

***Fuel Cycle Research and Development  
Used Fuel Disposition***

***Low Level Waste Disposition –  
Quantity and Inventory***

***Prepared for  
U.S. Department of Energy  
Used Nuclear Fuel  
Robert H. Jones, SRS  
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## EXECUTIVE SUMMARY

This study has been prepared by the Used Fuel Disposition (UFD) campaign of the Fuel Cycle Research and Development (FCR&D) program. The purpose of this study is to provide an estimate of the volume of low level waste resulting from a variety of commercial fuel cycle alternatives in order to support subsequent system-level evaluations of disposal system performance. This study provides an estimate of Class A/B/C low level waste (LLW), greater than Class C (GTCC) waste, mixed LLW and mixed GTCC waste generated from the following initial set of fuel cycles and recycling processes:

1. Operations at a geologic repository based upon a once through light water reactor (LWR) fuel cycle
2. Aqueous recycling of LWR used nuclear fuel (UNF)
3. Electrochemical recycling of LWR used nuclear fuel

Low level waste generation for operations at a geologic repository ranges from 0.8 m<sup>3</sup>/MTHM of used fuel disposed to 3.7 m<sup>3</sup>/MTHM depending on the fraction of used fuel that is prepackaged in canisters that are suitable for direct disposal at the repository. Figure EX-1 shows the waste generation rate with respect to the fraction of used fuel that is prepackaged in directly disposable canisters. These waste generation rates are based on data prepared for the Yucca Mountain repository which assumes repository operations for 57 years and subsequent monitoring for 50 years. Additional monitoring for 200 more years would add 0.2 m<sup>3</sup>/MTHM to the values shown in Figure EX-1. Repository operations are not expected to generate GTCC waste, mixed LLW or mixed GTCC waste.

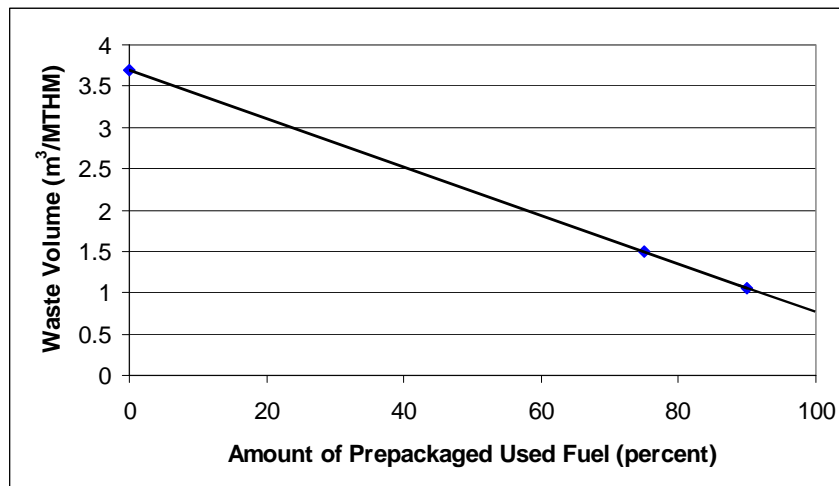


Figure EX-1  
Low Level Waste Generation Rates For Geologic Repository Operations

Waste generation rates for aqueous recycling were derived for various aqueous recycling technologies based on data from industry (AREVA and EnergySolutions), West Valley and the Engineering Alternatives Studies (EAS) for Separations. The technologies considered include co-extraction (AREVA), NUEX (EnergySolutions) and UREX+1a. The waste generation rates for aqueous recycling vary and are dependent on the recycling technology chosen and facility capacity. The waste generation rates are shown in Figures EX-2 through EX-5. Low level waste does not appear to be a significant discriminator among the recycling technologies; however, the generation rates vary significantly with respect to facility capacity. GTCC waste varies significantly with respect to both recycling technology and facility capacity, although the waste volumes are significantly smaller than those for LLW, especially at higher facility capacities. The data for mixed LLW and mixed GTCC waste is limited; however, the data indicates that mixed LLW is not a discriminator among recycling technologies but varies significantly with respect to facility capacity. Mixed GTCC waste does not appear to be a discriminator with respect to facility capacity but is with respect to recycling technology.

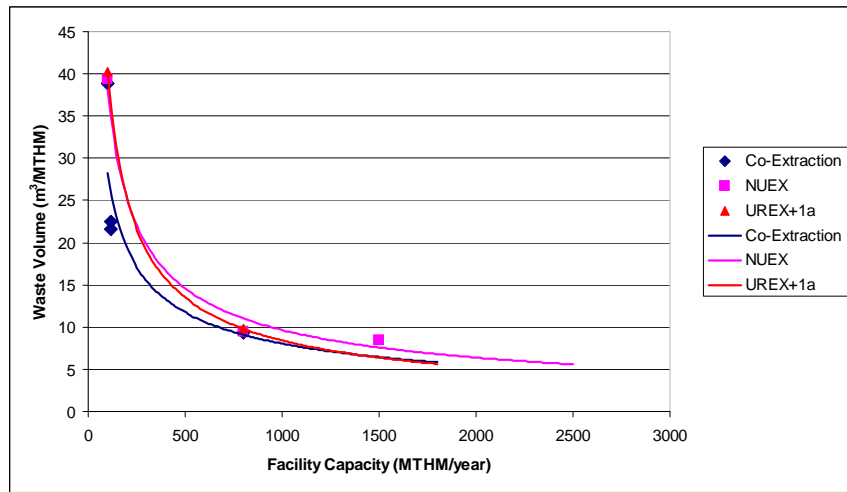


Figure EX-2  
Low Level Waste Volume For Aqueous Recycling



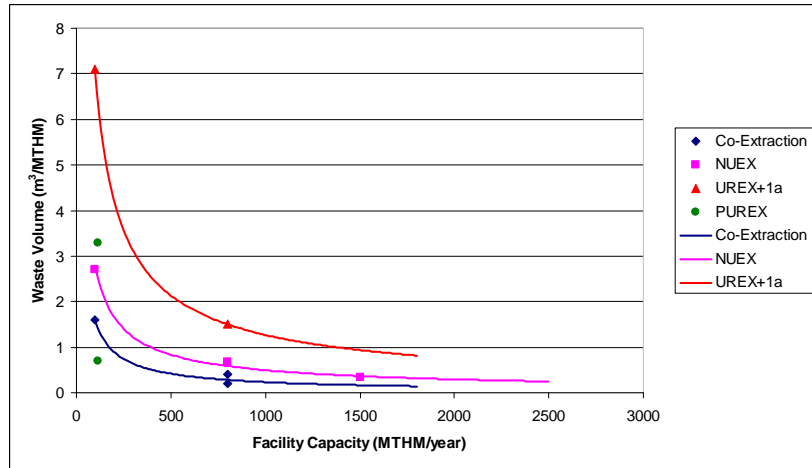


Figure EX-3  
 GTCC Waste Volume For Aqueous Recycling

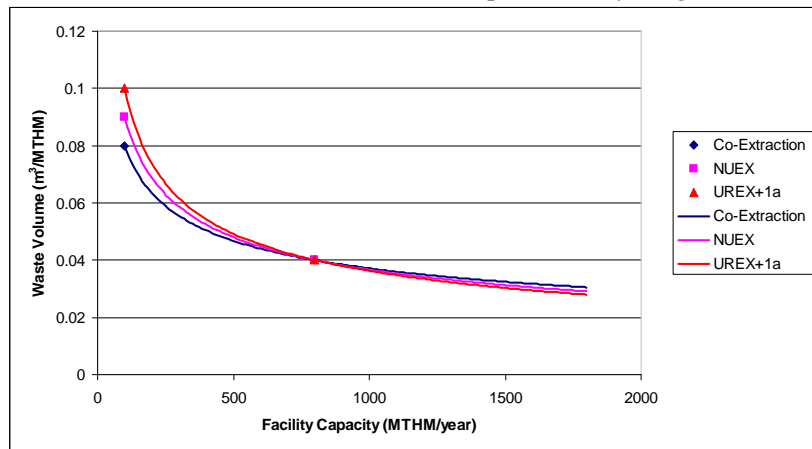


Figure EX-4  
 Mixed Low Level Waste Volume For Aqueous Recycling

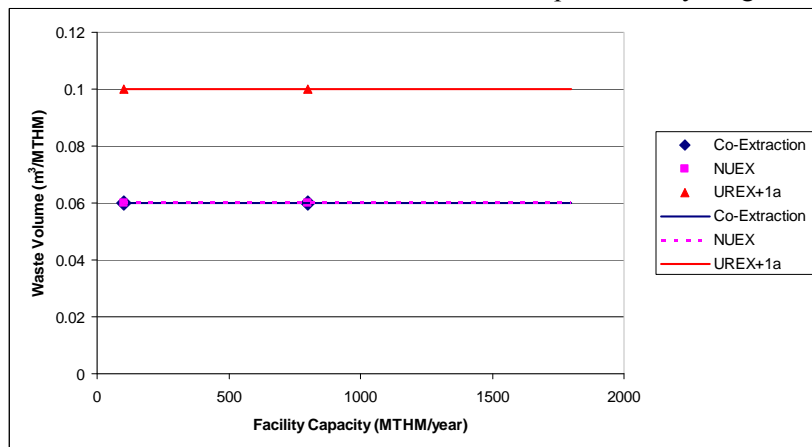


Figure EX-5  
 Mixed GTCC For Aqueous Recycling

Only one data source was used to estimate waste generation rates for electrochemical recycling. Waste generation rates likely vary with facility capacity similar to aqueous recycling; however the lack of data did not allow the generation of rate curves for electrochemical recycling as for aqueous recycling. For a 300 MTHM/year electrochemical recycling facility, low level waste is expected to be generated at the rate of 8.7 m<sup>3</sup>/MTHM of used fuel recycled. GTCC waste is expected to be generated at the rate of 3.1 m<sup>3</sup>/MTHM, mixed LLW at 0.1 m<sup>3</sup>/MTHM and mixed GTCC at 0.15 m<sup>3</sup>/MTHM.

Potential nuclear energy growth scenarios have been described in other documents. Although it is not the intent of this report to estimate the waste generated from every possible combination of nuclear energy growth, recycling facility capacity and recycling technology, Table EX-1 shows the amount of LLW generated from several recycling methods based on an assumption that the amount of current nuclear generation is maintained at the current levels (100 GWe/yr) with new reactors replacing the existing reactors as the existing reactors are decommissioned. Approximately 2,300 MTHM of used fuel is generated annually (rounded up to 2,400 to simplify the calculation) from this energy growth scenario. A comparison to the current average disposal rates for Class A LLW is also provided in Table EX-1.

Recycling Method	Number of Plants	Recycling Facility Capacity (MTHM/year)	Estimated Total LLW Generated from Recycling (m <sup>3</sup> /year)	Percentage of Annual Total LLW Generated <sup>1</sup>	Percentage of Annual Nuclear LLW Generated <sup>2</sup>
Co-extraction	2	1,200	16,800	25.2 %	32.3 %
	3	800	21,600	32.4 %	41.5 %
Electrochemical	8	300	20,880	31.3 %	40.2 %

1. Based on Class A LLW from all sources, nuclear and non-nuclear.
2. Based on Class A LLW from nuclear industrial and utility sources.

Table EX-2 compares the LLW resulting from the disposal of the same amount of used fuel at a geologic repository to the current rate of Class A LLW disposal.

Percentage of Used Fuel Pre-Packaged in Disposable Canisters	Monitoring Period (years)	LLW Generation Rate (m <sup>3</sup> /year)	Estimated Total LLW Generated from Geologic Disposal (m <sup>3</sup> /year)	Percentage of Annual Total LLW Generated <sup>1</sup>	Percentage of Annual Nuclear LLW Generated <sup>2</sup>
0	50	3.7	8,880	13.3 %	17.1 %
	250	3.9	9,360	14.0 %	18.0 %
75	50	1.5	3,600	5.4 %	6.9 %
	250	1.7	4,080	6.1 %	7.8 %

1. Based on Class A LLW from all sources, nuclear and non-nuclear.
2. Based on Class A LLW from nuclear industrial and utility sources.

## 1.0 INTRODUCTION

This study has been prepared by the Used Fuel Disposition (UFD) campaign of the Fuel Cycle Research and Development (FCR&D) program. The purpose of this study is to provide an estimate of the volume of low level waste resulting from a variety of commercial fuel cycle alternatives in order to support subsequent system-level evaluations of disposal system performance. This study provides an estimate of Class A/B/C low level waste (LLW), greater than Class C (GTCC) waste, mixed LLW and mixed GTCC waste generated from the following initial set of fuel cycles and recycling processes:

1. Operations at a geologic repository based upon a once through light water reactor (LWR) fuel cycle
2. Aqueous recycling of LWR used nuclear fuel (UNF)
3. Electrochemical recycling of LWR used nuclear fuel

The aqueous recycling fuel cycles evaluated in this initial study are those that are currently proposed by industry teams such as the co-extraction process (AREVA) or the NUEX process (EnergySolutions) or close variants such as the UREX+1a process. Additional alternative fuel cycles to be evaluated will be identified by the FCR&D options study. Once these additional fuel cycle alternatives are defined waste generation estimates will be completed for these alternatives in a follow-on study.

This study only addresses the waste associated with disposal of used nuclear fuel resulting from nuclear power plant operations. Waste associated with other components of nuclear fuel cycles, including mining, enrichment, fuel fabrication, and nuclear power plant operations are not within the scope of this study. This study provides a basis for estimating the volume of low level, GTCC, mixed low level and mixed GTCC wastes from future fuel cycles involving these processes. The estimates provided for aqueous recycling cover a range of recycling facility capacities that enable subsequent evaluations of recycling strategies, e.g. numerous small capacity facilities versus a few larger capacity facilities. To the extent possible, waste generation estimates are subdivided according to the existing waste classification system as defined in Title 10, Code of Federal Regulations (CFR), Part 61, *Licensing Requirements for Land Disposal of Radioactive Waste* (10CFR61).

Note: The term "co-extraction" is used in this report to describe a process generating a U/Pu product with all (non-gaseous) fission product wastes combined in a single vitrified waste form. The specific name given to the process proposed by AREVA, the COEX™ process, is a name applied to a variety of nuclear related products and processes.

## 2.0 WASTE ESTIMATES

### 2.1 Once-Through Fuel Cycle

Low level wastes associated with the once-through fuel cycle are those generated by the handling and emplacement activities involved in the disposal of used nuclear fuel at a geologic repository. Low level waste estimates for repository operations are provided in the *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (hereinafter referred to as the Draft Supplemental EIS).<sup>1</sup> These waste estimates are based on the disposal of 11,000 waste packages in the proposed Yucca Mountain repository containing no more than a total of 70,000 metric tons of heavy metal (MTHM) of used nuclear fuel and high level waste. The inventory of used nuclear fuel for the proposed repository consists of approximately:

- 63,000 MTHM of commercial used nuclear fuel from boiling-water and pressurized-water reactors, which includes commercial high level radioactive waste from the West Valley Demonstration Project,
- 2,333 MTHM of DOE used nuclear fuel, which includes about 65 MTHM of naval used nuclear fuel, and
- 4,667 MTHM of DOE high level radioactive waste.

Estimated low level waste volumes generated by repository operations are shown in Table 2.1-1 below.

Source	Waste Volume (m <sup>3</sup> )
Solidified low level liquid waste <sup>1</sup>	25,000
Dual-purpose canisters	9,800
Other operational and maintenance activities	39,200
Total (m <sup>3</sup> )	74,000
Total (m <sup>3</sup> /MTHM) <sup>2</sup>	1.06

1. The volume of solidified low level liquid waste is based on the use of a solidification agent such as WaterWorks Crystals resulting in a volume increase of approximately 57%.
2.  $74,000 \text{ m}^3 \div 70,000 \text{ MTHM} = 1.06 \text{ m}^3/\text{MTHM}$

The low level waste estimates assume that most of the used nuclear fuel and high level waste (90%) is received in disposable canisters that will not require opening at the repository but will be placed directly into a waste package for disposal in the repository. The estimate assumes the remaining 10% of the used fuel will arrive in dual purpose canisters that will require opening and repackaging of the fuel assemblies and disposal of the dual purpose canisters. All DOE used nuclear fuel, naval used nuclear fuel and high level radioactive waste will be received in disposable canisters.

The estimates are also based on 57 years of emplacement operations and 50 years of monitoring activities. The estimates do not include activities associated with closing the repository. Low level wastes from repository operations include solids and solidified liquids from the following sources:

- cask, facility and equipment decontamination activities
- pool system skimming and filtration operations
- used dual purpose canisters
- tooling and clothing
- facility ventilation filtration
- chemical sumps
- carrier and transporter washings

The Draft Supplemental EIS considers all of the low level waste generated to be Class A, B or C; however, a decomposition by waste class is not provided. GTCC waste, mixed LLW and mixed GTCC waste are not anticipated to be generated by repository operations.

Appendix A, Section A.2 of the Draft Supplemental EIS provides a sensitivity analysis that evaluates the impacts of receiving only 75% of commercial used fuel (47,250 MTHM) in disposable canisters (as compared to 90% or 56,700 MTHM). To accommodate the additional used fuel that would require repackaging at the repository, the analysis considers the construction and operation of an additional Wet Handling Facility and the elimination of one of three Canister Receipt and Closure Facilities. Operation of the additional Wet Handling Facility results in an additional 580 m<sup>3</sup>/year of low level waste. Elimination of one Canister Receipt and Closure Facility avoids the generation of 76 m<sup>3</sup>/year of low level waste. The net increase in low level waste volume is 504 m<sup>3</sup>/year or approximately 29,000 m<sup>3</sup> over the 57 year emplacement period; therefore, the total low level waste volume becomes 103,000 m<sup>3</sup> (74,000 + 29,000 = 103,000). This equates to 1.5 m<sup>3</sup> of low level waste per MTHM emplaced.

Neither of these scenarios captures 100% of the low level waste associated with packaging used fuel for disposal since the Draft Supplemental EIS assumes 90% (75% in the sensitivity analysis) of the used fuel is prepackaged in disposable canisters at the commercial reactor sites. Assuming five additional Wet Handling Facilities would be needed to repackage the remaining 75% of the fuel not considered in the sensitivity analysis and that the remaining two Canister Receipt and Closure Facilities can be eliminated, the incremental increase in low level waste volume to package 100% of the used fuel for disposal is 2,748 m<sup>3</sup> [(580 x 5) - (76 x 2) = 2,748] or approximately 157,000 m<sup>3</sup> over the 57 year emplacement period. The total low level waste volume then becomes 260,000 m<sup>3</sup> (103,000 + 157,000 = 260,000) or 3.7 m<sup>3</sup> of low level waste per MTHM emplaced.

The waste generated from handling and emplacement activities should comprise the largest percentage of low level waste generated at any large scale geologic repository. Waste generation rates should, therefore, be proportional to the amount of used fuel disposed. The normalized waste generation rate of 1.06 m<sup>3</sup>/MTHM should be valid across a wide range of disposal scenarios provided that one assumes most of the fuel is received in a canister that does not require repackaging and disposal of the internal shipping container. If most of the fuel is received in canisters that require repackaging and subsequent disposal of the original canister, the waste generation rate would be higher, up to 3.7 m<sup>3</sup>/MTHM.

Figure 2.1-1 shows the low level waste generation rate as a function of the prepackaging fraction. The data has been extrapolated to indicate a waste generation rate of 0.8 m<sup>3</sup>/MTHM at a 100% prepackaging level.

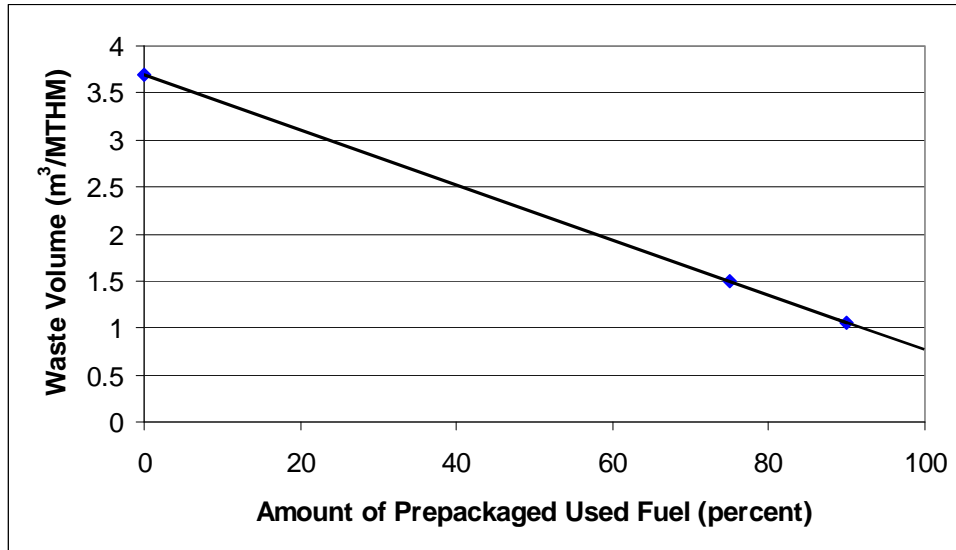


Figure 2.1-1  
Low Level Waste Volume

The Draft Supplemental EIS also considered the impacts of an extended monitoring period after the emplacement of the last waste package, i.e. 250 years versus 50 years. According to the Draft Supplemental EIS, Appendix A, Section A.5.1.7, the extended monitoring period would add an additional 13,000 m<sup>3</sup> (or 0.2 m<sup>3</sup>/MTHM) of low level waste to the totals for each of the scenarios described above and shown in Figure 2.1-1.

## 2.2 Aqueous Recycling

### 2.2.1 Waste Estimates

Estimates of the volume of low level waste resulting from a variety of recycling processes is available from several sources and used in the preparation of this study. Two industry teams, AREVA and EnergySolutions, have proposed aqueous recycling facilities for construction in the United States and published waste generation estimates for these facilities. AREVA proposes the use of a co-extraction process (COEX<sup>®</sup>) as depicted in Figure 2.2-1. EnergySolutions proposes the use of their NUEX process depicted in Figure 2.2-2. Historical data is available from West Valley which operated from 1966 to 1971 using the PUREX process. An advanced separation process, UREX+1a, as shown in Figure 2.2-3 is also considered in this initial study.

