250	39800	205900	-63200
		0.95	250	29800	167600	-47200
		1.40	250	20200	151100	-32000
		2.00	250	14100	141700	-22400
		4.00	250	8300	93300	-13100
	VERY HIGH	0.71	250	69700	540300	-110600
		0.95	250	52100	456400	-82600
		1.40	250	35400	320000	-56100
		2.00	250	24800	272500	-39200
		4.00	250	16500	177800	-26200
PIXRESIN	LOW	0.71	500	3400	78300	-2100
		0.95	500	5300	61000	-4400
		1.40	500	3800	52400	-3100
		2.00	500	2700	59400	-2300
		4.00	500	3400	41800	-2700
	TYPICAL	0.71	500	19000	110300	-15400
		0.95	500	21300	95500	-17200
		1.40	500	14400	79100	-11700
		2.00	500	10100	78000	-8200
		4.00	500	5000	49700	-4100

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*Differential costs compared to 1000 mile distance case

Table B.2 (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PIXRESIN	HIGH	0.71	500	56900	223000	-46100
		0.95	500	42500	180300	-34500
		1.40	500	28800	159700	-23400
		2.00	500	20200	147700	-16400
		4.00	500	11800	96800	-9600
	VERY HIGH	0.71	500	99500	570100	-80800
		0.95	500	74400	478700	-60400
		1.40	500	50500	335100	-41000
		2.00	500	35300	283100	-28700
		4.00	500	23600	184800	-19100
PIXRESIN	LOW	0.71	2000	11000	85900	5500
		0.95	2000	19200	74900	9500
		1.40	2000	13600	62200	6700
		2.00	2000	9700	66400	4800
		4.00	2000	11900	50300	5800
	TYPICAL	0.71	2000	66900	158200	32600
		0.95	2000	75000	149300	36500
		1.40	2000	50900	115500	24800
		2.00	2000	35600	103500	17300
		4.00	2000	17800	62500	8700
	HIGH	0.71	2000	200700	366800	97700
		0.95	2000	150000	287800	73000
		1.40	2000	101800	232600	49500
		2.00	2000	71200	198800	34700
		4.00	2000	41600	126600	20200
	VERY HIGH	0.71	2000	351200	821800	170900
		0.95	2000	262500	666800	127700
		1.40	2000	178100	462700	86700
		2.00	2000	124700	372400	60700
		4.00	2000	83100	244400	40400

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*Differential costs compared to 1000 mile distance case

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PIXRESIN	LOW	0.71	3000	16500	91400	11000
		0.95	3000	28700	84400	18900
		1.40	3000	20300	68900	13400
		2.00	3000	14500	71200	9600
		4.00	3000	17700	56100	11600
	TYPICAL	0.71	3000	99400	190800	65100
		0.95	3000	111500	185800	73000
		1.40	3000	75600	140300	49500
		2.00	3000	53000	120800	34700
		4.00	3000	26500	71100	17300
	HIGH	0.71	3000	298300	464400	195300
		0.95	3000	223000	360800	146000
		1.40	3000	151300	282200	99000
		2.00	3000	105900	233400	69300
		4.00	3000	61800	146800	40400
	VERY HIGH	0.71	3000	522100	992700	341800
		0.95	3000	390200	794500	255400
		1.40	3000	264800	549400	173300
		2.00	3000	185300	433100	121300
		4.00	3000	123600	284800	80900
PCONCLIQ	LOW	0.71	250	2400	73500	-3000
		3.70	250	300	27000	-400
		5.40	250	200	14700	-300
		6.60	250	200	19100	-300
		10.40	250	500	17000	-800
	TYPICAL	0.71	250	2400	77500	-3000
		3.70	250	2500	32400	-4000
		5.40	250	1700	18500	-2800
		6.60	250	1400	22100	-2300
		10.40	250	900	18800	-1400

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*Differential costs compared to 1000 mile distance case