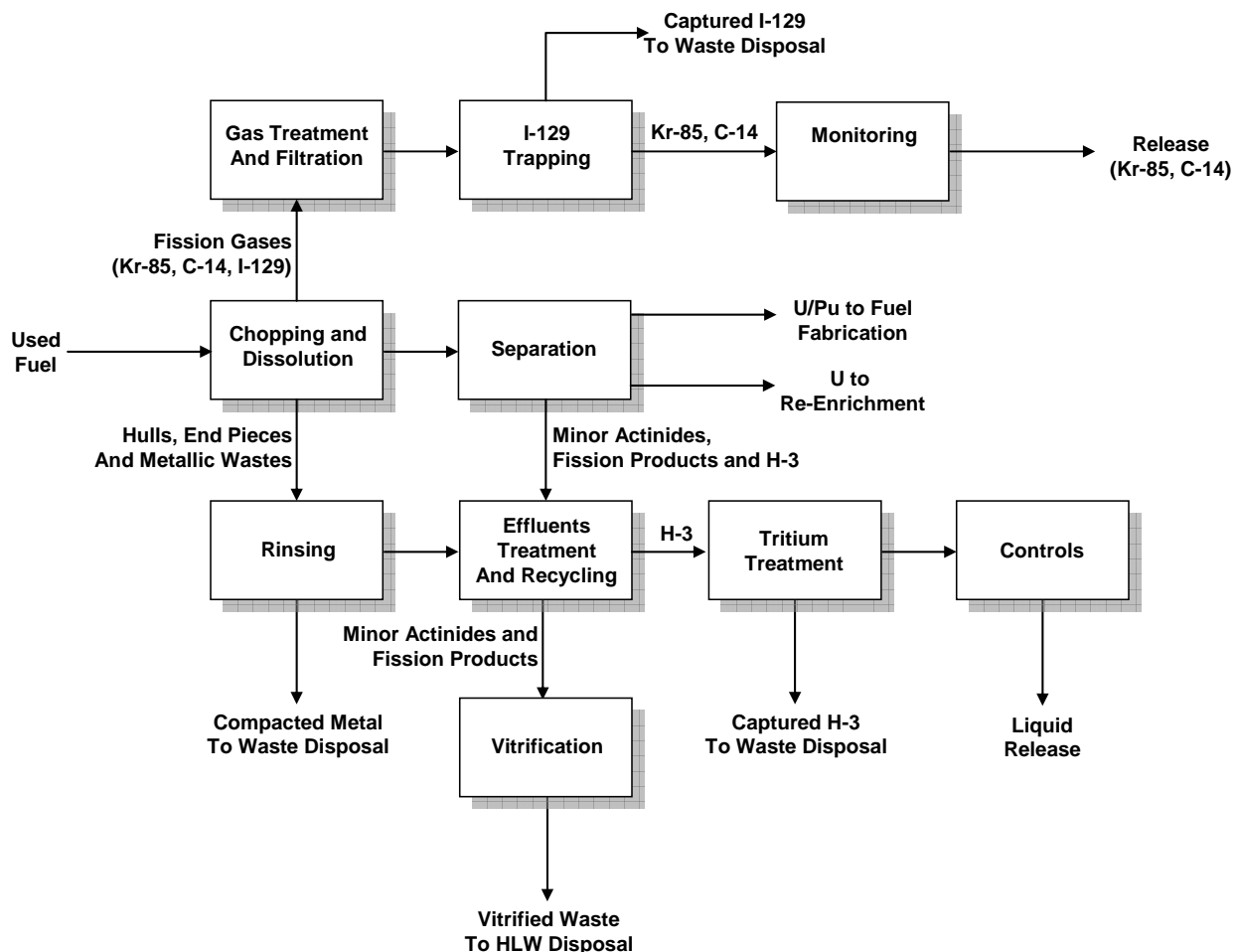


Figure 2.2-1  
 AREVA COEX<sup>®</sup> Recycling Process

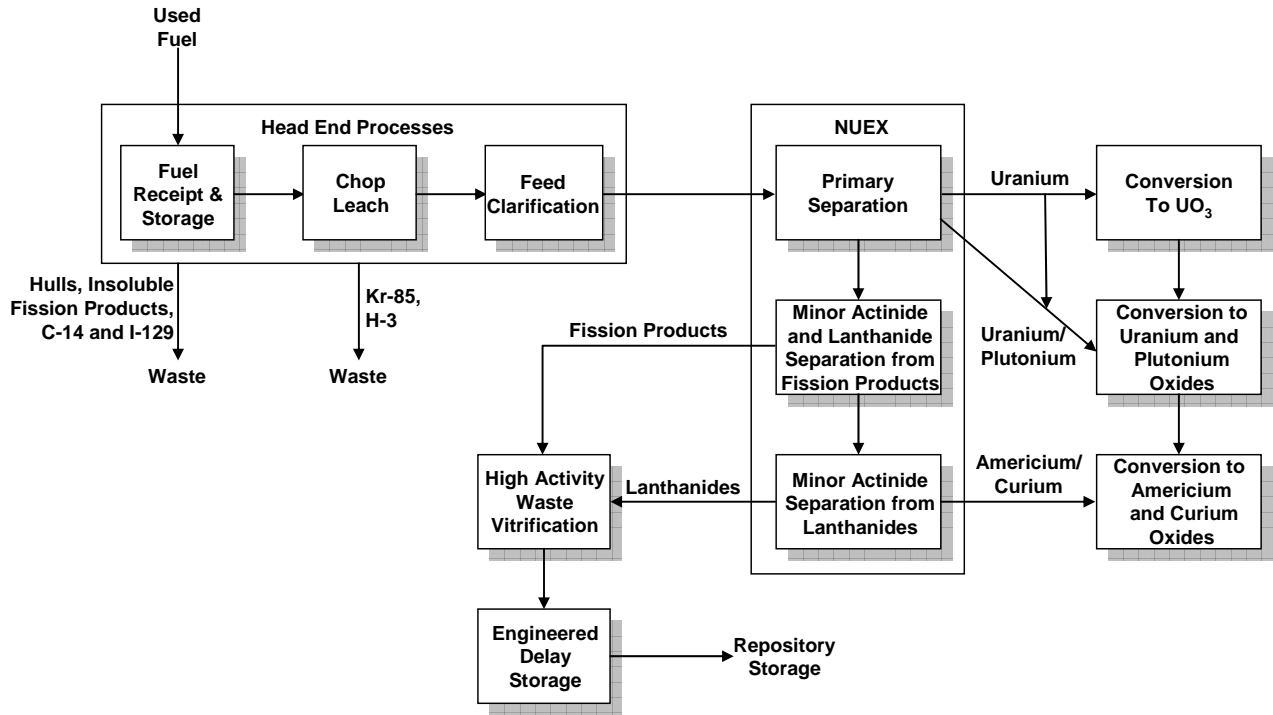


Figure 2.2-2  
EnergySolutions NUEX Recycling Process



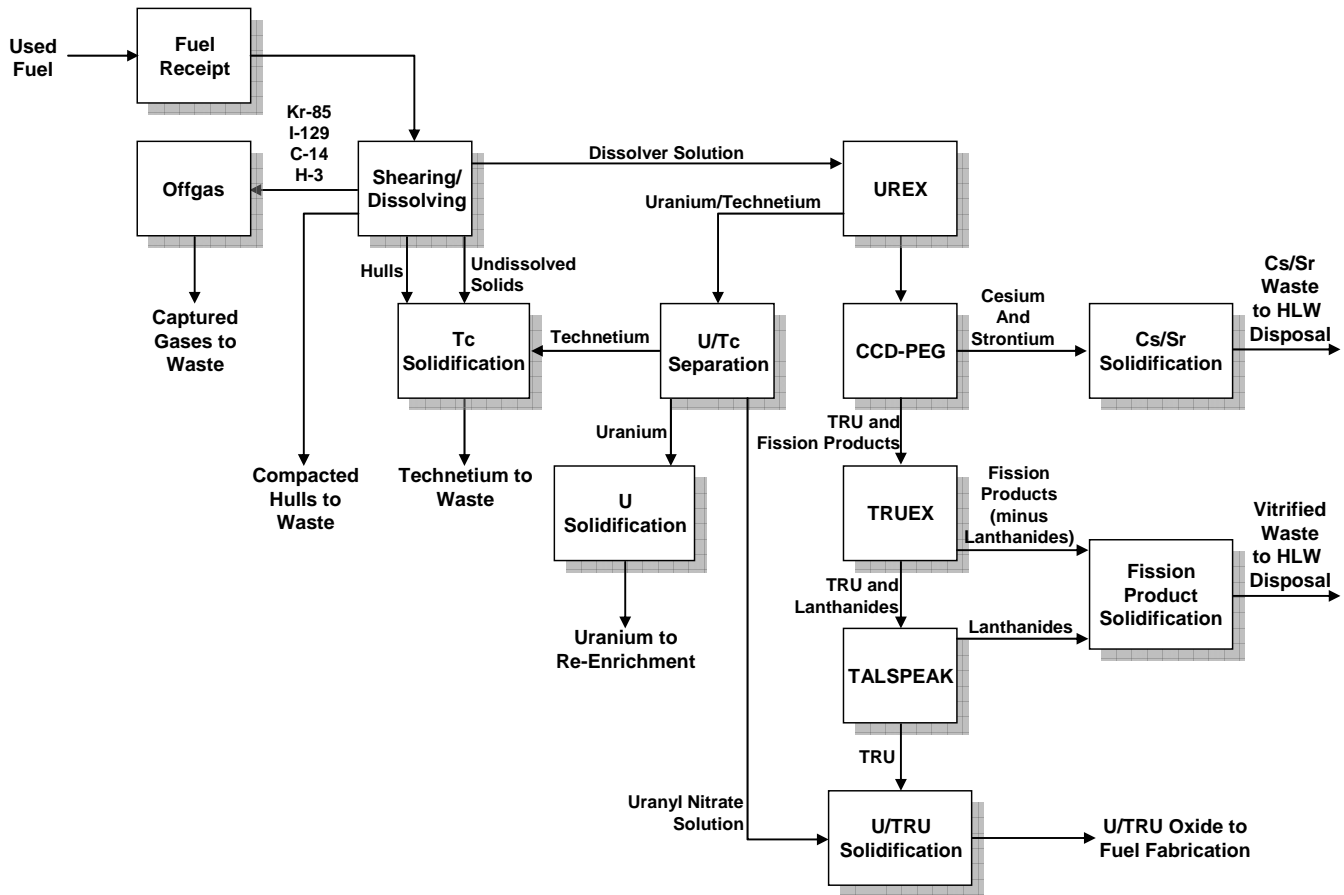


Figure 2.2-3  
 UREX+1a Recycling Process

Waste estimates from AREVA and EnergySolutions are provided in publicly available documents such as the presentations made to the Nuclear Waste Technical Review Board (NWTRB) on September 23, 2009.<sup>3,4</sup> The waste estimates provided by AREVA and EnergySolutions in these documents are based on experience from their respective operating facilities. The AREVA data derived from these documents for a proposed 800 MTHM/year facility is provided in Appendix A. The EnergySolutions data for a 1,500 MTHM/year facility is provided in Appendix B. West Valley provided actual waste generation volumes for recycling and vitrification operations associated with reprocessing 640 MTHM of fuel over a 5½ year period. The West Valley data is provided in Appendix C.

The Engineering Alternatives Studies (EAS) for Separations provided a forecast of waste generated from a recycling facility utilizing the UREX+1a process at capacities of 800 MTHM/year and 100 MTHM/year.<sup>5</sup> Waste estimates for the 800 MTHM/year facility were prepared based on estimated annual waste quantities from each of the major process functions of the UREX+1a process (see Appendix D for a list of the major process functions comprising the UREX+1a process). For the 100 MTHM/year facility, the waste volumes from the 800 MTHM/year case are adjusted by factors based on parameters such as capacity, staffing levels, quantity of radiological workers and facility footprint (see Appendix D). A summary of the data contained in Reference 5 is provided in Appendix D. Reference 5 should be consulted for additional detail not provided in Appendix D.

The method used to develop the EAS waste estimates allows manipulation of the data to estimate waste from other process variants by the elimination (or duplication) of appropriate process functions (e.g. CCD/PEG). The EAS data is used in this manner to estimate waste from a co-extraction process, a “NUEX” process and a West Valley process (PUREX) for comparison to the industry data for these processes. Validation of the EAS data with the industry provided data will provide greater confidence in using the EAS data to estimate waste volumes from other processes or facility capacities. The EAS based co-extraction and NUEX waste estimates and the EAS UREX+1a process functions used to derive the waste estimates are provided in Appendix E (co-extraction) and Appendix F (NUEX).

Other facilities considered but not included in the data compilation in this report include:

- the F and H Canyons at the Savannah River Site
- the PUREX Plant at the Hanford Site
- the Chem Plant at the Idaho National Laboratory
- foreign reprocessing facilities such as La Hague, THORP and Rokkasho

The F and H Canyons, the PUREX Plant and the Chem Plant were not considered since they did not represent a complete recycling facility comparable to the other data sources considered in this report. For instance, none of the facilities listed above include vitrification of high level waste; therefore, the wastes associated with operation of those processes is not available. Operating experience from the F and H Canyons was used, however, by the EAS program during the development of the EAS waste estimates. The foreign facilities were not considered because the waste generation estimates provided by AREVA and EnergySolutions are based on operating experience at their foreign facilities but converted from the European waste classification system to those based on 10CFR61.

Table 2.2-1 provides a summary of the waste estimates provided in Appendices A through F. Waste volume estimates are provided in terms of total annual waste generation (m<sup>3</sup>/year) and a normalized value expressed as waste per metric ton of heavy metal (MTHM) processed. Table 2.2-2 shows the percentage that each waste stream contributes to the total waste volume (LLW + GTCC + Mixed LLW + Mixed GTCC). Also shown, where data is available, is the percentage of sub-categories of waste relative to the waste category (e.g. Class A relative to total LLW). As can be seen from the table, in all cases LLW is by far the largest fraction of waste produced.

Data Source <sup>1</sup>	Estimate Basis (MTHM/yr)	Volume	Low Level Waste				GTCC Waste			Mixed LLW	Mixed GTCC
			Class			Total	CH-TRU	RH-TRU + GTCC	Total		
			A	B	C						
AREVA	800	m <sup>3</sup> /year				1,228			148		
		m <sup>3</sup> /MTHM				1.5			0.2		
Energy Solutions	1,500	m <sup>3</sup> /year	12,600		113	12,713	130	371	501		
		m <sup>3</sup> /MTHM	8.4		0.08	8.5	0.09	0.25	0.33		
West Valley	115	m <sup>3</sup> /year	2,420	9	83	2,511			384.0		
		m <sup>3</sup> /MTHM	20.8	0.1	0.7	21.6			3.3		
EAS UREX+1a	800	m <sup>3</sup> /year				7,801			1,229	32	76.9
		m <sup>3</sup> /MTHM				9.8			1.5	0.04	0.1
	100	m <sup>3</sup> /year				4,026			705	9.6	9.7
		m <sup>3</sup> /MTHM				40.3			7.1	0.1	0.1
EAS Co-Extraction	800	m <sup>3</sup> /year				7,479			323	28.6	44.8
		m <sup>3</sup> /MTHM				9.3			0.40	0.04	0.06
	100	m <sup>3</sup> /year				3,884			159	8.4	5.6
		m <sup>3</sup> /MTHM				38.8			1.6	0.08	0.06
EAS "NUEX"	800	m <sup>3</sup> /year				7,590			539	29.8	44.8
		m <sup>3</sup> /MTHM				9.5			0.67	0.04	0.06
	100	m <sup>3</sup> /year				3,935			268	8.8	5.6
		m <sup>3</sup> /MTHM				39.4			2.7	0.09	0.06
EAS West Valley	115	m <sup>3</sup> /year				2,590			83		
		m <sup>3</sup> /MTHM				22.5			0.7		

1. AREVA - Appendix A
- Energy Solutions - Appendix B
- West Valley - Appendix C
- EAS UREX+1a - Appendix D
- EAS Co-Extraction - Appendix E
- EAS "NUEX" - Appendix F
- EAS West Valley - Appendix C

Data Source	Estimate Basis (MTHM/yr)	Volume	Low Level Waste				GTCC Waste			Mixed LLW	Mixed GTCC
			Class			Total	CH-TRU	RH-TRU + GTCC	Total		
			A	B	C						
AREVA	800	m <sup>3</sup> /year				1,228			148		
		% of total				89.2			10.8		
Energy Solutions	1,500	m <sup>3</sup> /year	12,600		113	12,713	130	371	501		
		% of category	99.1		0.9		25.9	74.1			
		% of total	95.4		0.9	96.2	1.0	2.8	3.8		
West Valley	115	m <sup>3</sup> /year	2,420	9	83	2,511			384.0		
		% of category	96.3	0.4	3.3						
		% of total	83.6	0.3	2.9	86.7			13.3		
EAS UREX+1a	800	m <sup>3</sup> /year				7,801			1,229	32	76.9
		% of total				85.4			13.4	0.4	0.8
	100	m <sup>3</sup> /year				4,026			705	9.6	9.7
		% of total				84.8			14.8	0.2	0.2
EAS Co-Extraction	800	m <sup>3</sup> /year				7,479			323	28.6	44.8
		% of total				95.0			4.1	0.4	0.6
	100	m <sup>3</sup> /year				3,884			159	8.4	5.6
		% of total				95.7			3.9	0.2	0.1
EAS "NUEX"	800	m <sup>3</sup> /year				7,590			539	29.8	44.8
		% of total				92.5			6.6	0.4	0.5
	100	m <sup>3</sup> /year				3,935			268	8.8	5.6
		% of total				93.3			6.4	0.2	0.1
EAS West Valley	115	m <sup>3</sup> /year				2,590			83		
		% of total				96.9			3.1		

1. Percentages are rounded to the nearest decimal place and may not sum to the totals indicated or to 100%.

## 2.2.2 Aqueous Recycling Estimate Observations

The estimates reveal that all aqueous recycling will generate LLW (Class A/B/C) and GTCC waste with most of the waste being Class A/B/C LLW. Based upon the Energy Solutions and West Valley data, most of the low-level waste volume will be Class A waste. It appears that as plant capacity increases, there is not a corresponding increase in the amount of waste generated. In fact the amount of waste generated per MTHM of used fuel recycled decreases to some point.

The range of Class A/B/C LLW estimated for a 100 MTHM plant is 21.6 m<sup>3</sup> to 40.3 m<sup>3</sup> per MTHM of used fuel recycled. For an 800-1500 MTHM plant capacity, the Class A/B/C LLW generation estimate range is 1.5 m<sup>3</sup> to 9.8 m<sup>3</sup> (~7-48 55 gallon drums) per MTHM of material processed. Without the AREVA estimate, the LLW generation is 8.5 m<sup>3</sup> to 9.8 m<sup>3</sup> (~42 – 48 55 gallon drums) per MTHM of material processed.

Other direct and simplistic observations regarding the data summarized in Tables 2.2-1 and 2.2-2 above can be made. These include the following:

1. AREVA waste estimates compared to the EAS Co-Extraction waste estimates:
  - LLW volume estimates for the EAS Co-Extraction facility are approximately 6.1 times greater than the AREVA estimates ( $7,479 \div 1,228 = 6.1$ ).
  - GTCC waste volume estimates for the EAS Co-Extraction facility are in closer agreement with the AREVA estimates but still approximately 2.2 times greater than the AREVA estimates ( $323 \div 148 = 2.2$ ).
  - The ratio of LLW volume to GTCC waste volume for the EAS Co-Extraction facility is approximately 23.2 ( $7,479 \div 323 = 23.2$ ) and approximately 8.3 for the AREVA facility ( $1,228 \div 148 = 8.3$ ), the disparity driven primarily by the difference in LLW volumes.
  - Total waste volume estimates (LLW + GTCC) for the EAS Co-Extraction facility are approximately 5.7 times greater than the AREVA estimates [ $(7,479 + 323) \div (1,228 + 148) = 5.7$ ], the disparity driven primarily by the difference in LLW volumes.
2. EnergySolutions waste estimates compared to the EAS NUEX waste estimates:
  - LLW volume estimates for the EAS NUEX facility are in very close agreement with the EnergySolutions estimates, approximately 1.1 times greater than the EnergySolutions estimates [ $(7,590 \div 800) \div (12,713 \div 1,500) = 1.1$ ].
  - GTCC waste volume estimates for the EAS NUEX facility are approximately 2.0 times greater than the EnergySolutions estimates [ $(539 \div 800) \div (501 \div 1,500) = 2.0$ ].
  - The ratio of LLW volume to GTCC waste volume for the EAS NUEX facility is approximately 14.1 ( $7,590 \div 539 = 14.1$ ) and approximately 25.4 for the EnergySolutions facility ( $12,713 \div 501 = 25.4$ ), the disparity driven primarily by the difference in GTCC waste volumes.
  - Total waste volume estimates (LLW + GTCC) for the EAS NUEX facility are in close agreement with the EnergySolutions estimates, approximately 1.2 times greater than the EnergySolutions estimates [ $((7,590 + 539) \div 800) \div ((12,713 + 501) \div 1,500) = 1.2$ ].
  - Note that the above calculations are based on the “per MTHM” waste volumes since the EAS and the EnergySolutions waste estimates have a different facility capacity basis.
3. EAS UREX+1a and EAS NUEX processes compared to the EAS Co-Extraction process:
  - LLW volume varies little, approximately 4.3% for UREX+1a vs. Co-Extraction [ $((7,801 - 7,479) \div 7,479) \times 100 = 4.3$ ] and approximately 1.5% for NUEX vs. Co-Extraction [ $((7,590 - 7,479) \div 7,479) \times 100 = 1.5$ ].
  - GTCC waste volume varies significantly, approximately 280% for UREX+1a vs. Co-Extraction [ $((1,229 - 323) \div 323) \times 100 = 280$ ] and approximately 67% for NUEX vs. Co-Extraction [ $((539 - 323) \div 323) \times 100 = 67$ ]. The differences lie primarily in the amount of job control waste associated with process functions that require handling and processing transuranic or other GTCC significant radioisotopes (e.g. Tc Solidification, TALSPEAK, etc.).
  - Mixed LLW volume varies little, approximately 12% for UREX+1a vs. Co-Extraction [ $((32 - 28.6) \div 28.6) \times 100 = 12$ ] and approximately 3.6% for NUEX vs. Co-Extraction [ $((29.8 - 28.6) \div 28.6) \times 100 = 3.6$ ].

- Mixed GTCC waste volume varies significantly for UREX+1a vs. Co-Extraction, approximately 72% [ $((76.9 - 44.8) \div 44.8) \times 100 = 72$ ] but none for NUEX vs. Co-Extraction [ $((44.8 - 44.8) \div 44.8) \times 100 = 0$ ]. The differences are primarily associated with maintenance waste from process functions that require handling and processing GTCC significant radioisotopes (e.g. Tc Solidification and Cs/Sr Solidification).
- 4. EAS 800 MT/year cases compared to the EAS 100 MT/year cases:
  - The 8X reduction in capacity reduces LLW volume generation to only about half of the 800 MT/year levels, approximately 52% for the UREX+1a process ( $4,026 \div 7,801 \times 100 = 52\%$ ), approximately 52% for the Co-Extraction process ( $3,884 \div 7,479 \times 100 = 52\%$ ) and approximately 52% for the “NUEX” process ( $3,935 \div 7,590 \times 100 = 52\%$ ). LLW generation is not driven by primary process wastes but by job control and maintenance waste. Because job control waste and maintenance waste are heavily influenced by parameters such as staffing levels and facility size and because these parameters do not vary linearly with capacity, LLW generation is not linear with capacity.
  - The 8X reduction in capacity reduces GTCC waste volume generation to only about half of the 800 MT/year levels, approximately 57% for the UREX+1a process ( $705 \div 1,229 \times 100 = 57\%$ ), approximately 49% for the Co-Extraction process ( $159 \div 323 \times 100 = 49\%$ ) and approximately 50% for the “NUEX” process ( $268 \div 539 \times 100 = 50\%$ ). GTCC waste generation is not driven by primary process wastes but by job control waste. Because job control waste is heavily influenced by parameters such as staffing levels and facility size and because these parameters do not vary linearly with capacity, GTCC waste generation is not linear with capacity.
  - The 8X reduction in capacity reduces mixed LLW volume generation to only about a third of the 800 MT/year levels, approximately 30% for the UREX+1a process ( $9.6 \div 32 \times 100 = 30\%$ ), approximately 29% for the Co-Extraction process ( $8.4 \div 28.6 \times 100 = 29\%$ ) and approximately 30% for the “NUEX” process ( $8.8 \div 29.8 \times 100 = 30\%$ ). Most of the mixed LLW is proportional to capacity; however, some of the Balance of Plant mixed LLW is proportional to facility size which is not proportional to capacity. The Balance of Plant waste prevents the total, overall mixed LLW volume from being proportional to capacity.
  - Mixed GTCC waste is the only waste stream that is reduced proportionally to capacity. The 8X reduction in capacity reduces mixed GTCC waste volume generation to 12.5% for the UREX+1a process ( $9.7 \div 76.9 \times 100 = 12.5\%$ ), approximately 12.5% for the Co-Extraction process ( $5.6 \div 44.8 \times 100 = 12.5\%$ ) and approximately 12.5% for the “NUEX” process ( $5.6 \div 44.8 \times 100 = 12.5\%$ ).

Figures 2.2-1 through 2.2-4 show scatter plots of the annual waste volume (m<sup>3</sup>/year) for each data source and waste category.

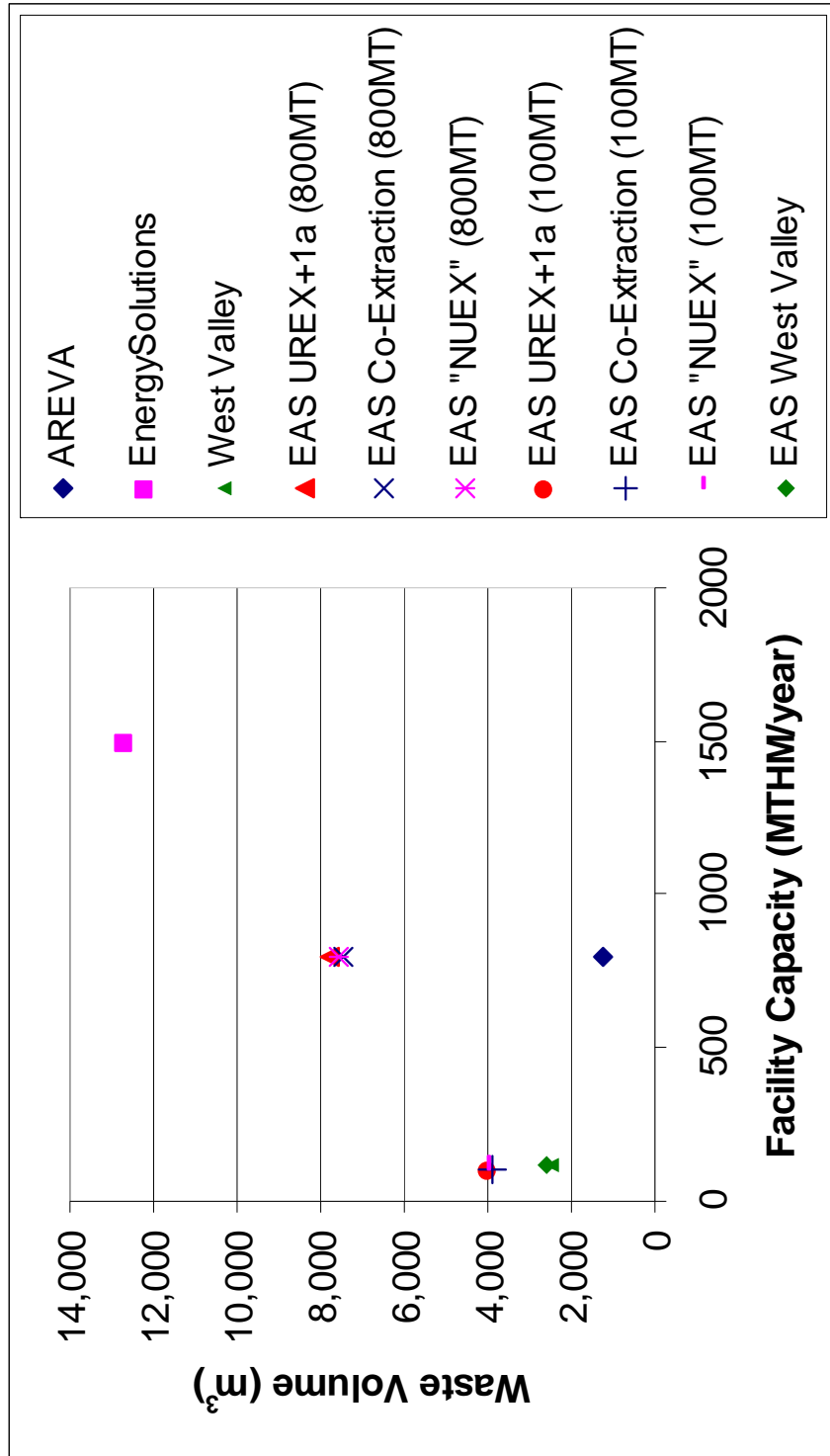


Figure 2.2-1  
 Annual Low Level Waste Volume

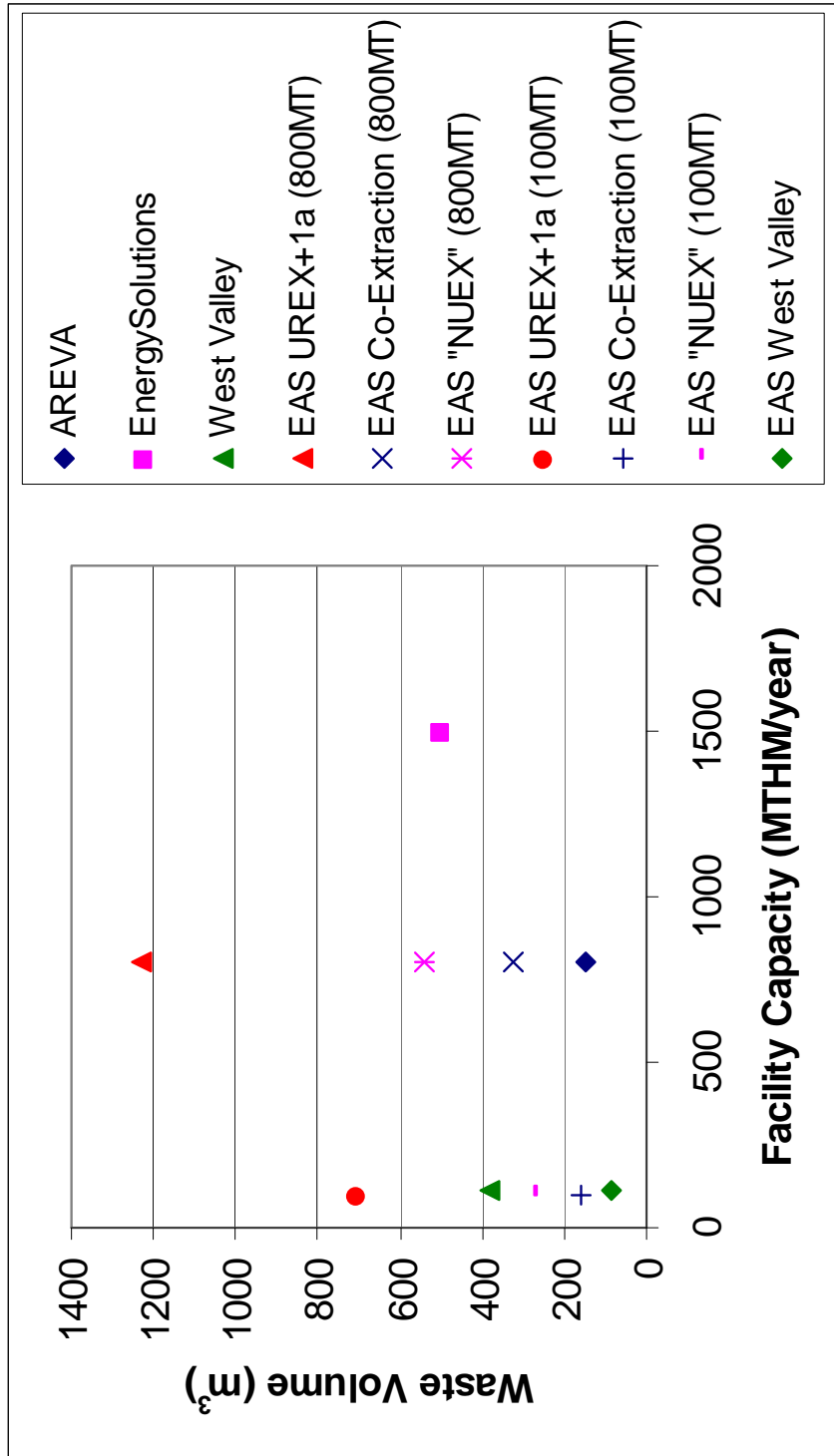


Figure 2.2-2  
 Annual GTCC Waste Volume



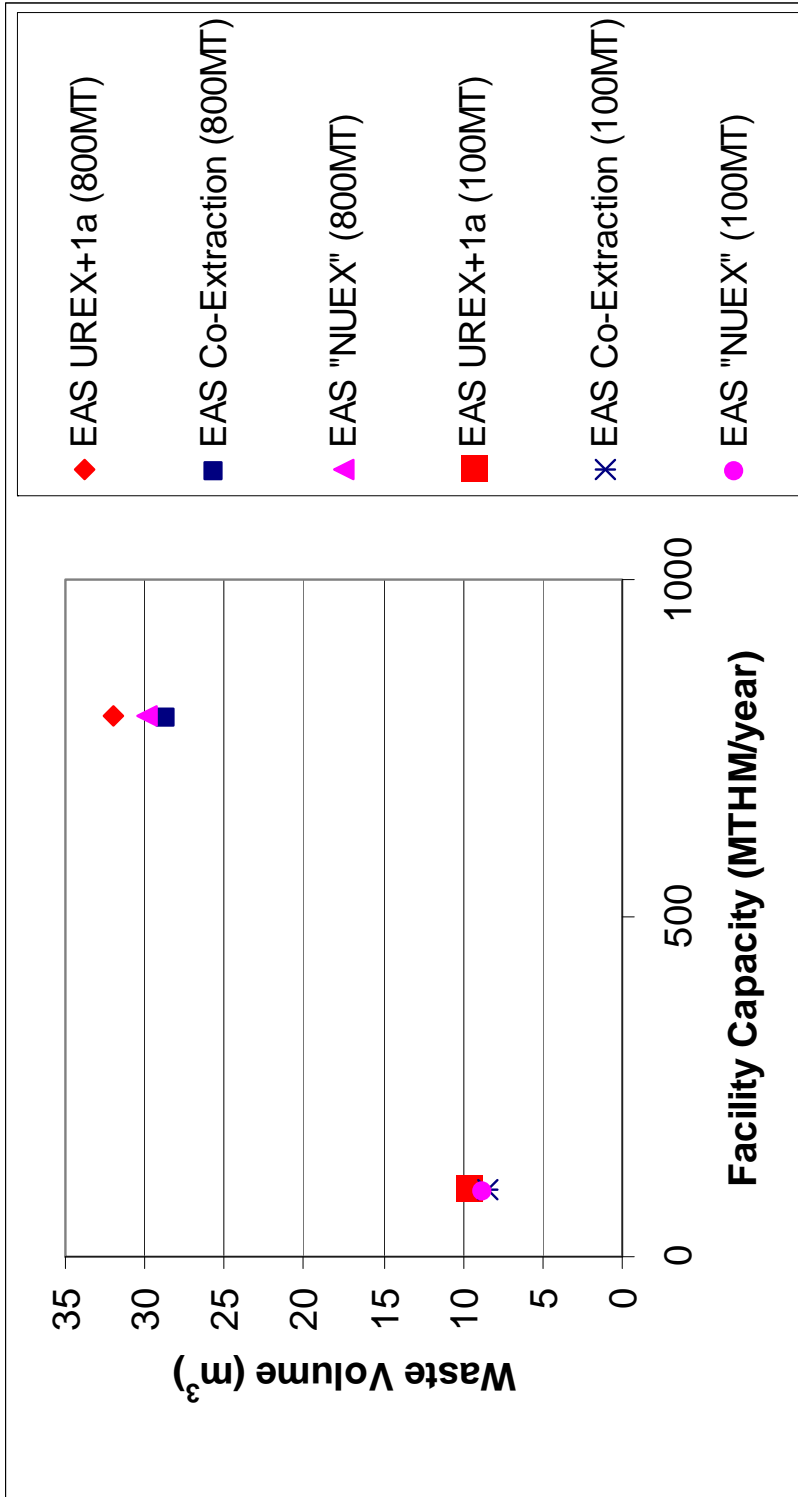


Figure 2.2-3  
 Annual Mixed Low Level Waste Volume

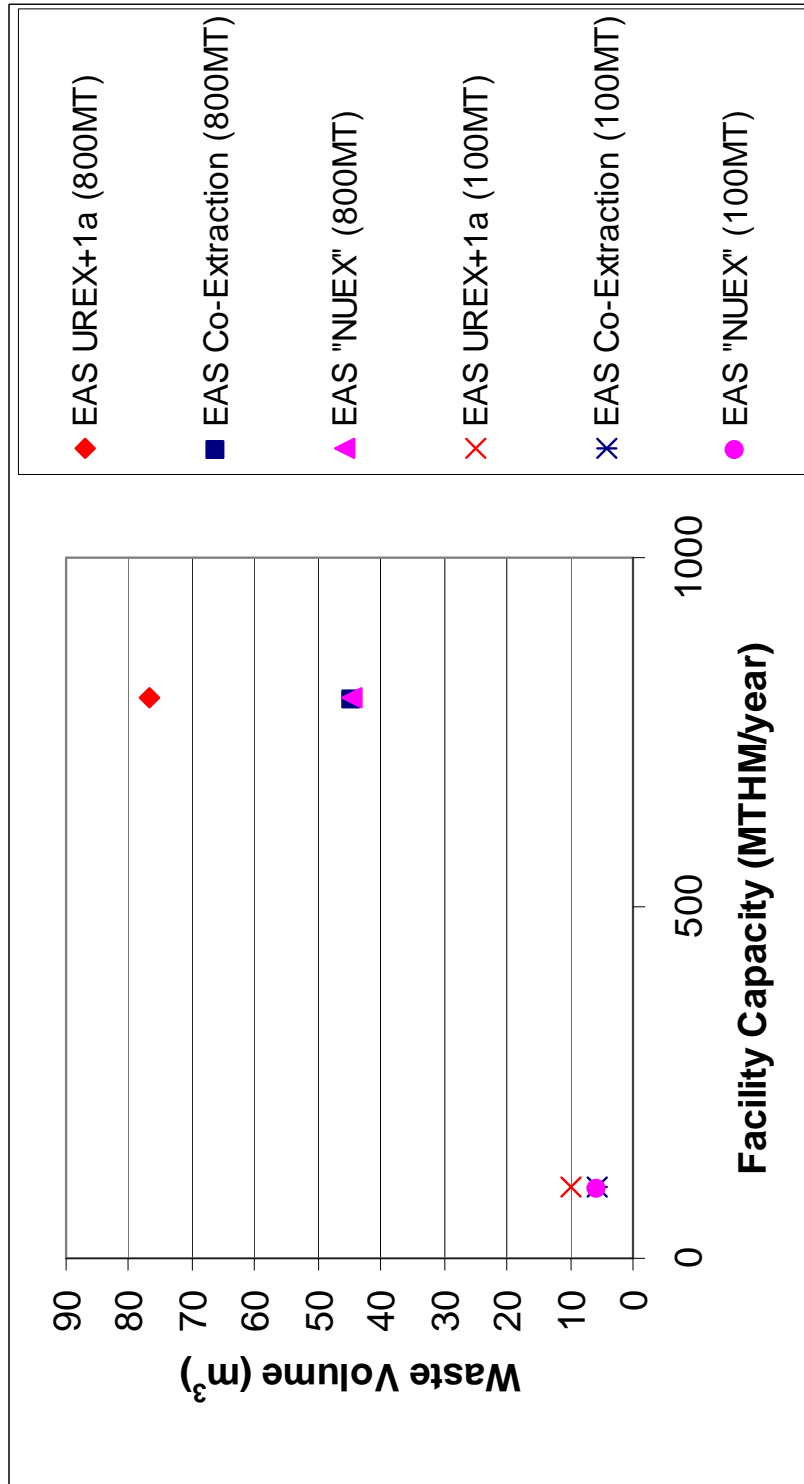


Figure 2.2-4  
 Annual Mixed GTCC Waste Volume

### 2.2.3 Waste Generation Rates By Facility Capacity

Microsoft Excel was used to generate curves that can be used to estimate waste generation rates from facilities of varying capacity. The normalized waste generation rates for each process alternative were used to generate the plots in Figures 2.2-5 through 2.2-9. These plots were fitted with a power trendline that is forecasted 1,000 units beyond the last data point. A power trendline was chosen based on engineering judgment since there are insufficient data points to generate a statistically accurate curve with confidence. A curve that decreases as facility capacity increases and levels off to a minimum rate seems appropriate. The power trendline produces this type of curve and provides more conservative predictions above a facility capacity of about 1,300 MTHM/year than other types of trendlines. Below about 1,300 MTHM/year, the curve is flatter than other types of trendlines but with a correspondingly steeper decline immediately after the 100 MTHM/year facility capacity. Other trendline types were rejected since they were not as conservative above 1,300 MTHM/year. Some types of trendlines even trended below zero as the facility capacity increased which is certainly not realistic.

A variation of the low level waste curve is provided (Figure 2.2-6) that eliminates the AREVA data point which does not appear to be in good agreement with the other data points in Table 2.2-1. AREVA has verbally stated that they are in the process of reviewing their waste estimates and that the estimates could possibly be revised based on the results of the review.<sup>6</sup> Elimination of the AREVA data point produces a curve as shown in Figure 2.2-6 that provides a more conservative estimate of LLW from a co-extraction facility. Figure 2.2-5 also shows a low level waste generation rate for NUEX greater than that for UREX+1a. This does not seem intuitive since the UREX+1a process is a more complex process; however, because the difference is not significant, no adjustment is made to the data/curve to address this observation.