Table B.2 (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PCONCLIQ	HIGH	0.71	250	13300	104800	-21100
		3.70	250	3600	40500	-6100
		5.40	250	5200	31800	-8300
		6.60	250	2100	27400	-3400
		10.40	250	2700	26700	-4300
	VERY HIGH	0.71	250	19900	167000	-31600
		3.70	250	8900	89200	-14100
		5.40	250	9200	75700	-14500
		6.60	250	5000	59100	-7900
		10.40	250	4800	53100	-7500
PCONCLIQ	LOW	0.71	500	3400	74500	-2000
		3.70	500	500	27100	-300
		5.40	500	300	14800	-200
		6.60	500	300	19200	-200
		10.40	500	700	17200	-600
	TYPICAL	0.71	500	3400	78500	-2000
		3.70	500	3600	33500	-3000
		5.40	500	2500	19200	-2000
		6.60	500	2000	22700	-1700
		10.40	500	1300	19100	-1100
	HIGH	0.71	500	19000	110500	-15400
		3.70	500	5500	42100	-4400
		5.40	500	7500	34100	-6100
		6.60	500	3100	28300	-2500
		10.40	500	3900	27800	-3200
	VERY HIGH	0.71	500	28400	175500	-23100
		3.70	500	12700	93000	-10300
		5.40	500	13100	79700	-10600
		6.60	500	7100	61300	-5800
		10.40	500	6800	55100	-5500

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*Differential costs compared to 1000 mile distance case

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE,MI	TRANSPORT COSTS,$	TOTAL COSTS,$	DIFFERENTIAL* TRANSP COSTS,$
PCONCLIQ	LOW	0.71	2000	10800	81900	5400
		3.70	2000	1600	28200	800
		5.40	2000	1000	15500	500
		6.60	2000	1100	20000	500
		10.40	2000	2500	19000	1200
	TYPICAL	0.71	2000	10800	85900	5400
		3.70	2000	12800	42700	6200
		5.40	2000	8800	25500	4300
		6.60	2000	7200	27900	3500
		10.40	2000	4600	22400	2200
	HIGH	0.71	2000	66900	158400	32600
		3.70	2000	19300	55900	9400
		5.40	2000	26400	53000	12800
		6.60	2000	10800	36000	5300
		10.40	2000	13700	37700	6700
	VERY HIGH	0.71	2000	100300	247400	48800
		3.70	2000	44900	125200	21900
		5.40	2000	46200	112800	22500
		6.60	2000	25200	79300	12300
		10.40	2000	24000	72300	11700
PCONCLIQ	LOW	0.71	3000	16200	87300	10800
		3.70	3000	2300	28900	1600
		5.40	3000	1600	16100	1000
		6.60	3000	1600	20500	1100
		10.40	3000	3700	20200	2400
	TYPICAL	0.71	3000	16200	91300	10800
		3.70	3000	19100	49000	12500
		5.40	3000	13100	29800	8600
		6.60	3000	10700	31400	7000
		10.40	3000	6800	24600	4400

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*Differential costs compared to 1000 mile distance cas

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PCONCLIQ	HIGH	0.71	3000	99400	191000	65100
		3.70	3000	28600	65300	18700
		5.40	3000	39200	65800	25700
		6.60	3000	16000	41300	10500
		10.40	3000	20400	44300	13300
	VERY HIGH	0.71	3000	149200	296300	97700
		3.70	3000	66800	147100	43700
		5.40	3000	68600	135200	44900
		6.60	3000	37400	91600	24500
		10.40	3000	35600	84000	23300
PFSLUDGE	LOW	0.56	250	3100	98000	-3900
		2.00	250	1900	43200	-3000
		4.00	250	2400	39900	-3700
	TYPICAL	0.56	250	16800	132600	-26700
		2.00	250	7100	58300	-11200
		4.00	250	3500	48000	-5600
	HIGH	0.56	250	25300	185800	-40100
		2.00	250	14100	104000	-22400
		4.00	250	8300	84200	-13100
	VERY HIGH	0.56	250	58900	507700	-93500
		2.00	250	24800	231700	-39200
		4.00	250	16500	177200	-26200
PFSLUDGE	LOW	0.56	500	4400	99300	-2600
		2.00	500	2700	44000	-2300
		4.00	500	3400	40900	-2700
	TYPICAL	0.56	500	24000	139800	-19500
		2.00	500	10100	61300	-8200
		4.00	500	5000	49500	-4100