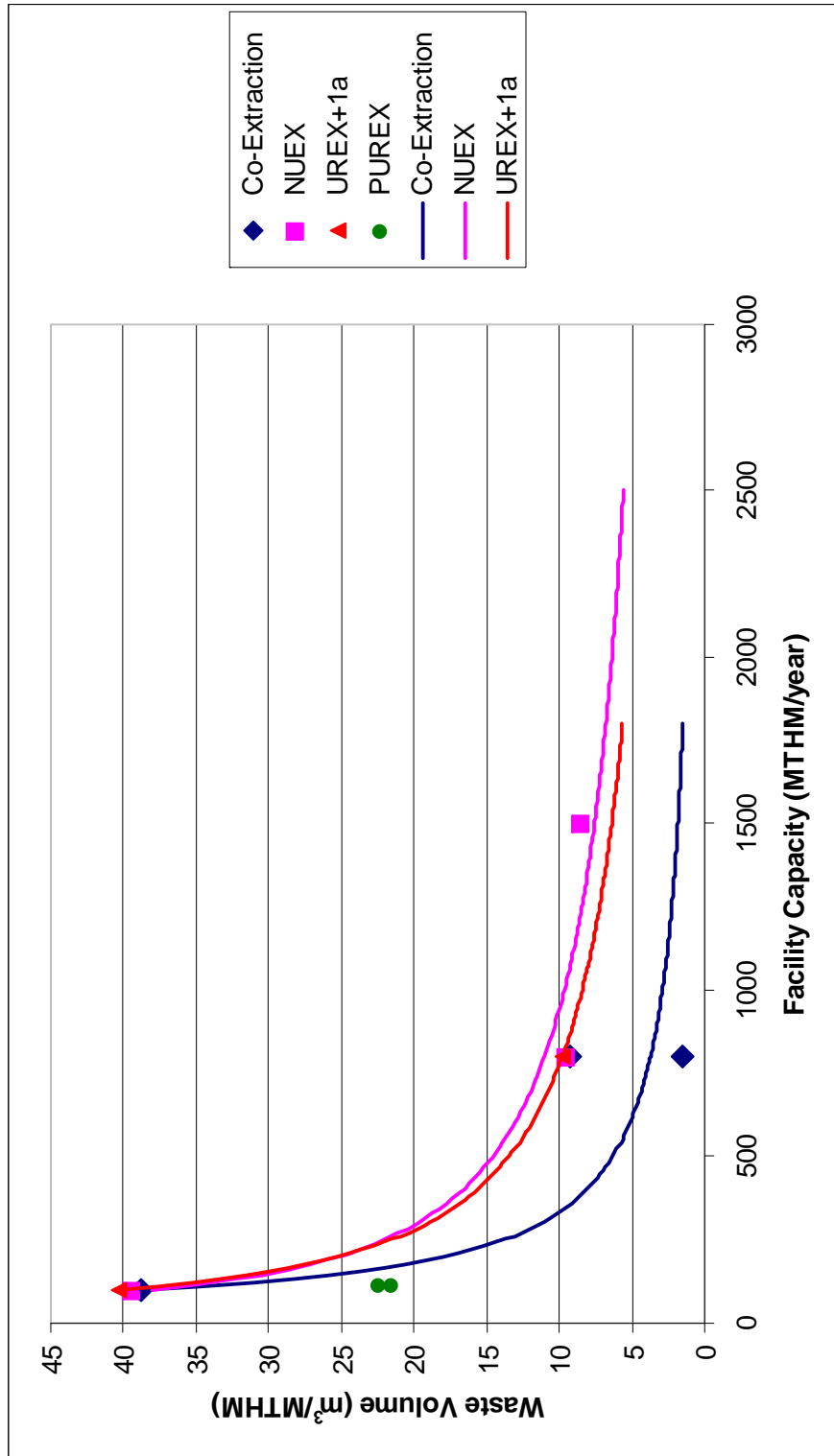


Figure 2.2-5  
Normalized Low Level Waste Volume

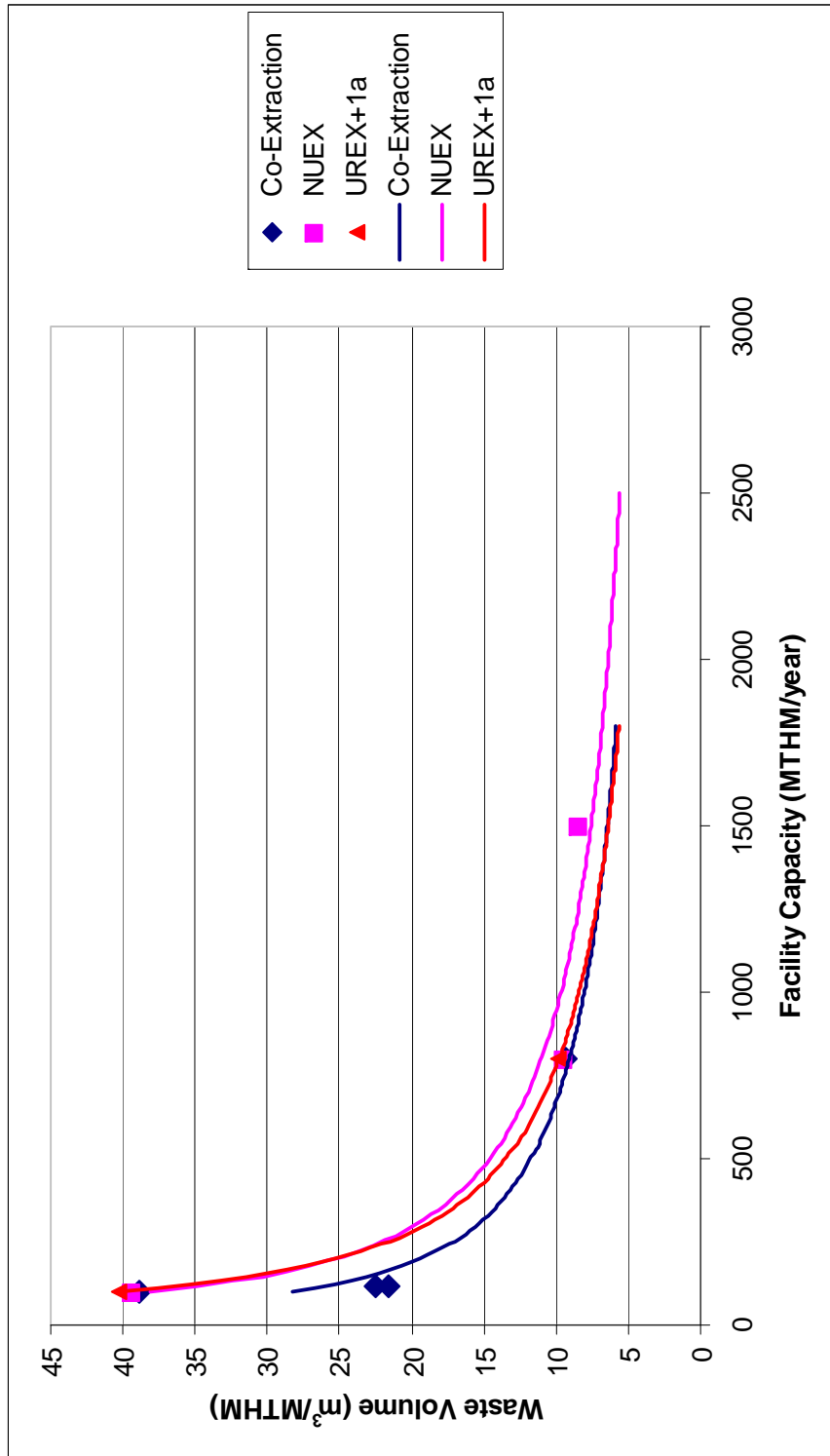


Figure 2.2-6  
Normalized Low Level Waste Volume  
(Excluding the AREVA Data Point)

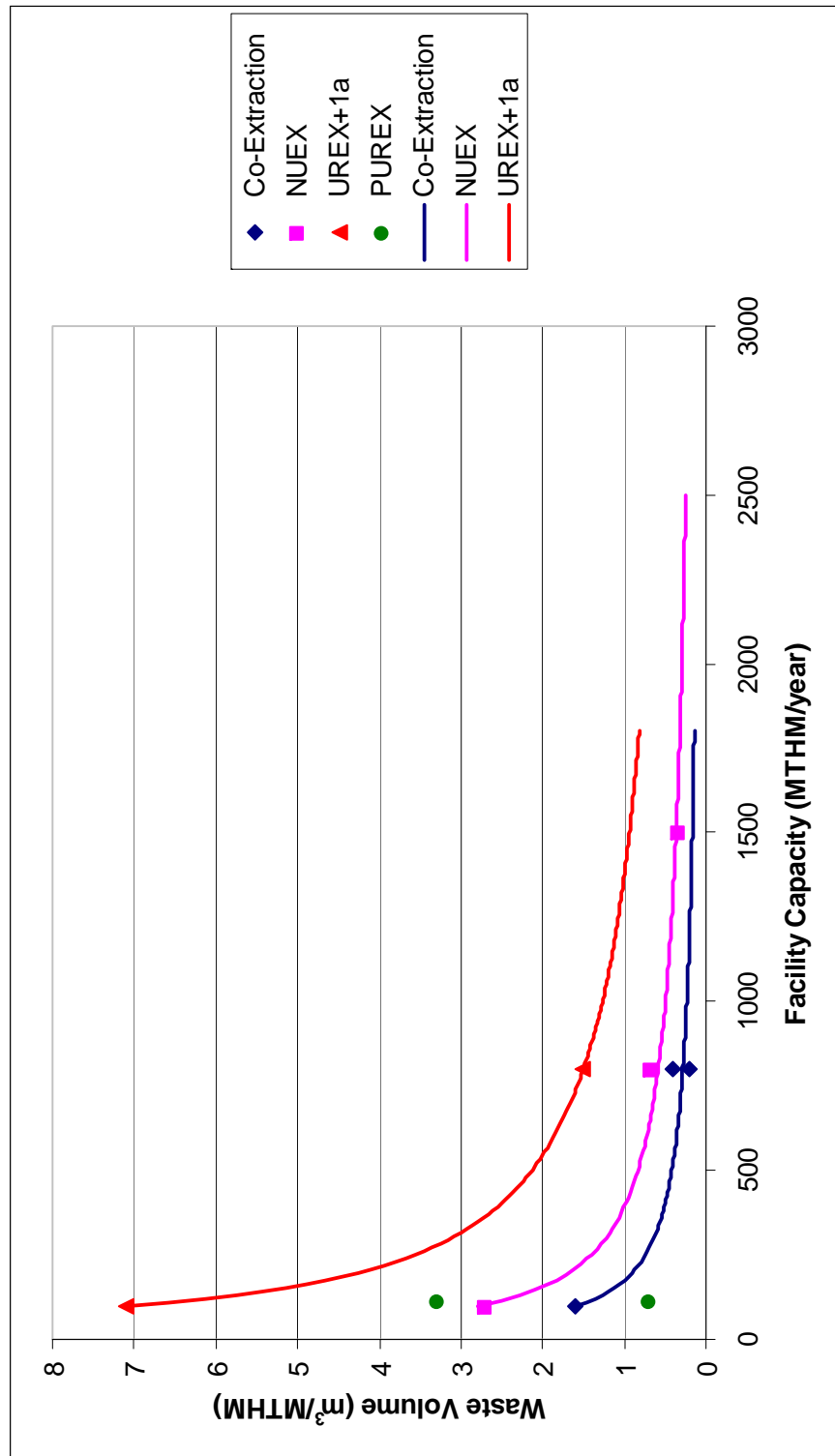


Figure 2.2-7  
 Normalized GTCC Waste Volume

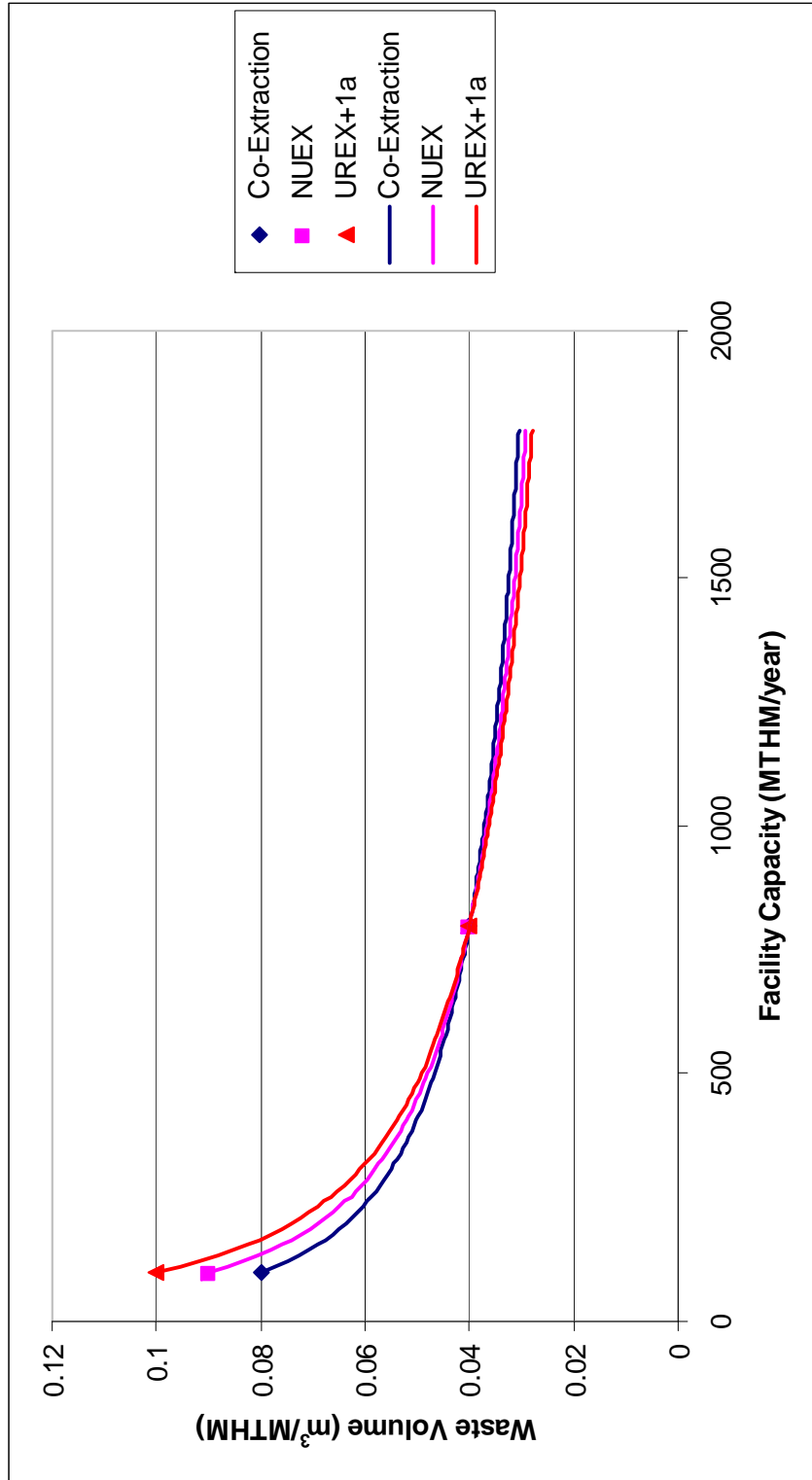


Figure 2.2-8  
Normalized Mixed Low Level Waste Volume

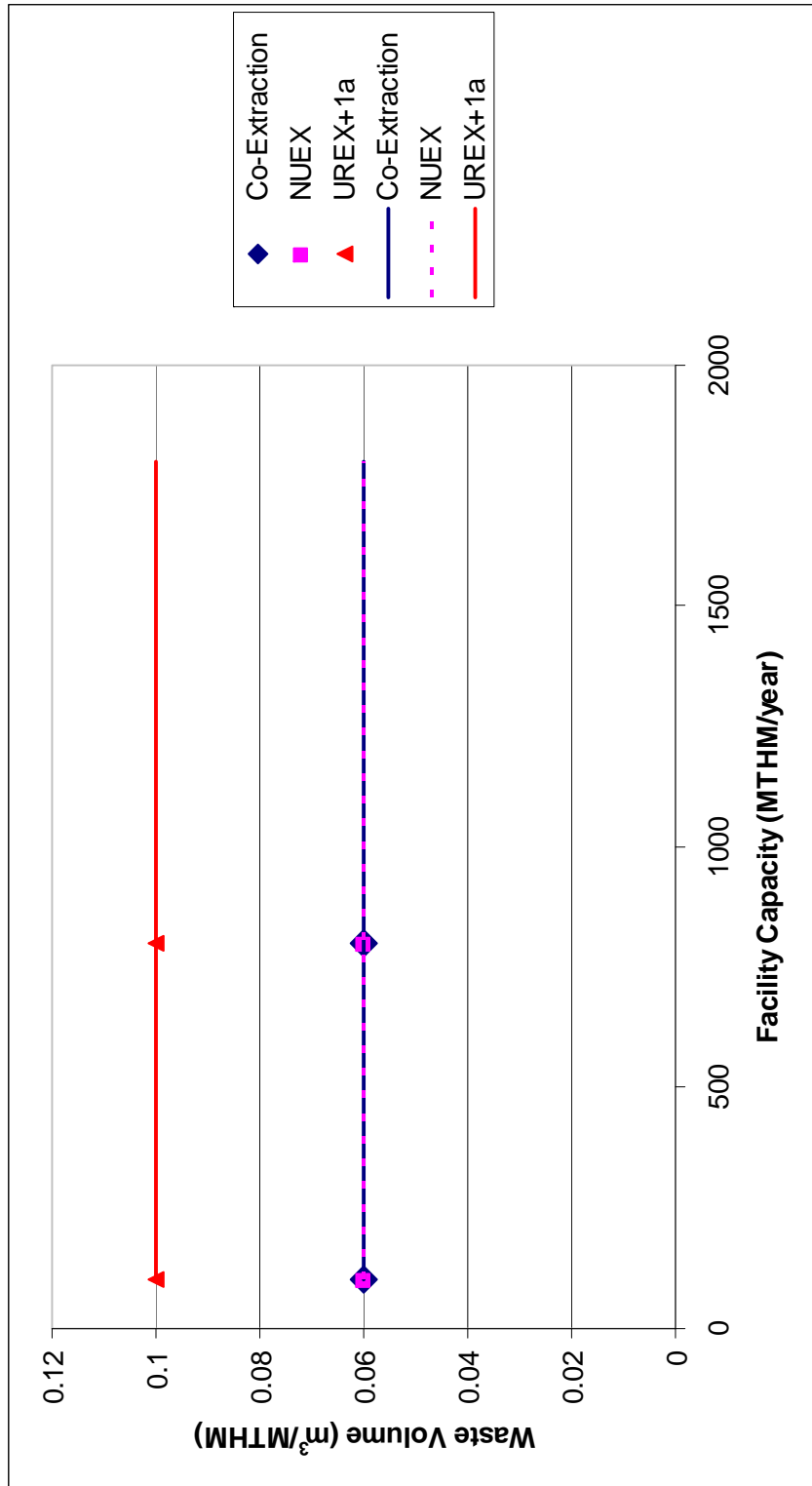


Figure 2.2-9  
Normalized Mixed GTCC Waste Volume



The data presented above is based on specific facility capacities. For instance, 1,500 MTHM of used fuel could be processed per year in a single facility with a capacity of 1,500 MTHM/year or in two separate facilities, each with a capacity of 750 MTHM/year. The waste volumes generated from these two scenarios will be different. Using Figure 2.2-5, a single facility (1,500 MTHM/year) co-extraction scenario will generate about 2 m<sup>3</sup> of LLW per MTHM processed for an annual total of 3,000 m<sup>3</sup>. The two facility co-extraction scenario (750 MTHM/year each) will generate about 4 m<sup>3</sup> of LLW per MTHM processed for an annual total of 6,000 m<sup>3</sup>. Coincidentally, this value is twice that of the single facility scenario. A three facility co-extraction scenario (500 MTHM/year each) will generate about 7 m<sup>3</sup> of LLW per MTHM processed for an annual total of 10,500 m<sup>3</sup> or 3.5 times the single facility scenario.

#### 2.2.4 Data Limitations

Comparison of the data from the various sources is complicated by the lack of knowledge about the assumptions on which the estimates are based. For example, all of the waste volume estimates provided by the industry teams are packaged waste volumes. The EAS estimates provide packaged waste volume estimates also; however, the unpackaged waste volumes are available. Assumptions related to waste packaging such as packing efficiency, the application of package interior volumes and package exterior volumes, waste treatment operations (e.g. compaction), etc. are unknown yet have a significant influence on the final waste volume estimates. Other assumptions with potentially significant impacts on waste volume estimates include the facility design and operating philosophy, the facility maintenance philosophy (e.g. remotely maintained versus dark cells), and the staffing levels associated with the operating and maintenance philosophies.

The data from West Valley includes some decommissioning wastes that are not separable from the waste generation data resulting in waste generation volumes that may not be comparable to other estimates. Additionally, waste management practices, equipment, and process technologies to reduce waste volumes have improved since the 1970's when West Valley operated further suggesting that waste volumes may be different than those from more modern facilities.

Many of the data points for low level waste generation are heavily dependent on the EAS waste estimates. The 100 MT/year EAS based variants of the co-extraction, NUEX processes and West Valley processes are based on the 100 MT/year EAS UREX+1a estimate which itself is derived from the 800 MT/year EAS UREX+1a estimate. In general though, the EAS data appears to be in good agreement with other data with the exception of the AREVA low level waste data. Even though there appears to be a relatively large number of data points for low level and GTCC waste, actual unique data points for Class A/B/C low level and GTCC wastes are limited to AREVA, EnergySolutions, West Valley and the EAS 800 MTHM/year UREX+1a waste estimates. Although the curves in Figures 2.2-5 through 2.2-9 are almost entirely dependent on EAS data for the 100 MTHM/year facilities, the data is somewhat validated by the West Valley data, especially for low level waste. The data points for mixed LLW and mixed GTCC wastes are all reliant upon EAS data.

## 2.3 Electrochemical Recycling

One of the industry teams, GE-Hitachi, has proposed recycling facilities utilizing the electrochemical process; however, publicly available information from GE-Hitachi does not include waste volume estimates.<sup>7</sup> The Engineering Alternatives Studies (EAS) for Separations provided a forecast of waste generated from a recycling facility utilizing the electrochemical process at a capacity of 300 MTHM/year.<sup>8</sup> Figure 2.3-1 shows the process flowsheet used as the basis for the EAS waste estimates. The EAS study utilizes a bottoms up method to estimate annual waste quantities from each of the major process functions of the electrochemical process (e.g. fuel receipt, electro reduction, offgas, electro refining, U/TRU electrolysis, Ln solidification, etc.). A summary of the data contained in Reference 7 is provided in Appendix G. Reference 7 should be consulted for additional detail not provided in Appendix G.

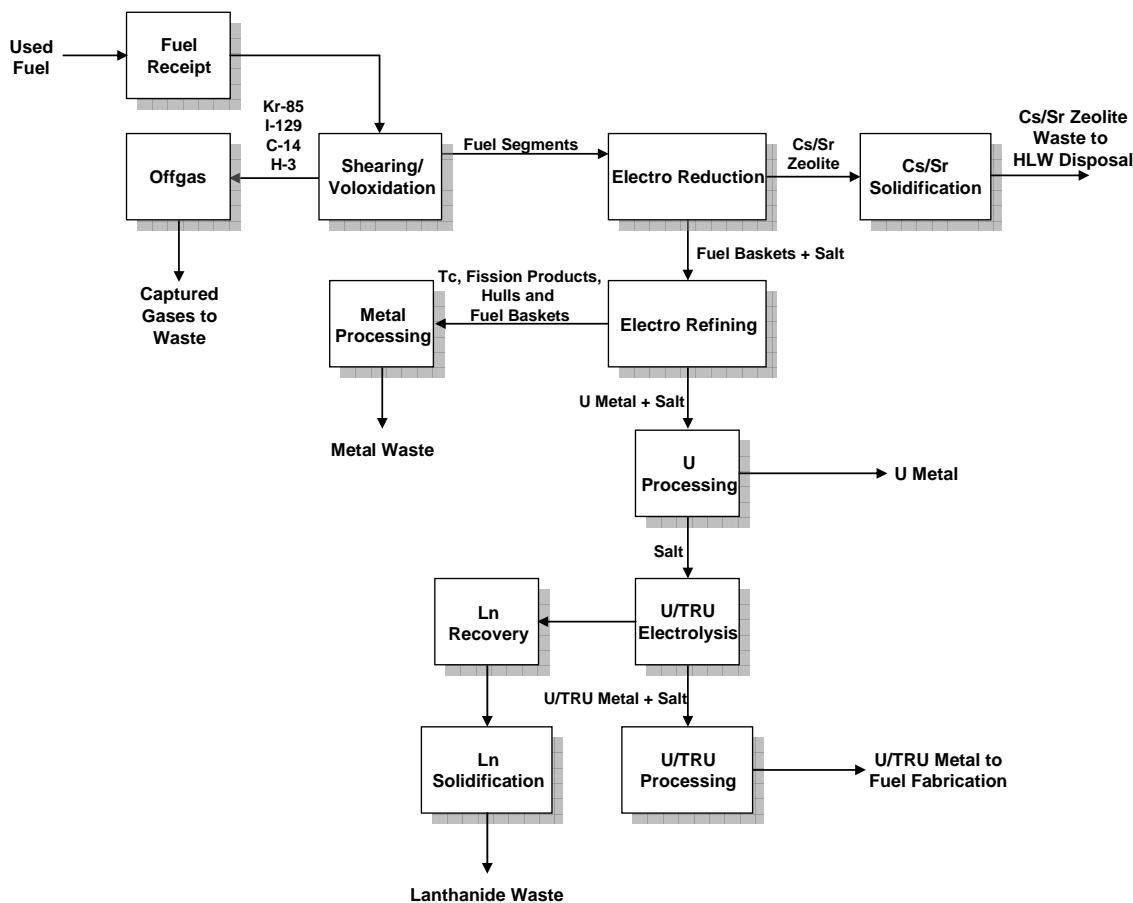


Figure 2.3-1  
 Electrochemical Recycling Process

Table 2.3-1 provides a summary of the waste estimates provided in Appendix G. Waste volume estimates are provided in terms of total annual waste generation (m<sup>3</sup>/year) and a normalized value expressed as waste per metric ton of heavy metal processed.

Data Source <sup>1</sup>	Estimate Basis (MTHM/yr)	Volume	Low Level Waste			Total	GTCC Waste			Mixed LLW	Mixed GTCC
			Class				CH-TRU	RH-TRU + GTCC	Total		
			A	B	C						
EAS Electrochemical	300	m <sup>3</sup> /year				2,616.1			919	29	43.6
		m <sup>3</sup> /MTHM				8.7			3.1	0.1	0.15

1. EAS Electrochemical – Appendix G

The data presented above is based on a specific facility capacity of 300 MTHM/year. The waste volumes generated from facilities with other capacities will be different and are not expected to be linear. The normalized waste generation rate in Table 2.3-1 should not be used to estimate waste volumes from other electrochemical recycling facilities with different capacities.

### 3.0 CONCLUSIONS AND RECOMMENDATIONS

#### 3.1 Once-Through Fuel Cycle

Although the data provided for the once-through fuel cycle in Section 2.1 is very specific to Yucca Mountain, the surface operations that were planned for Yucca Mountain should be applicable to other large scale geologic repository operations including repositories based on disposal in other environments such as clay, granite, salt, etc. Since the operations are similar, the waste quantities and types associated with the once-through fuel cycle should be independent of the disposal technology chosen. Obviously, a used fuel disposal technology with waste preparation operations significantly different than that planned for Yucca Mountain (possibly borehole disposal) will potentially produce different quantities and types of waste.

For disposal of used fuel in a geologic repository, it is recommended that the normalized waste generation rates as derived in Section 2.1 be used to estimate waste volumes resulting from disposal of used fuel from future once-through fuel cycles. The rate used is dependent, however, on the amount of used fuel that is assumed to be prepackaged in disposal-ready canisters prior to delivery to the repository. The rate is linear with respect to the repackaging fraction as shown in Figure 2.1-1 and rates for repackaging scenarios from 0-100 percent can be determined.

## 3.2 Aqueous Recycling

The waste generation rates for aqueous recycling are not linear with facility capacity. The availability of multiple data sources for aqueous recycling allows for the creation of curves to estimate waste generation rates from facilities of varying capacity. These curves are based on engineering judgment since there are insufficient data points to generate a statistically accurate curve with confidence. The curves provided in Figures 2.2-6 through 2.2-9 can be used for this purpose. The use of Figure 2.2-6 in lieu of Figure 2.2-5 is recommended to provide a more conservative estimate of LLW from the co-extraction process.

The differences between the co-extraction, NUEX, and UREX+1a processes do not appear to be a major discriminator for Class A/B/C LLW generation. Rather the main discriminator is facility capacity. The facility size that results in little or no further reduction in LLW is not known but the curves suggest there is little reduction in LLW generation per MTHM of used fuel recycled for facilities greater than approximately 1,500 MTHM.

The differences between the co-extraction, NUEX, and UREX+1a processes do appear to be a discriminator for GTCC waste generation. The difference is most apparent at lower facility capacities. At higher facility capacities (e.g. 1,500 MTHM/year) the volumes are significantly lower overall but still roughly in the same proportions as at the lower capacities.

The differences between the co-extraction, NUEX, and UREX+1a processes do not appear to be a major discriminator for mixed Class A/B/C LLW generation. As with “normal” LLW, the main discriminator is facility capacity. Similar to LLW, the facility size that results in little or no further reduction in LLW is not known but the curves suggest there is little reduction in mixed LLW generation per MTHM of used fuel recycled for facilities greater than approximately 1,500 MTHM.

The differences between the co-extraction and NUEX processes do not appear to be a discriminator for mixed GTCC waste generation; however, mixed GTCC waste generation for the UREX+1a process is significantly higher (approximately 67% higher) although overall waste generation rates are relatively low for all processes. The difference is consistent (i.e. linear and flat) for all facility capacities. This relationship is questionable given the reliance on the EAS data alone.

## 3.3 Electrochemical Recycling

The lack of multiple data sources for electrochemical recycling does not allow for the creation of curves to estimate waste generation rates from facilities of varying capacity. The data presented in Section 2.3 is based on a specific facility capacity of 300 MTHM/year and is derived from only one source. The waste generation rates for electrochemical recycling are not expected to be linear with respect to facility capacity. It is recommended that the normalized waste generation rates contained in Table 2.3.1 be used to estimate waste volumes resulting from recycling of used fuel in an electrochemical recycling facility operating at a capacity of 300 MTHM/year.

## 4.0 COMPARISON TO CURRENT DISPOSAL CAPACITY

Appendix H provides a compilation of LLW generation and disposal over the period of 1986 through 2008 and computes an average disposal rate for this period. This information was obtained from the U.S. DOE Office of Environmental Management’s Manifest Information Management System (MIMS). Data is available from MIMS for academic, government, industry, medical, undefined, and utility LLW generators. A summary of the average disposal rates for the period between 1986 and 2008 is shown in Table 4.0-1.

<b>Source</b>	<b>Class A (m<sup>3</sup>/year)</b>	<b>Class B (m<sup>3</sup>/year)</b>	<b>Class C (m<sup>3</sup>/year)</b>	<b>Total (m<sup>3</sup>/year)</b>
Academic	270	0.2	2	272.2
Medical	150	0.1	1	151.1
Government	14,000	7	11	14,018
Undefined	310	0.1	0.1	310.2
Industry	45,000	20	20	45,040
Utility	7,000	320	280	7,600
<b>TOTAL</b>	<b>66,730</b>	<b>347.4</b>	<b>314.1</b>	<b>67,391.5</b>

Many scenarios for recycling used fuel are possible and the waste generated from these activities is dependent on the amount of used fuel assumed to be recycled annually and on the recycling facility capacity and technology (e.g. aqueous, electrochemical) selected. Reference 9 describes several possible nuclear energy growth scenarios that determine the amount of used fuel available for recycling as follows:

Scenario 1 assumes no replacement of existing nuclear generation reactors.

Scenario 2 assumes the amount of current nuclear generation is maintained at the current levels (100 GWe/yr) with new reactors replacing the existing reactors as the existing reactors are decommissioned.

Scenario 3 assumes the amount of nuclear generation will increase to 200 GWe/yr from 2020 to 2060.

Scenario 4 assumes the amount of nuclear generation will increase to 400 GWe/yr from 2020 to 2060.

It is not the intent of this report to estimate the waste generated from every possible combination of nuclear energy growth scenario, recycling facility capacity and recycling technology. As an example, Scenario 2 is chosen in which approximately 2,300 MTHM of used fuel is generated annually (rounded up to 2,400 to simplify the calculation in the example that follows). Possible recycling scenarios include two 1,200 MTHM/year co-extraction facilities, three 800 MTHM/year co-extraction facilities, or eight 300 MTHM/year electrochemical recycling facilities. From Figure 2.2-6, approximately 7.0 m<sup>3</sup>/MTHM of used fuel recycled is generated from a 1,200 MTHM/year co-extraction recycling facility. Likewise, approximately 9.0 m<sup>3</sup>/MTHM is generated from an 800 MTHM/year co-extraction recycling facility. From Section 2.3, a 300 MTHM/year electrochemical recycling facility generates approximately 8.7 m<sup>3</sup>/MTHM of used fuel recycled. Table 4.0-2 summarizes the amount of LLW generated from recycling 2,400 MTHM of used fuel based on these facility assumptions and its relationship to the current rate of Class A LLW disposal.

Recycling Method	Number of Plants	Recycling Facility Capacity (MTHM/year)	Estimated Total LLW Generated from Recycling (m <sup>3</sup> /year)	Percentage of Annual Total LLW Generated <sup>1</sup>	Percentage of Annual Nuclear LLW Generated <sup>2</sup>
Co-extraction	2	1,200	16,800	25.2 %	32.3 %
	3	800	21,600	32.4 %	41.5 %
Electrochemical	8	300	20,880	31.3 %	40.2 %

1. Estimated Annual Total Class A LLW Generated from Table 4.0-1: 66,730 m<sup>3</sup>/year.
2. Estimated Annual Nuclear LLW Generated by Industry and Utility sources from Table 4.0-1: 45,000 m<sup>3</sup>/year + 7,000 m<sup>3</sup>/year = 52,000 m<sup>3</sup>/year.

Waste generation estimates for GTCC waste, mixed LLW and mixed GTCC waste can be similarly calculated for these scenarios as well as others based on the data provided in Section 2.0 of the report. Table 4.0-2 compares the LLW resulting from the disposal of the same amount of used fuel at a geologic repository to the current rate of Class A LLW disposal based on the data in Section 2.1.

Percentage of Used Fuel Pre-Packaged in Disposable Canisters	Monitoring Period (years)	LLW Generation Rate (m <sup>3</sup> /year) <sup>1</sup>	Estimated Total LLW Generated from Geologic Disposal (m <sup>3</sup> /year)	Percentage of Annual Total LLW Generated <sup>2</sup>	Percentage of Annual Nuclear LLW Generated <sup>3</sup>
0	50	3.7	8,880	13.3 %	17.1 %
	250	3.9	9,360	14.0 %	18.0 %
75	50	1.5	3,600	5.4 %	6.9 %
	250	1.7	4,080	6.1 %	7.8 %

1. From Section 2.1.
2. Estimated Annual Total Class A LLW Generated from Table 4.0-1: 66,730 m<sup>3</sup>/year.
3. Estimated Annual Nuclear LLW Generated by Industry and Utility sources from Table 4.0-1: 45,000 m<sup>3</sup>/year + 7,000 m<sup>3</sup>/year = 52,000 m<sup>3</sup>/year.

## 5.0 REFERENCES

1. DOE/EIS-0250F-S1D, *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, October 2007
2. Draft Repository SEIS Calculation Package, Project Working File Number YMS-1223, *Waste Generation Calculations*, September 19, 2007
3. Presentation by Dorothy Davidson, AREVA, to the U.S. Nuclear Waste Technical Review Board, *Waste Generated from Recycling of Used Nuclear Fuel*, September 23, 2009
4. Presentation by EnergySolutions to the U.S. Nuclear Waste Technical Review Board, *Closing the Nuclear Fuel Cycle, Implications for Nuclear Waste Management and Disposal*, September 23, 2009
5. WH-G-ESR-G-00051, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 800 MT/year UREX+1a*, August 4, 2008, Revision 2
6. As stated at the Used Fuel Disposition Campaign Working Group Meeting, Albuquerque, NM, January 28-29, 2010
7. Presentation by Eric P. Loewen, GE-Hitachi, to the U.S. Nuclear Waste Technical Review Board, *Recycle in Fast Reactors*, September 23, 2009
8. WH-G-ESR-G-00054, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 300 MT/year Electrochemical Process*, August 4, 2008, Revision 2
9. Joe T. Carter, Alan J. Luptak, FCR&D-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, March 2010, Revision 1

## 6.0 ACKNOWLEDGEMENTS

The following people contributed to the preparation of this report:

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## Appendix A

### Waste Estimates for the Proposed AREVA Recycling Facility

### **A.1.0 Introduction**

AREVA has provided waste estimates for a proposed used fuel recycling facility for the United States in several presentations, one of the most recent and most complete estimates was presented to the Nuclear Waste Technical Review Board (NWTRB) on September 23, 2009.<sup>1</sup> The NWTRB presentation provides waste estimates for Class A, B and C low level waste (combined) for near surface disposal and Greater Than Class C (GTCC) waste and high level waste (HLW) for disposal in a deep geologic repository. Note that HLW is not within the scope of the LLW Disposition - Quantities and Inventories study; therefore, it is not addressed in this appendix. Mixed low level waste is mentioned in the NWTRB presentation; however, it is not quantified and its disposition is listed as TBD (To Be Determined). The waste estimates provided in the NWTRB presentation are given in terms of package quantities for an 800 MTHM/year recycling facility and total volume per MTHM processed.

### **A.2.0 AREVA Waste Packages**

The radioactive waste packages proposed for use by AREVA include two sizes of steel drums, two sizes of fiber reinforced concrete overpacks, a steel package for alpha (i.e. transuranic) waste and the universal container similar to the container used for vitrified HLW. Details of the containers are shown in Table A.2.0-1 and Figure A.2.0-1 below.

<b>Table A.2.0-1 AREVA Radioactive Waste Packages</b>						
<b>Container</b>	<b>Description</b>	<b>Exterior Dimensions</b>	<b>Exterior Volume</b>	<b>Interior Volume</b>	<b>Weight</b>	<b>Usage</b>
120L	- steel drum		120 liters (0.120 m <sup>3</sup> )	~120 liters (0.120 m <sup>3</sup> )		- Class A, B or C waste - non-compactable waste - bulk loaded into drum
C0	- steel drum		213 liters (0.213 m <sup>3</sup> )	~213 liters (0.213 m <sup>3</sup> )		- Class A, B or C waste - immobilized, compactable waste - waste placed into 120L container, compacted together (drum and all), stacked into C0 container (nominally 5 high) and cemented inside C0 container
CBF-C1	- cylindrical - fiber reinforced concrete - poured concrete encapsulation and closure - recessed band for handling	840 mm dia. 1,200 mm high	0.665 m <sup>3</sup>	340 liters (0.340 m <sup>3</sup> )	690 kg empty	- Class A, B or C waste - encapsulated, compactable waste - waste placed into 120L container, compacted together (drum and all), stacked into C0 container (nominally 5 high, no cement within C0 container), C0 container placed in CBF-C1 container and cemented inside CBF-C1 container
CBF-C2	- cylindrical - fiber reinforced concrete - poured concrete encapsulation and closure - recessed band for handling	1,000 mm dia. 1,500 mm high	1.178 m <sup>3</sup>	670 liters (0.670 m <sup>3</sup> )	1,083 kg empty	- Class A, B or C waste and GTCC waste - encapsulated, non-compactable waste - waste placed into specific container (no cement inside specific container), placed into CBF-C2 container and cemented inside CBF-C2 container
S5 (see Note 1)			~213 liters (0.213 m <sup>3</sup> )	213 liters (0.213 m <sup>3</sup> )		- Alpha (TRU) waste
UC-C	- stainless steel - welded closure - concentric neck and flange for remote handling	430 mm dia. 1,340 mm high	0.195 m <sup>3</sup> (see Note 2)			- GTCC waste (hulls and hardware and other “technological” waste) - compactable waste - waste compacted into pucks to 1/5 of their original volume and stacked into UC-C container (nominally 8 high)

1. Details of the S5 container are not provided in the NWTRB presentation or in any other information that could be obtained. Information shown such as volume and sizes are assumed.
2. Exterior volume is simply calculated from the bounding exterior dimensions given in the table.

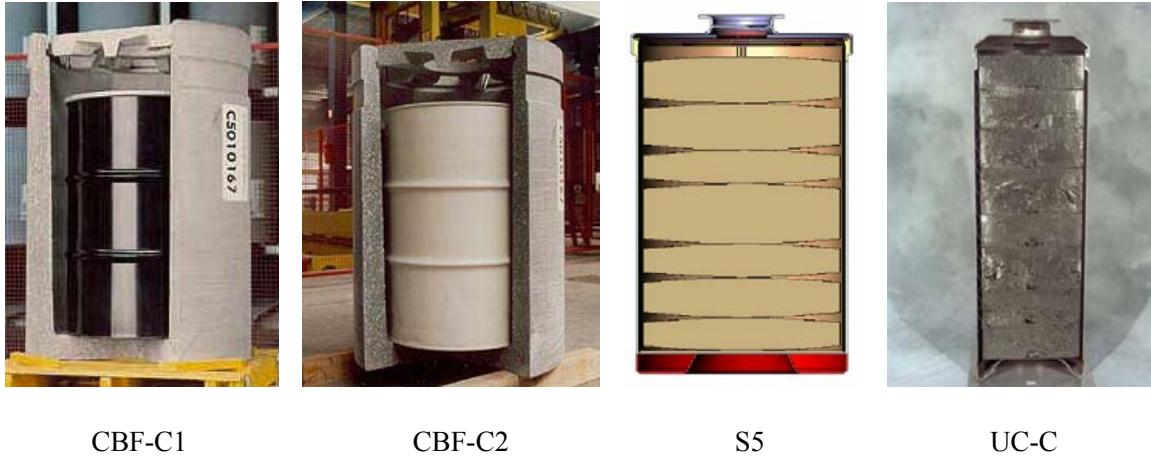


Figure A.2.0-1  
AREVA Radioactive Waste Packages

### A.3.0 AREVA Packaged Waste Volume Estimates

The waste estimates provided by AREVA in the NWTRB presentation in terms of container quantity are shown below in Tables A.3.0-1 and A.3.0-2. Using the container information shown in Table A.2.0-1 above, the waste estimates provided in the NWTRB presentation can be converted to volume. The converted waste volume estimates are also shown in Tables A.3.0-1 and A.3.0-2 below. As stated previously, these estimates are based on an annual processing capacity of 800 MTHM and represent final waste package volumes which include allowances for waste minimization such as compaction and for other treatment processes. The NWTRB presentation provides insufficient detail on the origin of the waste streams to enable an extensive breakdown of the wastes relative to their source in the process; however, the waste streams can be divided between “Process” and “Maintenance and Operational” sources.

Table A.3.0-1 Summary of AREVA Packaged Low Level Class A, B and C Radioactive Waste Volume Estimates						
System <sup>1</sup>	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
Fuel Receipt	CBF-C2	10	11.78			11.78
Solvent Extraction	C0	50	10.65			10.65
Balance of Plant	120L	200	24			24
All systems	120L			4800	576	576
	C0			800	170.4	170.4
	CBF-C1			300	199.5	199.5
	CBF-C2			200	235.6	235.6
<b>Subtotal</b>			<b>46.43</b>		<b>1,181.5</b>	<b>1,227.9</b>
<b>TOTAL (m<sup>3</sup>)</b>	<b>1,227.9</b>					
<b>TOTAL (m<sup>3</sup>/MTHM) <sup>2</sup></b>	<b>1.5</b>					

- The AREVA presentation to the NWTRB does not provide sufficient detail to segregate the sources of LLW by system other than that shown. "Fuel Receipt" waste consists of cemented spent resins. "Solvent Extraction" waste consists of mineralized and cemented spent solvent. "Balance of Plant" waste consists of solidified nitrate liquid effluents.
- The AREVA presentation to the NWTRB gives a value of 50 ft<sup>3</sup>/MTHM or 1.416 m<sup>3</sup>/MTHM. The value in the table above (i.e. 1.535 m<sup>3</sup> or 54 ft<sup>3</sup>) is in close agreement with the value given in the NWTRB presentation; therefore, the assumptions relative to individual waste container volumes appear to be valid.
- Shaded areas (i.e. ) indicate compacted waste.

Table A.3.0-2 Summary of AREVA Packaged Greater Than Class C Radioactive Waste Volume Estimates						
System <sup>1</sup>	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
All systems	CBF-C2			15	17.67	17.67
	S5			100	21.3	21.3
	UC-C (see Note 2)	560	109.2			109.2
<b>Subtotal</b>			<b>109.2</b>		<b>38.97</b>	<b>148.2</b>
<b>TOTAL (m<sup>3</sup>)</b>	<b>148.2</b>					
<b>TOTAL (m<sup>3</sup>/MTHM) <sup>3</sup></b>	<b>0.2</b>					

1. The AREVA presentation to the NWTRB does not provide sufficient detail to segregate the sources of GTCC waste by system.
2. Waste packaged into UC-C containers is assumed to be primarily compacted hulls and hardware (i.e. Process waste); however, according to the AREVA presentation to the NWTRB, some Maintenance and Operational waste is packaged into UC-C containers also. The AREVA presentation does not provide sufficient detail to segregate the UC-C waste between Process waste streams and Maintenance and Operational waste streams.
3. The AREVA presentation to the NWTRB gives a value of 10 ft<sup>3</sup>/MTHM or 0.283 m<sup>3</sup>/MTHM. The value in the NWTRB presentation includes vitrified high level waste; therefore, a comparison of this value (i.e. 0.283 m<sup>3</sup>) with the value in Table A.3.0-2 (i.e. 0.185 m<sup>3</sup>) is not relevant.
4. Shaded areas (i.e. ) indicate compacted waste.