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*Differential costs compared to 1000 mile distance case

Table B.2. (Continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	TRANSPORT DISTANCE, MI	TRANSPORT COSTS, $	TOTAL COSTS, $	DIFFERENTIAL* TRANSP COSTS, $
PFSLUDGE	HIGH	0.56	500	36100	196600	-29300
		2.00	500	20200	110100	-16400
		4.00	500	11800	87700	-9600
	VERY HIGH	0.56	500	84100	532800	-68300
		2.00	500	35300	242300	-28700
		4.00	500	23600	184200	-19100
PFSLUDGE	LOW	0.56	2000	14000	108900	7000
		2.00	2000	9700	51000	4800
		4.00	2000	11900	49400	5600
	TYPICAL	0.56	2000	84800	200600	41300
		2.00	2000	35600	86800	17300
		4.00	2000	17800	62200	8700
	HIGH	0.56	2000	127200	287700	61900
		2.00	2000	71200	161100	34700
		4.00	2000	41600	117500	20200
	VERY HIGH	0.56	2000	296800	745500	144400
		2.00	2000	124700	331600	60700
		4.00	2000	83100	243800	40400
PFSLUDGE	LOW	0.56	3000	20900	115900	14000
		2.00	3000	14500	55800	9600
		4.00	3000	17700	55200	11600
	TYPICAL	0.56	3000	126100	241900	52500
		2.00	3000	53000	104200	34700
		4.00	3000	26500	70900	17300
	HIGH	0.56	3000	189100	349600	123800
		2.00	3000	105900	195800	69300
		4.00	3000	61800	137700	40400

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*Differential costs compared to 1000 mile distance case

APPENDIX C

SITE-SPECIFIC BURIAL COSTS

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

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS,$	BARNWELL BUR COSTS,$	AVERAGE BUR COSTS,$	DIFFERENTIAL* U.S.EC - AVG	DIFFERENTIAL** BNWL - AVG
BNCTRASH	LOW to TYPICAL	0.20	99000	128600	113800	-14800	14800
		0.40	49500	64300	56900	-7400	7400
		0.60	33000	42900	37900	-4900	5000
		0.80	24800	32100	28400	-3600	3700
	HIGH	0.20	99000	141400	120200	-21200	21200
		0.40	49500	72300	60900	-11400	11400
		0.60	33000	50600	41800	-8800	8800
		0.80	24800	39700	32200	-7400	7500
	VERY HIGH	0.20	140600	196800	168700	-28100	28100
		0.40	70300	110600	90400	-20100	20200
		0.60	46900	136300	91600	-44700	44700
		0.80	35100	108300	71700	-36600	36600
BCOTRASH	LOW TO TYPICAL	2.27	8700	11300	10000	-1300	1300
		3.78	5200	6800	6000	-800	800
		5.67	3500	4500	4000	-500	500
		8.69	2300	3000	2600	-300	400
		113.40	200	500	300	-100	200
	HIGH	2.27	9400	12500	11000	-1600	1500
		3.78	5700	7500	6600	-900	900
		5.67	3800	5100	4400	-600	700
		8.69	2500	3500	3000	-500	500
		113.40	300	800	500	-200	300
	VERY HIGH	2.27	13700	17300	15500	-1800	1800
		3.78	8200	11700	10000	-1800	1700
		5.67	5900	9400	7600	-1700	1800
		8.69	3800	6200	5000	-1200	1200
		113.40	600	1600	1100	-500	500