#### A.5.0 References

1. Presentation by Dorothy Davidson, AREVA, *Waste Generated from Recycling of Used Nuclear Fuel*, to the U.S. Nuclear Waste Technical Review Board, September 23, 2009
2. AREVA brochure, *Compacting Structural and Technological Waste, Processing Active Liquid Effluents*
3. Presentation by Christian Barandas, *The Reprocessing Process*, at the AREVA Technical Days 2, December 4-5, 2002
4. Sogefibre product literature for cylindrical containers CBF-C1 and CBF-C2, [http://www.sogefibre.com/produits\\_cylindriques\\_uk.htm](http://www.sogefibre.com/produits_cylindriques_uk.htm)

Appendix B

Waste Estimates for the Proposed Energy *Solutions* Recycling Facility

### **B.1.0 Introduction**

EnergySolutions has provided waste estimates for a proposed used fuel recycling facility for the United States in several presentations, one of the most recent and most complete estimates was presented to the Nuclear Waste Technical Review Board (NWTRB) on September 23, 2009.<sup>1</sup> The NWTRB presentation provides waste estimates for Class A and C low level waste, contact handled transuranic (TRU) waste, remote handled TRU and GTCC waste (combined), captured <sup>85</sup>Kr waste and high level waste (HLW). Note that HLW is not within the scope of the LLW Disposition - Quantities and Inventories study; therefore, it is not addressed in this appendix. Mixed low level waste is mentioned in the NWTRB presentation; however, it is not quantified. The waste estimates provided in the NWTRB presentation are given in terms of volume and package quantities for a 1,500 MTHM/year recycling facility.

### **B.2.0 EnergySolutions Waste Packages**

The radioactive waste packages proposed for use by EnergySolutions include drums, half-height 20' cargo containers, 210-liners, RH-72B waste containers (as used at the Waste Isolation Pilot Plant) and gas bottles for captured <sup>85</sup>Kr waste. Details of the containers are shown in Table B.2.0-1 and Figure B.2.0-1 below.



Container	Description	Exterior Dimensions	Exterior Volume	Interior Volume	Weight	Usage
Drum	- assumed to be carbon steel		55 gallon drum: 0.212 m <sup>3</sup>  100 gallon drum: 0.386 m <sup>3</sup> (see Note 1)	55 gallons (0.208 m <sup>3</sup> )  100 gallons (0.379 m <sup>3</sup> )		- Class A and C waste and contact handled TRU waste - waste supercompacted within 55 gallon drums to minimize volume (the drums are supercompacted along with their contents to form compacted pucks) - compacted pucks are stacked into 100 gallon drums and grouted - See Note 2
Half-height 20' cargo container <sup>3</sup>	- half-height cargo container - top loading - steel floor	- 19'-10" long - 4'-3" high - 8' wide	674 ft <sup>3</sup> (19.1 m <sup>3</sup> )	535 ft <sup>3</sup> (15.15 m <sup>3</sup> )	- 7,000 lbs tare weight - 48,150 lbs capacity - 55,150 lbs gross weight	- Class A waste (grouted tritiated water, <sup>14</sup> C slurry and salt concentrate)
210-Liners <sup>4</sup>	- disposable steel liners ½" to 1-½" thick - polyethylene liners available - used in the Model 14/210 or Model 14/215H cask	See Table B.2.0-2	See "Burial Volume" in Table B.2.0-2	See Table B.2.0-2 and Note 5	See Table B.2.0-2	- Spent ion exchange resin
RH-72B <sup>6</sup>	- stainless steel, lead shielded cask - NRC certified - shielded with 1-7/8" lead	- 15'-7 ¾" long x 6'-4" diameter when assembled with impact limiters - cask 11'-9 ¾" long x 3'-5 5/8" diameter - inner vessel 10'-10" long x 2'-8" diameter	- inner vessel volume 60.5 ft <sup>3</sup> (1.71m <sup>3</sup> )	- inner vessel volume 54.2 ft <sup>3</sup> (1.53m <sup>3</sup> )	- maximum package weight with contents 45,000 lbs - maximum weight of contents including waste canister 8,000 lbs	- remote handled TRU and GTCC waste - waste packaged into waste container and transported in RH-72B cask - waste container sized to fit into inner vessel of cask
Gas bottles						- Captured <sup>85</sup> Kr gas

- Reference 2 lists the displacement volume (i.e. external volume) for 55 gallon drums as 7.50 ft<sup>3</sup> or 0.212 m<sup>3</sup> and for 110 gallon drums as 15.00 ft<sup>3</sup> or 0.425 m<sup>3</sup>. The external volume of 100 gallon drums is determined (prorated) based on the ratio determined from these external volumes relative to the internal volume.
- Reference 3 describes the supercompaction process as compaction of waste in 200 liter drums to form compacted pucks which are in turn stacked into a 500 liter drum and grouted. Although not specifically stated in the NWTRB presentation, the information contained in the NWTRB presentation is interpreted as supercompaction in 55 gallon drums with subsequent placement and grouting in 100 gallon drums.
- Data for the half-height cargo container is obtained from Reference 4.
- Data for the 210-liners is obtained from Reference 5.
- Various liners are available for the 14/210 and 14/215H casks as indicated in Table B.2.0-2; however, data provided by EnergySolutions in the NWTRB presentation indicates an individual waste package volume of approximately 185 ft<sup>3</sup>. A liner such as the PL14-195 or the L14-170 would provide a burial volume close to this value.
- Data for the RH-72B is obtained from Reference 6.

**Figure B.2.0-2  
 Liners for Model 14/210 and 14/215H Casks**

Liners	Material	Height (inches)	Diameter (inches)	Burial Volume (ft <sup>3</sup> )	Maximum Internal Volume (ft <sup>3</sup> )	Usable Volume (ft <sup>3</sup> )	Gross Weight (lbs)	Empty Weight (lbs)
PL6-80	polyethylene	56.5	57.0	83.4	73.3	62-64	5,000	500
PL8-120	polyethylene	73.5	60.0	120.3	107.6	99-101	10,000	600
PL14-170	polyethylene	71.5	72.5	170.8	150.3	138-141	10,800	800
PL14-195	polyethylene	78.0	74.0	194.1	171.4	159-162	12,200	900
PL14-215	polyethylene	78.375	76.0	205.8	189.2	174-177	19,500	1,250
L6-80	carbon steel	57.0	58.0	87.2	82.9	62-80	9,900	1,000
L7-100	carbon steel	40.0	74.5	100.9	94.1	89	10,800	1,300
L8-120	carbon steel	74.0	61.0	125.2	120.2	112-117	14,500	1,200
L14-170	carbon steel	71.375	74.5	180.1	172.7	160-168	20,750	1,550
L14-195	carbon steel	79.0	76.0	207.4	199.6	187-195	23,700	1,650



Supercompacted Drums



Half-Height 20' Cargo Container



RH-72B

Figure B.2.0-1  
 EnergySolutions Radioactive Waste Packages

**B.3.0 EnergySolutions Packaged Waste Volume Estimates**

The waste estimates provided by EnergySolutions in the NWTRB presentation are shown below in Tables B.3.0-1 through B.3.0-5. As stated previously, these estimates are based on an annual processing capacity of 1,500 MTHM and represent final waste package volumes which include allowances for waste minimization such as compaction and for other treatment processes. Waste streams that include compaction are indicated in the tables by shading. The NWTRB presentation provides insufficient detail on the origin of the waste streams to enable an extensive breakdown of the wastes relative to their source in the process; however, the waste streams can be divided between “Process” and “Maintenance and Operational” sources.

System	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
All systems <sup>1</sup>	55/100 gal. drums			3,602	1,335	1,335
	half-height 20' cargo containers	672	11,122			11,122
	100 gal. drums	349	132			132
	210-liners	2.1	11			11
<b>Subtotal</b>			<b>11,265</b>		<b>1,335</b>	<b>12,600</b>
<b>TOTAL (m<sup>3</sup>)</b>	<b>12,600</b>					
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>8.4</b>					

- The EnergySolutions presentation to the NWTRB does not provide sufficient detail to segregate the sources of Class A LLW by system. Waste packaged in 55 and 100 gallon drums (1,335 m<sup>3</sup>) consists of waste from maintenance and clean up operations. Waste packaged in half-height 20' cargo containers consists of grouted tritiated water, <sup>14</sup>C slurry and salt concentrate. Waste packaged in 100 gallon drums (132 m<sup>3</sup>) consists of pyrolyzed solvent ash. Waste packaged in 210-liners consists of spent ion exchange resin.
- Shaded areas (i.e. ) indicate waste streams that include compaction.

Table B.3.0-2 Summary of EnergySolutions Packaged Low Level Class C Radioactive Waste Volume Estimates						
System	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
All systems <sup>1</sup>	55/100 gal. drums			282	113	113
<b>Subtotal</b>					<b>113</b>	<b>113</b>
<b>TOTAL (m<sup>3</sup>)</b>	<b>113</b>					
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.08</b>					

1. The EnergySolutions presentation to the NWTRB does not provide sufficient detail to segregate the sources of Class C LLW by system. Waste packaged in 55 and 100 gallon drums (113 m<sup>3</sup>) consists of waste from maintenance and clean up operations.
2. Shaded areas (i.e. ) indicate waste streams that include compaction.

Table B.3.0-3 Summary of EnergySolutions Packaged Contact Handled TRU Radioactive Waste Volume Estimates						
System	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
All systems <sup>1</sup>	55/100 gal. drums			326	130	130
<b>Subtotal</b>					<b>130</b>	<b>130</b>
<b>TOTAL (m<sup>3</sup>)</b>	<b>130</b>					
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.09</b>					

1. The EnergySolutions presentation to the NWTRB does not provide sufficient detail to segregate the sources of contact handled TRU waste by system. Waste packaged in 55 and 100 gallon drums (113 m<sup>3</sup>) consists of waste from maintenance and clean up operations.
2. Shaded areas (i.e. ) indicate waste streams that include compaction.

Table B.3.0-4 Summary of EnergySolutions Packaged Remote Handled TRU and GTCC Radioactive Waste Volume Estimates						
System	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
All systems <sup>1</sup>	RH-72B			419	371	371
<b>Subtotal</b>					<b>371</b>	<b>371</b>
<b>TOTAL (m<sup>3</sup>)</b>						<b>371</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>						<b>0.25</b>

1. The EnergySolutions presentation to the NWTRB does not provide sufficient detail to segregate the sources of remote handled TRU and GTCC waste by system. Waste packaged in RH-72B containers consists of fuel assembly hulls and ends plus <sup>129</sup>I waste (captured on silver mordenite).
2. Shaded areas (i.e. ) indicate waste streams that include compaction.

Table B.3.0-5 Summary of EnergySolutions Packaged <sup>85</sup> Kr Volume Estimates						
System	Container	Process		Maintenance and Operational		Subtotal (m <sup>3</sup> )
		Container Quantity	Volume (m <sup>3</sup> )	Container Quantity	Volume (m <sup>3</sup> )	
Offgas <sup>1</sup>	RH-72B			103	3	3
<b>Subtotal</b>					<b>3</b>	<b>3</b>
<b>TOTAL (m<sup>3</sup>)</b>						<b>3</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>						<b>0.002</b>

1. Waste packaged in gas bottles consists of <sup>85</sup>Kr gas to be placed in decay storage prior to eventual release. EnergySolutions does not define <sup>85</sup>Kr gas as a specific waste type.

#### B.4.0 References

1. Presentation by EnergySolutions to the U.S. Nuclear Waste Technical Review Board, *Closing the Nuclear Fuel Cycle, Implications for Nuclear Waste Management and Disposal*, September 23, 2009
2. S20-AD-010, *Barnwell Waste Management Facility Site Disposal Criteria Chem-Nuclear Systems Barnwell Office*, January 31, 2009, Revision 23
3. *Treatment of Plutonium Contaminated Material at Sellafield, Stakeholder Consultation, Briefing Note*, British Nuclear Group
4. *DOT Steel Box Reference Sheet*, Associated Container Sales and Fabrication, Inc. - Container Reference Sheet (available at [www.stomax.com](http://www.stomax.com))
5. *Cask Book for Model 14/210 & 14/215H*, EnergySolutions, Revision 14
6. Certificate of Compliance for Radioactive Material Packages, U.S. Nuclear Regulatory Commission, Certificate Number 9212, Revision 4, Docket Number 71-9212, Package Identification Number USA/9212/B(M)F-96

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## Appendix C

### Low Level Waste from Recycling and Vitrification Operations at the West Valley Reprocessing Facility

### C.1.0 Introduction

The West Valley reprocessing facility operated from April 1966 to November 1971. During that time 640 metric tons of used fuel was recycled using the PUREX process. The recycled fuel included commercial light water reactor (LWR) fuel from both pressurized water reactors (PWR) and boiling water reactors (BWR), and fuel from reactors owned by the federal government. During the period of operation, low level waste (LLW) was generated and disposed of in two disposal areas on site, one located within the plant exclusion area and licensed by the Nuclear Regulatory Commission (NRC) and the other located on site and licensed by the State of New York. Typically, leached hulls, non-fuel bearing assembly components, and other plant-generated waste too radioactive for disposal in the adjacent State-licensed disposal area (SDA) were buried in the NRC Disposal Area (NDA). High level liquid waste generated during reprocessing operations was stored in underground tanks. The high level liquid waste was later vitrified as part of the West Valley Demonstration Project (WVDP). Vitrification operations occurred over an approximately 5½ year period from June 1996 to November 2001. Low level waste from reprocessing operations (e.g. 1966 - 1971) and vitrification operations (e.g. 1996 - 2001) are combined to allow a more accurate comparison to low level waste estimates from other sources even though these operations were not conducted concurrently.

Comparison of West Valley LLW volumes to that of other recycling waste estimates such as the AREVA co-extraction facility (800 MTHM/year), the EnergySolutions NUEX facility (1,500 MTHM/year) or the Engineering Alternative Studies (EAS) UREX+1a facility (800 MTHM/year) facility is difficult. Since the West Valley facility operated at a capacity of about 100 MTHM/year, it would seem reasonable to compare it to the EAS 100 MTHM UREX+1a waste estimates; however, this comparison may not be valid since the design capacity of the West Valley facility was 300 MTHM/year. Nevertheless, a waste estimate based on the 100 MTHM/year EAS waste data is made for comparison, similar to that made for the EAS Co-Extraction facility and the EAS NUEX Facility in Appendices D and E respectively.

The EAS estimates provide a forecast of waste generated from a recycling facility utilizing the UREX+1a process at capacities of 800 MTHM/year and 100 MTHM/year (see Reference 1 and Appendix D). Since the EAS waste estimates are developed using a bottoms up methodology for each of the major process functions, an “EAS” estimate for the West Valley facility can be made by eliminating those process functions that are not relevant. Specifically, the following process functions can be eliminated to determine a waste estimate for the West Valley recycling facility based on the EAS data.

Offgas

U/Tc Separation

Tc Solidification

CCD/PEG

Cs/Sr Solidification

TRUEX

TALSPEAK

U/TRU Solidification (one half of the EAS values are retained, see discussion in paragraph below)



The “UREX” process function remains to provide an estimate of waste streams from the PUREX cycle since the two process cycles are similar. The FP Solidification process function is retained to account for low level waste generated as a result of high level waste vitrification operations. The plutonium product from West Valley reprocessing operations was a solution not an oxide powder; therefore, the “U/TRU Solidification” function is not relevant. One half of the U/TRU Solidification waste is retained, however, as an allowance for the West Valley Pu solution concentration and packaging operations. Similarly, waste from the Balance of Plant function is reduced by half to correspond with the elimination of many of the process functions not associated with the West Valley process.

### C.2.0 West Valley Waste Volume

Low level waste from West Valley reprocessing operations was disposed of in both the NDA and SDA. The total volume of waste disposed in the NDA and SDA at the West Valley reprocessing facility is documented in various publications such as the *Final Environmental Impact Statement for Decommissioning and/or Long-Term Stewardship at the West Valley Demonstration Project and Western New York Nuclear Service Center*.<sup>2</sup> Because disposal of wastes in these areas continued after reprocessing operations ceased and because disposal preceded the definitions of waste classifications contained in 10CFR61, *Licensing Requirements for Land Disposal of Radioactive Waste*, it is difficult to determine specific volumes of Class A, B, C and greater than Class C (GTCC) waste generated by West Valley reprocessing operations. Correspondence with personnel from the WVDP has provided an estimate of wastes generated by reprocessing operations at West Valley based on the waste classifications contained in 10CFR61.<sup>3</sup> These estimates are shown in Table C.2.0-1. Mixed waste volumes were not identified or quantified by the WVDP personnel.

Estimate Basis (MTHM)	Disposal Area <sup>2</sup>	Volume and Radioactivity	Class A/B/C Low Level Waste				GTCC
			A	B	C	Total	
640 (Note 3)	SDA	m <sup>3</sup>	9,108	0	6	9,114	0
		Curies	33.9	0	0.3	34.2	0
	NDA	m <sup>3</sup>	885	37	430	1,352	2,081
		Curies	29.6	12.0	512.1	553.7	296,026
Total		m <sup>3</sup>	9,993	37	436	10,466	2,081
		m <sup>3</sup> /year	1,816.9	6.7	79.3	1,902.9	378.4
		m <sup>3</sup> /MTHM	15.6	0.1	0.7	16.4	3.3
		Curies	63.5	12.0	512.4	587.9	296,026
		Curies/m <sup>3</sup>	0.0064	0.32	1.18	0.056	142.25

1. Data was obtained from correspondence with personnel with the West Valley Demonstration Project (Reference 3).
2. SDA - State Licensed Disposal Area, NDA - NRC Licensed Disposal Area
3. The West Valley reprocessing facility had a design capacity of 300 MTHM/year. The facility actually processed 640 MTHM over a period of about 5½ years.

Low level waste from West Valley vitrification operations was disposed of in the NDA only. Correspondence with personnel from the WVDP has provided an estimate of wastes generated by vitrification operations at West Valley based on the waste classifications contained in 10CFR61.<sup>3</sup> These estimates are shown in Table C.2.0-2. Mixed waste volumes were not identified or quantified by the WVDP personnel.

Estimate Basis (MTHM)	Disposal Area <sup>2</sup>	Volume and Radioactivity	Class A/B/C Low Level Waste				GTCC
			A	B	C	Total	
640 (Note 3)	SDA	m <sup>3</sup>	0	0	0	0	0
		Curies	0	0	0	0	0
	NDA	m <sup>3</sup>	3,317	11	18	3,346	31
		Curies	26.9	5.8	6.6	39.3	1,159
Total		m <sup>3</sup>	3,317	11	18	3,346	31
		m <sup>3</sup> /year	603.1	2.0	3.2	608.4	5.6
		m <sup>3</sup> /MTHM (Note 4)	5.2	0.1	0.1	5.2	3.3
		Curies	26.9	5.8	6.6	39.3	1,159
		Curies/m <sup>3</sup>	0.008	0.53	0.37	0.012	37.39

1. Data was obtained from correspondence with personnel with the West Valley Demonstration Project (Reference 3).
2. SDA - State Licensed Disposal Area, NDA - NRC Licensed Disposal Area
3. The West Valley reprocessing facility had a design capacity of 300 MTHM/year. The facility actually processed 640 MTHM over a period of about 5½ years.
4. Normalized values for Class B and C wastes are rounded up to the nearest tenth; therefore, the individual values do not sum to the total shown.

The total low level waste volumes from reprocessing and vitrification combined are shown in Table C.2.0-3.

Operational Phase	Class A/B/C Low Level Waste				GTCC
	A	B	C	Total	
Reprocessing	9,993	37	436	10,466	2,081
Vitrification	3,317	11	18	3,346	31
Total (m <sup>3</sup> )	13,310	48	454	13,812	2,112
Total (m <sup>3</sup> /year) <sup>1</sup>	2,420.0	8.7	82.6	2,511.3	384.0
Total (m <sup>3</sup> /MTHM) <sup>2</sup>	20.8	0.1	0.7	21.6	3.3

1. Annual volume is based on operation for 5½ years.
2. The normalized waste volume is based on a total of 640 MTHM processed, nominally 115 MTHM/year.

### **C.3.0 Waste Volume Estimates for West Valley Reprocessing Operations Based on EAS Waste Estimates**

Tables C.3.0-1 through C.3.0-4 below provide waste estimates for the West Valley reprocessing facility based on the EAS data for the 100 MTHM/year UREX+1a process provided in Appendix D, Tables D.4.0-1 through D.4.0-4. Relevant process functions have been deleted to determine these waste estimates as described in Section C.1.0 above. Mixed waste volumes are not estimated since there are no historical mixed waste volume quantities to compare.