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

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

Table C.1. (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS,$	BARNWELL BUR COSTS,$	AVERAGE BUR COSTS,$	DIFFERENTIAL* U.S.EC - AVG	DIFFERENTIAL** BNWL - AVG
BIXRESIN	LOW	0.71	30100	45200	37700	-7600	7500
		0.95	22500	33200	27900	-5400	5300
		1.40	18300	28100	23200	-4900	4900
		2.00	14100	22100	18100	-4000	4000
		4.00	7000	11100	9000	-2000	2100
	TYPICAL	0.71	46800	75400	61100	-14300	14300
		0.95	35000	64000	49500	-14500	14500
		1.40	27100	53900	40500	-13400	13400
		2.00	23500	37700	30600	-7100	7100
		4.00	13300	31300	22300	-9000	9000
	HIGH	0.71	88400	203800	146100	-57700	57700
		0.95	106800	192300	149600	-42800	42700
		1.40	90300	150700	120500	-30200	30200
		2.00	66400	156200	111300	-44900	44900
		4.00	38800	113900	76400	-37600	37500
	VERY HIGH	0.71	219700	786200	502900	-283200	283300
		0.95	164900	695400	430100	-265200	265300
		1.40	112900	471900	292400	-179500	179500
		2.00	90700	436100	263400	-172700	172700
		4.00	46900	286300	166600	-119700	119700
BCONCLIQ	LOW	0.71	30100	44500	37300	-7200	7200
		1.90	14800	23300	19000	-4200	4300
		2.40	11700	18400	15100	-3400	3300
		3.80	7400	11600	9500	-2100	2100
		4.50	6900	9800	8400	-1500	1400
	TYPICAL	0.71	46800	75400	61100	-14300	14300
		1.90	24700	39700	32200	-7500	7500
		2.40	19600	31400	25500	-5900	5900
		3.80	14000	32900	23500	-9500	9400
		4.50	13900	27800	20900	-7000	6900
	HIGH	0.71	88400	203800	146100	-57700	57700
		1.90	69800	127300	98600	-28800	28700
		2.40	55400	130200	92800	-37400	37400
		3.80	40800	119900	80400	-39600	39500
		4.50	34500	101300	67900	-33400	33400

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*U.S. Ecology site burial costs minus average burial costs.
**Barnwell, SC site burial costs minus average burial costs.

Table C.1. (continued

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS,$	BARNWELL BUR COSTS,$	AVERAGE BUR COSTS,$	DIFFERENTIAL* U.S.EC - AVG	DIFFERENTIAL** BNWL - AVG
	VERY HIGH	0.71	219500	786200	502900	-283400	283300
		1.90	95200	459100	277200	-182000	181900
		2.40	76000	363400	219700	-143700	143700
		3.80	49100	301400	175200	-126100	126200
		4.50	41900	254500	148200	-106300	106300
BFSLUDGE	LOW	0.56	38200	57000	47600	-9400	9400
		2.00	14100	22100	18100	-4000	4000
		4.00	8300	13400	10800	-2500	2600
	TYPICAL	0.56	59300	95500	77400	-18100	18100
		2.00	23500	37700	30600	-7100	7100
		4.00	15700	31300	23500	-7800	7800
	HIGH	0.56	112000	258400	185200	-73200	73200
		2.00	66500	156200	111300	-44800	44900
		4.00	38900	139500	89200	-50300	50300
	VERY HIGH	0.56	278600	996800	637700	-359100	359100
		2.00	91700	572600	332200	-240500	240400
		4.00	47800	286300	167100	-119300	119200

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*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

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS,$	BARNWELL BUR COSTS,$	AVERAGE BUR COSTS,$	DIFFERENTIAL* U.S.EC - AVG	DIFFERENTIAL** BNWL - AVG
PNCTRASH	LOW TO TYPICAL	0.20	99000	128600	113800	-14800	14800
		0.40	49500	64300	56900	-7400	7400
		0.60	33000	42900	37900	-4900	5000
		0.80	24800	32100	28400	-3600	3700
	HIGH	0.20	107000	144800	125900	-18900	18900
		0.40	53500	79300	66400	-12900	12900
		0.60	35700	57700	46700	-11000	11000
		0.80	26800	46400	36600	-9800	9800
	VERY HIGH	0.20	155600	221200	188400	-32800	32800
		0.40	83100	133800	108400	-25300	25400
		0.60	55400	163900	109700	-54300	54200
		0.80	41500	123000	82200	-40700	40800
PCOTRASH	LOW TO TYPICAL	3.78	5200	6800	6000	-800	800
		5.67	3500	4500	4000	-500	500
		8.69	2300	3000	2600	-300	400
		113.40	200	500	300	-100	200
	HIGH	3.78	5700	7500	6600	-900	900
		5.67	3800	5400	4600	-800	800
		8.69	2500	3800	3100	-600	700
		113.40	300	860	600	-300	200
	VERY HIGH	3.78	10000	14200	12100	-2100	2100
		5.67	6700	9400	8100	-1400	1300
		8.69	4400	7000	5700	-1300	1300
		113.40	1100	2100	1600	-500	500
PIXRESIN	LOW	0.71	27900	41200	34500	-6600	6700
		0.95	22500	31600	27000	-4500	4600
		1.40	15300	23100	19200	-3900	3900
		2.00	10700	16300	13500	-2800	2800
		4.00	7000	11100	9000	-2000	2100

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

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

Table C.2. (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS,$	BARNWELL BUR COSTS,$	AVERAGE BUR COSTS,$	DIFFERENTIAL* U.S.EC - AVG	DIFFERENTIAL** BNWL - AVG
PIXRESIN	TYPICAL	0.71	39600	62300	51000	-11400	11300
		0.95	35000	56300	45600	-10600	10700
		1.40	27100	43400	35300	-8200	8100
		2.00	19000	30400	24700	-5700	5700
		4.00	11800	18900	15300	-3500	3600
	HIGH	0.71	75100	176300	125700	-50600	50600
		0.95	66100	152300	109200	-43100	43100
		1.40	72500	130500	101500	-29000	29000
		2.00	63200	105500	84300	-21100	21200
		4.00	33200	78100	55700	-22500	22400
	VERY HIGH	0.71	218500	642000	430200	-211700	211800
		0.95	163800	587600	375700	-211900	211900
		1.40	111800	398700	255200	-143400	143500
		2.00	78800	330300	204500	-125700	125800
		4.00	45700	218100	131900	-86200	86200
PCONCLIQ	LOW	0.71	27900	36200	32100	-4200	4100
		3.70	5400	7700	6500	-1100	1200
		5.40	3700	5200	4500	-800	700
		6.60	3000	4400	3700	-700	700
		10.40	2100	3100	2600	-500	500
	TYPICAL	0.71	27900	41100	34500	-6600	6600
		3.70	7600	12000	9800	-2200	2200
		5.40	5200	8200	6700	-1500	1500
		6.60	4300	6700	5500	-1200	1200
		10.40	3000	4700	3900	-900	600
	HIGH	0.71	39600	62300	51000	-11400	11300
		3.70	12700	20400	16600	-3900	3800
		5.40	9900	23200	16500	-6600	6700
		6.60	7100	12900	10000	-2900	2900
		10.40	6000	13900	10000	-4000	3900
	VERY HIGH	0.71	66200	146800	106500	-40300	40300
		3.70	35900	84400	60200	-24300	24200
		5.40	28700	84400	56500	-27800	27900
		6.60	20200	57700	38900	-18700	18800
		10.40	15000	53700	34300	-19300	19400

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

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

Table C.2. (continued)

WASTE TYPE	ACTIVITY LEVEL	VRF	U.S. ECOLOGY BUR COSTS,$	BARNWELL BUR COSTS,$	AVERAGE BUR COSTS,$	DIFFERENTIAL* U.S.EC - AVG	DIFFERENTIAL** BNWL - AVG
PFSLUDGE	LOW	0.56	35400	52200	43800	-8400	8400
		2.00	10700	15100	12900	-2200	2200
		4.00	7000	9800	8400	-1400	1400
	TYPICAL	0.56	50200	79000	64600	-14400	14400
		2.00	19000	26800	22900	-3900	3900
		4.00	11800	18900	15300	-3500	3600
	HIGH	0.56	84000	134700	109400	-25400	25300
		2.00	50700	72300	61500	-10800	10800
		4.00	33200	60500	46800	-13600	13700
	VERY HIGH	0.56	237200	557900	397600	-160400	160300
		2.00	78100	279100	178600	-100500	100500
		4.00	45100	218100	131600	-86500	86500

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

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

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13. ABSTRACT (200 words or less)

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 radwastes 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 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 are explored and important sensitivities identified. Occupational radiation exposure associated with in-plant handling of the wastes is also discussed.

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