<b>Table C.3.0-1                      Summary Of Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates                      For The West Valley Reprocessing Facility Based On EAS Data</b>					
<b>System</b>	<b>Container <sup>1</sup></b>	<b>Annual Waste Volume (m<sup>3</sup>)</b>			
		<b>Operational</b>	<b>Job Control</b>	<b>Maintenance</b>	<b>Subtotal</b>
Fuel Receipt	E	6.0			6.0
	H	4.2		1.0	5.2
	L	18.1	447.5	1.8	467.4
Shearing/Dissolving	E		0	3.4	3.4
	L		310.7	0.4	311.1
Offgas		Not Applicable			0
UREX	E		0	4.9	4.9
	L		130.6	0	130.6
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	E		0	3.4	3.4
	L		251.7	1.6	253.3
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUOX		Not Applicable			0
FP Solidification	E		0	7.2	7.2
	L		374.6	1.4	376.0
TALSPEAK		Not Applicable			0
U/TRU Solidification <sup>2</sup>	E		0	0.1	0.1
	L	0.2	66.0	0.5	66.7
Acid Recovery	E		0	2.7	2.7
	L		68.4	1.3	69.7
Solvent Recovery	E		0	10.3	10.3
	L		464.4	0	464.4
HAW	E		0	6.3	6.3
	L		117.5	0	117.5
LAW	E		0	3.5	3.5
	L		117.5	0	117.5
Waste Handling	L	16.8	803.3	0.6	820.7
Analytical	L		1,206.7	0.9	1,207.6
Chemical Receipt			0	0	0
Balance of Plant <sup>3</sup>	E		0	8.6	8.6
	L		2,534.2	2,507.8	5,042.0
	S	75.0	0	0	75.0
<b>Subtotal</b>		<b>120.3</b>	<b>6,893.1</b>	<b>2,567.7</b>	<b>9,581.1</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>9,581.1</b>			
<b>TOTAL (m<sup>3</sup>/MTHM) <sup>4</sup></b>		<b>83.3</b>			

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box
2. The values listed for U/TRU Solidification are half of the values listed for the EAS 100 MTHM/year UREX+1a facility since the West Valley plutonium product was a concentrated solution and not oxide powder.
3. The values listed for Balance of Plant function are half of the values listed for the EAS 100 MTHM/year UREX+1a facility to correspond with the elimination of many of the process functions not associated with the West Valley process.
4. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM ÷ 5.5 years ≈ 115)

**Table C.3.0-2  
 Summary Of Annual Packaged Low Level Solid Waste Volume Estimates  
 For The West Valley Reprocessing Facility Based On EAS Data**

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	56.4	Undetermined	70.5	Undetermined	70.5
High integrity container	5.2	33	8.3	33	8.3
Low level waste disposal box <sup>3,5</sup>	9,444.5	4,723	11,807.5	945	2,361.1
Solidified low level waste disposal box	75	125	150.0	125	150.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>9,581.1</b>		<b>12,036.3</b>		<b>2,589.9</b>
<b>TOTAL (m<sup>3</sup>/MTHM) <sup>6</sup></b>	<b>83.3</b>		<b>104.7</b>		<b>22.5</b>

1. From Table C.3.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $56.4 \div 0.80 = 70.5$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.
5. Package Quantity for the uncompacted waste scenario is determined by application of an 80% packing efficiency, i.e.  $9,444.5 \div 0.80 \div 2.5$  (internal volume from Appendix D, Table D.2.0-1) = 4,723.
6. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM  $\div$  5.5 years  $\approx$  115)

<b>Table C.3.0-3</b>					
<b>Summary Of Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates</b>					
<b>For The West Valley Reprocessing Facility Based On EAS Data</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					0
Shearing/Dissolving	A	7.3			7.3
	G			0.1	0.1
Offgas		Not Applicable			0
UREX					0
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification					0
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification					0
TALSPEAK		Not Applicable			0
U/TRU Solidification <sup>2</sup>	E			0.3	0.3
	G	0.5	54.7	0.7	55.8
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	0.6			0.6
Analytical					0
Chemical Receipt					0
Balance of Plant					0
Subtotal		8.4	54.7	1.1	64.1
<b>TOTAL (m<sup>3</sup>)</b>		<b>64.1</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>0.6</b>			

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. The values listed for U/TRU Solidification are half of the values listed for the EAS 100 MTHM/year UREX+1a facility since the West Valley plutonium product was a concentrated solution and not oxide powder.

<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Universal container	7.3	9	8.1
Engineered container	0.3	Undetermined	0.4
GTCC waste disposal container <sup>3</sup>	56.5	44	74.8
<b>TOTAL (m<sup>3</sup>)</b>	<b>64.1</b>		<b>83.3</b>
<b>TOTAL (m<sup>3</sup>/MTHM)<sup>4</sup></b>	<b>0.6</b>		<b>0.7</b>

1. From Table C.3.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $0.3 \div 0.80 = 0.4$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Package Quantity is determined by application of an 80% packing efficiency, i.e.  $56.5 \div 0.80 \div 1.6$  (internal volume from Appendix D, Table D.2.0-1) = 44.
4. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley ( $640 \text{ MTHM} \div 5.5 \text{ years} \approx 115$ ).

#### C.4.0 Conclusions

Table C.4.0-1 shows a comparison of the actual West Valley waste data to waste estimates of West Valley waste volume based on EAS data. As can be seen from the data, low level waste (Class A, B and C) volumes are in very close agreement; however, GTCC waste volumes based on EAS data are much smaller than actual West Valley waste volumes.

<b>Waste Volume Basis</b>	<b>Volume</b>	<b>Class A/B/C Low Level Waste</b>				<b>GTCC</b>
		<b>A</b>	<b>B</b>	<b>C</b>	<b>Total</b>	
Actual West Valley Waste Volume	m <sup>3</sup> /year	2,420.0	8.7	82.6	2,511.3	384.0
	m <sup>3</sup> /MTHM	20.8	0.1	0.7	21.6	3.3
Estimated West Valley Waste Volume Based on EAS Data	m <sup>3</sup> /year				2,589.9	83.3
	m <sup>3</sup> /MTHM				22.5	0.7

Generating a West Valley waste volume estimate based on EAS data on one hand appears very accurate (i.e for low level waste). On the other hand, the process does not appear very reliable for GTCC waste. This can partially be explained by the assumption that only 50% of the waste volume from the EAS U/TRU Solidification function is applicable to the EAS West Valley estimate. Although a sensitivity analysis to determine the waste volume using 100% of the EAS U/TRU Solidification waste volume indicates better agreement (see Table 4.0-2 compared to Table 3.0-4), this does not necessarily invalidate the assumption but points out the limitations of the process and the sensitivity of the estimates to assumptions.

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Universal container	7.3	9	8.1
Engineered container	0.6	Undetermined	0.8
GTCC waste disposal container <sup>3</sup>	112.3	88	149.6
<b>TOTAL (m<sup>3</sup>)</b>	<b>120.2</b>		<b>158.5</b>
<b>TOTAL (m<sup>3</sup>/MTHM)<sup>4</sup></b>	<b>1.1</b>		<b>1.4</b>

### C.5.0 References

1. WH-G-ESR-G-00051, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 800 MT/year UREX+1a*, August 4, 2008, Revision 2
2. DOE/EIS-0226, *Final Environmental Impact Statement for Decommissioning and/or Long-Term Stewardship at the West Valley Demonstration Project and Western New York Nuclear Service Center*, January 2010
3. Personal correspondence, Sandra Birk of the Idaho National Laboratory with personnel from the West Valley Demonstration Project, December 2009 - January 2010.



## Appendix D

### Waste Estimates for the EAS UREX+1a Facility

### D.1.0 Introduction

The Engineering Alternatives Studies (EAS) for Separations provided a forecast of waste generated from a recycling facility utilizing the UREX+1a process at capacities of 800 MTHM/year and 100 MTHM/year.<sup>1</sup> The EAS study provides waste estimates for high level waste (HLW), Greater Than Class C (GTCC) waste, low level waste (LLW), mixed waste, hazardous waste and non-hazardous waste. The EAS study does not make a distinction between Class A, B or C waste types. Note that HLW, hazardous waste and non-hazardous waste are not within the scope of the LLW Disposition - Quantities and Inventories study; therefore, it is not addressed in this appendix.

For the 800 MTHM/year facility, the EAS study utilizes a bottoms up methodology to estimate annual waste quantities from each of the major process functions of the UREX+1a process (e.g. fuel receipt, dissolving, offgas, UREX, CCD/PEG/ fission product solidification, U/TRU solidification, etc.). For the 100 MTHM/year facility, the waste volumes from the 800 MTHM/year case are adjusted by factors based on parameters such as capacity, staffing levels, quantity of radiological workers and facility footprint. Waste from the major process operations is categorized as either operational waste, job control waste or maintenance waste. Waste is characterized based on its source and category (i.e. operational, job control, maintenance) as follows:

#### Low level waste

- operational and maintenance waste from process operations that do not handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55 (e.g. maintenance waste from the Cs/Sr Solidification process is generally considered GTCC waste)
- job control waste from routine operations and minor maintenance activities, even those associated with process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55
- 25% of the job control waste from major maintenance activities associated with process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55 (25% is an allowance for successful decontamination of GTCC waste to below low level limits)

#### GTCC waste

- operational and maintenance waste from process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55 (e.g. maintenance waste from the Cs/Sr Solidification process is considered GTCC waste)
- some allowance is made for decontamination of GTCC waste (such as some failed equipment) to low levels based on engineering judgment
- 75% of the job control waste from major maintenance activities associated with process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55

#### Mixed waste

- any low level or GTCC waste also containing hazardous constituents

**D.2.0 EAS Waste Packages**

The radioactive waste packages considered for use in the EAS study include:

- 55 gallon drums
- low level waste disposal boxes
- solidified low level waste disposal boxes
- high integrity containers
- GTCC disposal containers
- universal containers
- engineered containers of undetermined size

Details of the containers are shown in Table D.2.0-1 below.

<b>Table D.2.0-1 EAS Radioactive Waste Packages</b>						
<b>Container</b>	<b>Description</b>	<b>Exterior Dimensions</b>	<b>Exterior Volume</b>	<b>Interior Volume</b>	<b>Weight</b>	<b>Usage</b>
Drum			55 gallons (0.2 m <sup>3</sup> )	55 gallons (0.2 m <sup>3</sup> )		- mixed waste - bulk loaded into drum (not compacted)
Low level waste disposal box		6' long x 4' deep x 4' high	2.5 m <sup>3</sup>	2.5 m <sup>3</sup>		- solid low level waste - bagged waste loaded directly into container - compacted waste reduced to 25% of the original volume
Solidified low level waste disposal box		6' long x 4' deep x 2' high	1.2 m <sup>3</sup>	1.2 m <sup>3</sup>		- solidified liquid low activity waste - solidified waste placed directly into container
High integrity containers			0.25 m <sup>3</sup>	0.2 m <sup>3</sup>		- low level waste requiring greater containment
GTCC disposal containers	- similar to Waste Isolation Pilot Plant (WIPP) standard waste boxes (SWB)		1.7 m <sup>3</sup>	1.6 m <sup>3</sup>		- GTCC waste - bulk loaded into container - can be used to overpack 55 gallon drums
Universal containers	- stainless steel - welded closure - outwardly similar to high level vitrified waste canisters	2' diameter x 10' high	0.9 m <sup>3</sup>		3,600 kg capacity	- GTCC waste (hulls and hardware) - compactable waste
Engineered containers	- specifically designed to accommodate the waste item such as large failed equipment	unspecified	unspecified	unspecified		- used for waste that is not suitable for packaging into other standard containers

### **D.3.0 EAS Packaged Waste Volume Estimates for an 800 MTHM/year Recycling Facility Using the UREX+1a Process**

The waste estimates provided in the EAS study are stated in terms of the annual quantity of bulk (unpackaged) waste and packaged waste with no allowance for volume reduction (e.g. compaction). Additionally, an estimate of packaged low level waste volume is provided with an allowance for compaction. The packaged waste volume estimates (both with compaction and without compaction) include estimates of waste container quantities. The waste estimates for an 800 MTHM/year recycling facility using a UREX+1a process provided in the EAS study are shown below in Tables D.3.0-1 through D.3.0-8.

<b>Table D.3.0-1</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates</b>					
<b>From An 800 MTHM/year Recycling Facility Using The UREX+1a Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	48.0			48.0
	H	33.1		8.0	41.1
	L	144.3	693.0	14.5	851.8
Shearing/Dissolving	E		0	27.1	27.1
	L		481.2	2.9	484.1
Offgas	E		0	2.1	2.1
	L		33.6	0	33.6
UREX	E		0	39.2	39.2
	L		202.2	0	202.2
U/Tc Separation	E		0	11.6	11.6
	L		86.2	10.3	96.5
Tc Solidification	E		0	5.9	5.9
	L		102.2	10.3	112.5
U Solidification	E		0	27.0	27.0
	L		389.7	12.7	402.4
CCD/PEG	E		0	38.9	38.9
	L		76.6	0	76.6
Cs/Sr Solidification	E		0	8.3	8.3
	L		233.3	3.4	236.7
TRUEX	E		0	16.5	16.5
	L		202.2	0	202.2
FP Solidification	E		0	57.3	57.3
	L		580.1	10.7	590.8
TALSPEAK	E		0	16.8	16.8
	L		76.6	0	76.6
U/TRU Solidification	E		0	1.4	1.4
	L	2.5	204.5	6.6	213.6
Acid Recovery	E		0	21.6	21.6
	L		105.9	10.0	115.9
Solvent Recovery	E		0	82.6	82.6
	L		719.2	0	719.2
HAW	E		0	50.5	50.5
	L		181.9	0	181.9
LAW	E		0	27.9	27.9
	L		181.9	0	181.9
Waste Handling	L	135.5	1,243.9	4.7	1,384.1
Analytical	L		1,868.7	7.0	1,875.7
Chemical Receipt			0	0	0
Balance of Plant	E		0	137.0	137.0
	L		7,848.9	7,165.0	15,013.9
	S	1,200.0	0	0	1,200.0
<b>Subtotal</b>		<b>1,563.4</b>	<b>15,511.8</b>	<b>7,837.8</b>	<b>24,913.0</b>
<b>TOTAL (m<sup>3</sup>)</b>					<b>24,913.0</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>					<b>31.1</b>

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

<b>Table D.3.0-2</b>					
<b>Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates</b>					
<b>From An 800 MTHM/year Recycling Facility Using The UREX+1a Process</b>					
Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	619.7	Undetermined	774.6	Undetermined	774.6
High integrity container	41.1	257	64.0	257	64.0
Low level waste disposal box <sup>3</sup>	23,052.2	11,526	28,815.0	2,305	5,762.5
Solidified low level waste disposal box	1,200	1,000	1,200.0	1,000	1,200.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>24,913.0</b>		<b>30,853.6</b>		<b>7,801.1</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>31.1</b>		<b>38.6</b>		<b>9.8</b>

1. From Table D.3.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $619.7 \div 0.80 = 774.6$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	57.8			57.8
	G			0.3	0.3
Offgas	E			0.2	0.2
UREX					0
U/Tc Separation	E			0.5	0.5
	G		112.8		112.8
Tc Solidification	G	0.1	112.8		112.9
U Solidification					0
CCD/PEG	G		112.8		112.8
Cs/Sr Solidification	E			11.9	11.9
	G		169.2		169.2
TRUEX	E			27.2	27.2
FP Solidification					0
TALSPEAK	E			26.6	26.6
	G		112.8		112.8
U/TRU Solidification	E			3.4	3.4
	G	7.4	169.2	10.0	186.6
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	4.8			4.8
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>		<b>70.1</b>	<b>789.6</b>	<b>80.1</b>	<b>939.8</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>939.8</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>1.2</b>		

1. A – universal containers, E – engineered containers, G – GTCC disposal containers

<b>Table D.3.0-4                      Summary Of EAS Annual Packaged GTCC Solid                      Waste Volume Estimates From An                      800 MTHM/year Recycling Facility Using The UREX+1a Process</b>			
<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Universal container	57.8	70	63.0
Engineered container	69.8	Undetermined	87.3
GTCC waste disposal container	812.2	634	1,078.7
<b>TOTAL (m<sup>3</sup>)</b>	<b>939.8</b>		<b>1,229.0</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>1.2</b>		<b>1.5</b>

1. From Table D.3.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $69.8 \div 0.80 = 87.3$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table D.2.0-1.



System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.3	0.3
Shearing/Dissolving	D			0.8	0.8
	E			3.5	3.5
Offgas	D			0.3	0.3
UREX	D			0.3	0.3
U/Tc Separation	D			0.3	0.3
Tc Solidification	D			0.3	0.3
U Solidification	D			0.3	0.3
CCD/PEG	D			0.3	0.3
Cs/Sr Solidification	D			0.3	0.3
TRUEX	D			0.3	0.3
FP Solidification	D			0.4	0.4
TALSPEAK	D			0.3	0.3
U/TRU Solidification	D			0.3	0.3
Acid Recovery	D			0.3	0.3
Solvent Recovery	D			0.3	0.3
HAW	D			0.3	0.3
LAW	D			0.3	0.3
Waste Handling	D			1.5	1.5
Analytical	D			2.5	2.5
Chemical Receipt				0	0
Balance of Plant	D			2.9	2.9
<b>Subtotal</b>				<b>16.1</b>	<b>16.1</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>16.1</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.02</b>		

1. D – drums, E – engineered containers

<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Drum	12.6	126	25.2
Engineered container	3.5	Undetermined	7.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>16.1</b>		<b>32.2</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.02</b>		<b>0.04</b>

1. From Table D.3.0-5
2. Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $3.5 \div 0.50 = 7.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table D.2.0-1 with a packing efficiency of 50%.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving					
Offgas					
UREX					
U/Tc Separation					
Tc Solidification	E			3.6	3.6
U Solidification					
CCD/PEG					
Cs/Sr Solidification	E			20.9	20.9
TRUEX					
FP Solidification	E			34.1	34.1
TALSPEAK					
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>58.6</b>	<b>58.6</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>58.6</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.07</b>		

1. E – engineered containers

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	58.6	Undetermined	76.9
<b>TOTAL (m<sup>3</sup>)</b>	<b>58.6</b>		<b>76.9</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.07</b>		<b>0.1</b>

1. From Table D.3.0-7
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $58.6 \div 0.80 \times 1.05 = 76.9$ ).

The EAS study also estimated a low activity liquid waste stream. The EAS study assumed this waste stream would be sent to an offsite permitted facility for treatment and disposal and did not provide an estimate of final (i.e. treated) waste packages for this waste stream. The final waste volume is expected to be insignificant and is not considered further in this study. The estimates from the EAS study are provided for reference only in Table D.3.0-9 below.

<b>Table D.3.0-9</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Low Activity Liquid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (liters)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			100	100
Shearing/Dissolving	D			116	116
Offgas	D			100	100
UREX	D			80	80
U/Tc Separation	D			40	40
Tc Solidification	D			100	100
U Solidification	D			100	100
CCD/PEG	D			80	80
Cs/Sr Solidification	D			60	60
TRUEX	D			160	160
FP Solidification	D			200	200
TALSPEAK	D			160	160
U/TRU Solidification				0	0
Acid Recovery	D			60	60
Solvent Recovery	D			600	600
HAW	D			100	100
LAW	D			100	100
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>2,156</b>	<b>2,156</b>
<b>TOTAL (liters)</b>				<b>2,156</b>	
<b>TOTAL (liters/MTHM)</b>				<b>2.7</b>	

1. D – drums

#### **D.4.0 EAS Packaged Waste Volume Estimates for a 100 MTHM/year Recycling Facility Using the UREX+1a Process**

The waste estimates for a 100 MTHM/year recycling facility using the UREX+1a process provided in the EAS study are shown below in Tables D.4.0-1 through D.4.0-8.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	6.0			6.0
	H	4.2		1.0	5.2
	L	18.1	447.5	1.8	467.4
Shearing/Dissolving	E		0	3.4	3.4
	L		310.7	0.4	311.1
Offgas	E		0	0.3	0.3
	L		21.7	0	21.7
UREX	E		0	4.9	4.9
	L		130.6	0	130.6
U/Tc Separation	E		0	1.5	1.5
	L		55.7	1.3	57.0
Tc Solidification	E		0	0.8	0.8
	L		66.0	1.3	67.3
U Solidification	E		0	3.4	3.4
	L		251.7	1.6	253.3
CCD/PEG	E		0	4.9	4.9
	L		49.5	0	49.5
Cs/Sr Solidification	E		0	1.1	1.1
	L		150.7	0.5	151.2
TRUEX	E		0	2.1	2.1
	L		130.6	0	130.6
FP Solidification	E		0	7.2	7.2
	L		374.6	1.4	376.0
TALSPEAK	E		0	2.1	2.1
	L		49.5	0	49.5
U/TRU Solidification	E		0	0.2	0.2
	L	0.4	132.1	0.9	133.4
Acid Recovery	E		0	2.7	2.7
	L		68.4	1.3	69.7
Solvent Recovery	E		0	10.3	10.3
	L		464.4	0	464.4
HAW	E		0	6.3	6.3
	L		117.5	0	117.5
LAW	E		0	3.5	3.5
	L		117.5	0	117.5
Waste Handling	L	16.8	803.3	0.6	820.7
Analytical	L		1,206.7	0.9	1,207.6
Chemical Receipt			0	0	0
Balance of Plant	E		0	17.2	17.2
	L		5,068.4	5,015.5	10,083.9
	S	150.0	0	0	150.0
<b>Subtotal</b>		<b>195.5</b>	<b>10,017.1</b>	<b>5,100.4</b>	<b>15,313.0</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>15,313</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>153.1</b>		

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	77.9	Undetermined	97.4	Undetermined	97.4
High integrity container	5.2	32.5	8.2	257	8.2
Low level waste disposal box <sup>3</sup>	15,079.9	7,540	18,850.0	1,508	3,770.0
Solidified low level waste disposal box	150.0	125	150.0	125	150.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>15,313.0</b>		<b>19,105.6</b>		<b>4,025.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>153.1</b>		<b>191.1</b>		<b>40.3</b>

1. From Table D.4.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $77.9 \div 0.80 = 97.4$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.

<b>Table D.4.0-3</b>					
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	7.3			7.3
	G			0.1	0.1
Offgas	E			0.1	0.1
UREX					0
U/Tc Separation	E			0.1	0.1
	G		72.8		72.8
Tc Solidification	G	0.1	72.8		72.9
U Solidification					0
CCD/PEG	G		72.8		72.8
Cs/Sr Solidification	E			1.5	1.5
	G		109.3		109.3
TRUEX	E			3.4	3.4
FP Solidification					0
TALSPEAK	E			6.8	6.8
	G		72.8		72.8
U/TRU	E			0.5	0.5
Solidification	G	1.0	109.3	1.3	111.6
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	0.6			0.6
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>		<b>9.0</b>	<b>509.8</b>	<b>13.8</b>	<b>532.6</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>532.6</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>5.3</b>		

1. A – universal containers, E – engineered containers, G – GTCC disposal containers

<b>Table D.4.0-4</b>			
<b>Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process</b>			
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Universal container	7.3	9	8.1
Engineered container	12.4	Undetermined	15.5
GTCC waste disposal container	512.9	401	681.7
<b>TOTAL (m<sup>3</sup>)</b>	<b>532.6</b>		<b>705.3</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>5.3</b>		<b>7.1</b>

1. From Table D.4.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $12.4 \div 0.80 = 15.5$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table D.2.0-1.



<b>Table D.4.0-5</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.1	0.1
Shearing/Dissolving	D			0.1	0.1
	E			0.5	0.5
Offgas	D			0.1	0.1
UREX	D			0.1	0.1
U/Tc Separation	D			0.1	0.1
Tc Solidification	D			0.1	0.1
U Solidification	D			0.1	0.1
CCD/PEG	D			0.1	0.1
Cs/Sr Solidification	D			0.1	0.1
TRUEX	D			0.1	0.1
FP Solidification	D			0.1	0.1
TALSPEAK	D			0.1	0.1
U/TRU Solidification	D			0.1	0.1
Acid Recovery	D			0.1	0.1
Solvent Recovery	D			0.1	0.1
HAW	D			0.1	0.1
LAW	D			0.1	0.1
Waste Handling	D			0.2	0.2
Analytical	D			0.3	0.3
Chemical Receipt				0	0
Balance of Plant	D			2.1	2.1
<b>Subtotal</b>				<b>4.8</b>	<b>4.8</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>4.8</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.05</b>		

1. D – drums, E – engineered containers

<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Drum	4.3	43	8.6
Engineered container	0.5	Undetermined	1.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>4.8</b>		<b>9.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.05</b>		<b>0.1</b>

1. From Table D.4.0-5. Note that Tables A.2.5-2 and A.2.5-3 in Reference 1 list the bulk waste volume to be packaged in drums as 4.8 m<sup>3</sup> instead of the 4.3 m<sup>3</sup> listed above in Table D.4.0-6. The value listed in the tables in Reference 1 is in error.
2. Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $0.5 \div 0.50 = 1.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table D.2.0-1 with a packing efficiency of 50%.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving					
Offgas					
UREX					
U/Tc Separation					
Tc Solidification	E			0.5	0.5
U Solidification					
CCD/PEG					
Cs/Sr Solidification	E			2.6	2.6
TRUEX					
FP Solidification	E			4.3	4.3
TALSPEAK					
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>7.4</b>	<b>7.4</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>7.4</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.07</b>		

1. E – engineered containers

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	7.4	Undetermined	9.7
<b>TOTAL (m<sup>3</sup>)</b>	<b>7.4</b>		<b>9.7</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.07</b>		<b>0.1</b>

1. From Table D.4.0-7
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $7.4 \div 0.80 \times 1.05 = 9.7$ ).

The estimates from the EAS study for low activity liquid waste are provided for reference only in Table D.4.0-9 below. As stated previously for the 800 MTHM/year estimates, the final waste volume is expected to be insignificant and is not considered further in this study.

<b>Table D.4.0-9</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Low Activity Liquid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (liters)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			13	13
Shearing/Dissolving	D			15	15
Offgas	D			13	13
UREX	D			10	10
U/Tc Separation	D			5	5
Tc Solidification	D			13	13
U Solidification	D			13	13
CCD/PEG	D			10	10
Cs/Sr Solidification	D			8	8
TRUEX	D			20	20
FP Solidification	D			25	25
TALSPEAK	D			20	20
U/TRU Solidification				0	0
Acid Recovery	D			8	8
Solvent Recovery	D			75	75
HAW	D			13	13
LAW	D			13	13
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>274</b>	<b>274</b>
<b>TOTAL (liters)</b>				<b>274</b>	
<b>TOTAL (liters/MTHM)</b>				<b>2.7</b>	

1. D – drums

#### D.5.0 References

1. WH-G-ESR-G-00051, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 800 MT/year UREX+1a*, August 4, 2008, Revision 2

## Appendix E

### Waste Estimates for an EAS Co-Extraction Facility

### **E.1.0 Introduction**

The Engineering Alternatives Studies (EAS) for Separations provided a forecast of waste generated from a recycling facility utilizing the UREX+1a process at capacities of 800 MTHM/year and 100 MTHM/year (see Reference 1 and Appendix D). An estimate of wastes from an aqueous co-extraction facility were not made as part of the EAS; however, since the EAS waste estimates are developed using a bottoms up methodology for each of the major process functions, an estimate for an aqueous co-extraction facility can be made by eliminating those process functions that are not relevant to the co-extraction process. Specifically, the following process functions can be eliminated to determine a waste estimate for a co-extraction process based on the EAS data.

- U/Tc Separation
- Tc Solidification
- CCD/PEG
- Cs/Sr Solidification
- TRUEX
- TALSPEAK

The “UREX” process function remains to provide an estimate of waste streams from the co-extraction cycle since the two process cycles are similar. The “U/TRU Solidification” function remains to provide an estimate of the “U/Pu Solidification” function of the co-extraction process since those processes are also similar.

### **E.2.0 EAS Waste Packages**

The radioactive waste packages applicable to the co-extraction process are the same as those listed for the UREX+1a process in Appendix D.

### **E.3.0 EAS Packaged Waste Volume Estimates for an 800 MTHM/year Recycling Facility Using the Co-Extraction Process**

Tables E.3.0-1 through E.3.0-8 below provide waste estimates for an 800 MTHM/year co-extraction facility based on the EAS data for the UREX+1a process provided in Appendix D, Tables C.3.0-1 through C.3.0-8. Relevant process functions have been deleted to determine these waste estimates as described in Section E.1.0 above.

<b>Table E.3.0-1</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates</b>					
<b>From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	48.0			48.0
	H	33.1		8.0	41.1
	L	144.3	693.0	14.5	851.8
Shearing/Dissolving	E		0	27.1	27.1
	L		481.2	2.9	484.1
Offgas	E		0	2.1	2.1
	L		33.6	0	33.6
UREX	E		0	39.2	39.2
	L		202.2	0	202.2
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	E		0	27.0	27.0
	L		389.7	12.7	402.4
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification	E		0	57.3	57.3
	L		580.1	10.7	590.8
TALSPEAK		Not Applicable			0
U/TRU Solidification	E		0	1.4	1.4
	L	2.5	204.5	6.6	213.6
Acid Recovery	E		0	21.6	21.6
	L		105.9	10.0	115.9
Solvent Recovery	E		0	82.6	82.6
	L		719.2	0	719.2
HAW	E		0	50.5	50.5
	L		181.9	0	181.9
LAW	E		0	27.9	27.9
	L		181.9	0	181.9
Waste Handling	L	135.5	1,243.9	4.7	1,384.1
Analytical	L		1,868.7	7.0	1,875.7
Chemical Receipt			0	0	0
Balance of Plant	E		0	137.0	137.0
	L		7,848.9	7,165.0	15,013.9
	S	1,200.0	0	0	1,200.0
<b>Subtotal</b>		<b>1,563.4</b>	<b>14,734.7</b>	<b>7,715.8</b>	<b>24,013.9</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>24,013.9</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>30.0</b>			

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	521.7	Undetermined	652.1	Undetermined	652.1
High integrity container	41.1	257	64.0	257	64.0
Low level waste disposal box <sup>3,5</sup>	22,251.1	11,126	27,815.0	2,225	5,562.5
Solidified low level waste disposal box	1,200.0	1,000	1,200.0	1,000	1,200.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>24,013.9</b>		<b>29,731.1</b>		<b>7,478.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>30.0</b>		<b>37.2</b>		<b>9.3</b>

1. From Table E.3.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $521.7 \div 0.80 = 652.1$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.
5. Package Quantity for the uncompacted waste scenario is determined by application of an 80% packing efficiency, i.e.  $22,251.1 \div 0.80 \div 2.5$  (internal volume from Appendix D, Table D.2.0-1).



<b>Table E.3.0-3</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates</b>					
<b>From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	57.8			57.8
	G			0.3	0.3
Offgas	E			0.2	0.2
UREX					0
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification					0
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification					0
TALSPEAK		Not Applicable			0
U/TRU	E			3.4	3.4
Solidification	G	7.4	169.2	10.0	186.6
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	4.8			4.8
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>		<b>70.0</b>	<b>169.2</b>	<b>13.9</b>	<b>253.1</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>253.1</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>0.32</b>			

1. A – universal containers, E – engineered containers, G – GTCC disposal containers

<b>Table E.3.0-4</b>			
<b>Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process</b>			
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Universal container	57.8	70	63.0
Engineered container	3.6	Undetermined	4.5
GTCC waste disposal container <sup>3</sup>	191.7	150	255.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>253.1</b>		<b>322.5</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.32</b>		<b>0.40</b>

1. From Table E.3.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $3.6 \div 0.80 = 4.5$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Package Quantity is determined by application of an 80% packing efficiency, i.e.  $191.7 \div 0.80 \div 1.6$  (internal volume from Appendix D, Table D.2.0-1).

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.3	0.3
Shearing/Dissolving	D			0.8	0.8
	E			3.5	3.5
Offgas	D			0.3	0.3
UREX	D			0.3	0.3
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	D			0.3	0.3
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification	D			0.4	0.4
TALSPEAK		Not Applicable			0
U/TRU Solidification	D			0.3	0.3
Acid Recovery	D			0.3	0.3
Solvent Recovery	D			0.3	0.3
HAW	D			0.3	0.3
LAW	D			0.3	0.3
Waste Handling	D			1.5	1.5
Analytical	D			2.5	2.5
Chemical Receipt				0	0
Balance of Plant	D			2.9	2.9
<b>Subtotal</b>				<b>14.3</b>	<b>14.3</b>
<b>TOTAL (m<sup>3</sup>)</b>				<b>14.3</b>	
<b>TOTAL (m<sup>3</sup>/MTHM)</b>				<b>0.02</b>	

1. D – drums, E – engineered containers

<b>Table E.3.0-6</b>			
<b>Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process</b>			
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Drum	10.8	108	21.6
Engineered container	3.5	Undetermined	7.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>14.3</b>		<b>28.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.02</b>		<b>0.04</b>

1. From Table E.3.0-5
2. Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $3.5 \div 0.50 = 7.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1 with a packing efficiency of 50%.

<b>Table E.3.0-7</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			Subtotal
		Operational	Job Control	Maintenance	
Fuel Receipt					
Shearing/Dissolving					
Offgas					
UREX					
U/Tc Separation		Not Applicable			
Tc Solidification		Not Applicable			
U Solidification					
CCD/PEG		Not Applicable			
Cs/Sr Solidification		Not Applicable			
TRUEX		Not Applicable			
FP Solidification	E			34.1	34.1
TALSPEAK		Not Applicable			
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>34.1</b>	<b>34.1</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>34.1</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.04</b>		

1. E – engineered containers

<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	34.1	Undetermined	44.8
<b>TOTAL (m<sup>3</sup>)</b>	<b>34.1</b>		<b>44.8</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.04</b>		<b>0.06</b>

1. From Table E.3.0-7
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $34.1 \div 0.80 \times 1.05 = 44.8$ ).

**E.4.0 EAS Packaged Waste Volume Estimates for a 100 MTHM/year Recycling Facility Using the Co-Extraction Process**

Tables E.4.0-1 through E.4.0-8 below provide waste estimates for a 100 MTHM/year co-extraction facility based on the EAS data for the UREX+1a process provided in Appendix D, Tables C.4.0-1 through C.4.0-8. Relevant process functions have been deleted to determine these waste estimates as described in Section E.1.0 above.

<b>Table E.4.0-1</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates</b>					
<b>From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	6.0			6.0
	H	4.2		1.0	5.2
	L	18.1	447.5	1.8	467.4
Shearing/Dissolving	E		0	3.4	3.4
	L		310.7	0.4	311.1
Offgas	E		0	0.3	0.3
	L		21.7	0	21.7
UREX	E		0	4.9	4.9
	L		130.6	0	130.6
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	E		0	3.4	3.4
	L		251.7	1.6	253.3
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification	E		0	7.2	7.2
	L		374.6	1.4	376.0
TALSPEAK		Not Applicable			0
U/TRU Solidification	E		0	0.2	0.2
	L	0.4	132.1	0.9	133.4
Acid Recovery	E		0	2.7	2.7
	L		68.4	1.3	69.7
Solvent Recovery	E		0	10.3	10.3
	L		464.4	0	464.4
HAW	E		0	6.3	6.3
	L		117.5	0	117.5
LAW	E		0	3.5	3.5
	L		117.5	0	117.5
Waste Handling	L	16.8	803.3	0.6	820.7
Analytical	L		1,206.7	0.9	1,207.6
Chemical Receipt			0	0	0
Balance of Plant	E		0	17.2	17.2
	L		5,068.4	5,015.5	10,083.9
	S	150.0	0	0	150.0
<b>Subtotal</b>		<b>195.5</b>	<b>9,515.1</b>	<b>5,084.8</b>	<b>14,795.4</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>14,795.4</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>148.0</b>			

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

<b>Table E.4.0-2</b>					
<b>Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates</b>					
<b>From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Packaging Scenario Without Compaction</b>		<b>Packaging Scenario With Compaction</b>	
		<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	65.4	Undetermined	81.8	Undetermined	81.8
High integrity container	5.2	33	8.3	33	8.3
Low level waste disposal box <sup>3,5</sup>	14,574.8	7,288	18,220.0	1,458	3,643.8
Solidified low level waste disposal box	150.0	125	150.0	125	150.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>14,795.4</b>		<b>18,460.1</b>		<b>3,883.9</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>148</b>		<b>184.6</b>		<b>38.8</b>

1. From Table E.4.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $65.4 \div 0.80 = 81.8$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.
5. Package Quantity for the uncompacted waste scenario is determined by application of an 80% packing efficiency, i.e.  $14,574.8 \div 0.80 \div 2.5$  (internal volume from Appendix D, Table D.2.0-1).



<b>Table E.4.0-3</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates</b>					
<b>From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	7.3			7.3
	G			0.1	0.1
Offgas	E			0.1	0.1
UREX					0
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification					0
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification					0
TALSPEAK		Not Applicable			0
U/TRU	E			0.5	0.5
Solidification	G	1.0	109.3	1.3	111.6
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	0.6			0.6
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>		<b>8.9</b>	<b>109.3</b>	<b>2.0</b>	<b>120.2</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>120.2</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>1.2</b>			

1. A – universal containers, E – engineered containers, G – GTCC disposal containers

<b>Table E.4.0-4</b>			
<b>Summary Of EAS Annual Packaged GTCC Solid</b>			
<b>Waste Volume Estimates From A</b>			
<b>100 MTHM/year Recycling Facility Using The Co-Extraction Process</b>			
<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Universal container	7.3	9	8.1
Engineered container	0.6	Undetermined	0.8
GTCC waste disposal container <sup>3</sup>	112.3	88	149.6
<b>TOTAL (m<sup>3</sup>)</b>	<b>120.2</b>		<b>158.5</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>1.2</b>		<b>1.6</b>

1. From Table E.4.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $0.6 \div 0.80 = 0.8$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Package Quantity is determined by application of an 80% packing efficiency, i.e.  $112.3 \div 0.80 \div 1.6$  (internal volume from Appendix D, Table D.2.0-1).

<b>Table E.4.0-5</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.1	0.1
Shearing/Dissolving	D			0.1	0.1
	E			0.5	0.5
Offgas	D			0.1	0.1
UREX	D			0.1	0.1
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	D			0.1	0.1
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX		Not Applicable			0
FP Solidification	D			0.1	0.1
TALSPEAK		Not Applicable			0
U/TRU Solidification	D			0.1	0.1
Acid Recovery	D			0.1	0.1
Solvent Recovery	D			0.1	0.1
HAW	D			0.1	0.1
LAW	D			0.1	0.1
Waste Handling	D			0.2	0.2
Analytical	D			0.3	0.3
Chemical Receipt				0	0
Balance of Plant	D			2.1	2.1
<b>Subtotal</b>				<b>4.2</b>	<b>4.2</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>4.2</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.04</b>		

1. D – drums, E – engineered containers

<b>Table E.4.0-6</b>			
<b>Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process</b>			
<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Drum	3.7	37	7.4
Engineered container	0.5	Undetermined	1.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>4.2</b>		<b>8.4</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.04</b>		<b>0.08</b>

1. From Table E.4.0-5
2. Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $0.5 \div 0.50 = 1.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1 with a packing efficiency of 50%.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving					
Offgas					
UREX					
U/Tc Separation		Not Applicable			
Tc Solidification		Not Applicable			
U Solidification					
CCD/PEG		Not Applicable			
Cs/Sr Solidification		Not Applicable			
TRUEX		Not Applicable			
FP Solidification	E			4.3	4.3
TALSPEAK		Not Applicable			
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>4.3</b>	<b>4.3</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>4.3</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>0.04</b>			

1. E – engineered containers

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	4.3	Undetermined	5.6
<b>TOTAL (m<sup>3</sup>)</b>	<b>4.3</b>		<b>5.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.04</b>		<b>0.06</b>

- From Table E.4.0-7
- Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $4.3 \div 0.80 \times 1.05 = 5.6$ ).

### **E.5.0 References**

1. WH-G-ESR-G-00051, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 800 MT/year UREX+1a*, August 4, 2008, Revision 2

Appendix F

Waste Estimates for an EAS “NUEX” Facility

### **F.1.0 Introduction**

The Engineering Alternatives Studies (EAS) for Separations provided a forecast of waste generated from a recycling facility utilizing the UREX+1a process at a capacity of 800 MTHM/year and 100 MTHM/year (see Reference 1 and Appendix D). An estimate of wastes from an aqueous NUEX (as defined by *EnergySolutions*) facility were not made as part of the EAS; however, since the EAS waste estimates are developed using a bottoms up methodology for each of the major process functions, an estimate for an aqueous NUEX facility can be made by eliminating those process functions that are not relevant to the NUEX process. Specifically, the following process functions can be eliminated to determine a waste estimate for a NUEX process based on the EAS data.

- U/Tc Separation
- Tc Solidification
- CCD/PEG
- Cs/Sr Solidification

The “UREX” process function remains to provide an estimate of waste streams from the primary separation cycle of the NUEX process since the two process cycles are similar. The “U/TRU Solidification” function remains to provide an estimate of the “U/Pu Oxide Conversion” function of the NUEX process since those processes are also similar. TRUEX and TALSPEAK remain to provide estimates for the minor actinide/lanthanide/fission product separation functions of the NUEX process.

### **F.2.0 EAS Waste Packages**

The radioactive waste packages applicable to the NUEX process are the same as those listed for the UREX+1a process in Appendix D.

### **F.3.0 EAS Packaged Waste Volume Estimates for an 800 MTHM/year Recycling Facility Using the NUEX Process**

Tables F.3.0-1 through F.3.0-8 below provide waste estimates for an 800 MTHM/year co-extraction facility based on the EAS data for the UREX+1a process provided in Appendix D, Tables D.3.0-1 through D.3.0-8. Relevant process functions have been deleted to determine these waste estimates as described in Section F.1.0 above.



System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	48.0			48.0
	H	33.1		8.0	41.1
	L	144.3	693.0	14.5	851.8
Shearing/Dissolving	E		0	27.1	27.1
	L		481.2	2.9	484.1
Offgas	E		0	2.1	2.1
	L		33.6	0	33.6
UREX	E		0	39.2	39.2
	L		202.2	0	202.2
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	E		0	27.0	27.0
	L		389.7	12.7	402.4
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX	E		0	16.5	16.5
	L		202.2	0	202.2
FP Solidification	E		0	57.3	57.3
	L		580.1	10.7	590.8
TALSPEAK	E		0	16.8	16.8
	L		76.6	0	76.6
U/TRU Solidification	E		0	1.4	1.4
	L	2.5	204.5	6.6	213.6
Acid Recovery	E		0	21.6	21.6
	L		105.9	10.0	115.9
Solvent Recovery	E		0	82.6	82.6
	L		719.2	0	719.2
HAW	E		0	50.5	50.5
	L		181.9	0	181.9
LAW	E		0	27.9	27.9
	L		181.9	0	181.9
Waste Handling	L	135.5	1,243.9	4.7	1,384.1
Analytical	L		1,868.7	7.0	1,875.7
Chemical Receipt			0	0	0
Balance of Plant	E		0	137.0	137.0
	L		7,848.9	7,165.0	15,013.9
	S	1,200.0	0	0	1,200.0
<b>Subtotal</b>		<b>1,563.4</b>	<b>15,013.5</b>	<b>7749.1</b>	<b>24,326</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>24,326</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>30.4</b>			

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

<b>Table F.3.0-2</b>					
<b>Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates</b>					
<b>From An 800 MTHM/year Recycling Facility Using The NUEX Process</b>					
<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Packaging Scenario Without Compaction</b>		<b>Packaging Scenario With Compaction</b>	
		<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	555.0	Undetermined	693.8	Undetermined	693.8
High integrity container	41.1	257	64.0	257	64.0
Low level waste disposal box <sup>3,5</sup>	22,529.9	11,265	28,162.5	2,253	5,632.5
Solidified low level waste disposal box	1,200	1,000	1,200.0	1,000	1,200.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>24,326</b>		<b>30,120.3</b>		<b>7,590.3</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>30.4</b>		<b>37.7</b>		<b>9.5</b>

1. From Table F.3.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $555.0 \div 0.80 = 693.8$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.
5. Package Quantity for the uncompacted waste scenario is determined by application of an 80% packing efficiency, i.e.  $22,529.9 \div 0.80 \div 2.5$  (internal volume from Appendix D, Table D.2.0-1).

<b>Table F.3.0-3</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates</b>					
<b>From An 800 MTHM/year Recycling Facility Using The NUEX Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	57.8			57.8
	G			0.3	0.3
Offgas	E			0.2	0.2
UREX					0
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification					0
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX	E			27.2	27.2
FP Solidification					0
TALSPEAK	E			26.6	26.6
	G		112.8		112.8
U/TRU	E			3.4	3.4
Solidification	G	7.4	169.2	10.0	186.6
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	4.8			4.8
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>		<b>70.0</b>	<b>282.0</b>	<b>67.7</b>	<b>419.7</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>419.7</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>0.52</b>			

1. A – universal containers, E – engineered containers, G – GTCC disposal containers

<b>Table F.3.0-4                      Summary Of EAS Annual Packaged GTCC Solid                      Waste Volume Estimates From An                      800 MTHM/year Recycling Facility Using The NUEX Process</b>			
<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Universal container	57.8	70	63.0
Engineered container	57.4	Undetermined	71.8
GTCC waste disposal container <sup>3</sup>	304.5	237.9	404.4
<b>TOTAL (m<sup>3</sup>)</b>	<b>419.7</b>		<b>539.2</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.52</b>		<b>0.67</b>

1. From Table F.3.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $57.4 \div 0.80 = 71.8$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Package Quantity is determined by application of an 80% packing efficiency, i.e.  $304.5 \div 0.80 \div 1.6$  (internal volume from Appendix D, Table D.2.0-1).

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.3	0.3
Shearing/Dissolving	D			0.8	0.8
	E			3.5	3.5
Offgas	D			0.3	0.3
UREX	D			0.3	0.3
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	D			0.3	0.3
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX	D			0.3	0.3
FP Solidification	D			0.4	0.4
TALSPEAK	D			0.3	0.3
U/TRU Solidification	D			0.3	0.3
Acid Recovery	D			0.3	0.3
Solvent Recovery	D			0.3	0.3
HAW	D			0.3	0.3
LAW	D			0.3	0.3
Waste Handling	D			1.5	1.5
Analytical	D			2.5	2.5
Chemical Receipt				0	0
Balance of Plant	D			2.9	2.9
<b>Subtotal</b>				<b>14.9</b>	<b>14.9</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>14.9</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.02</b>		

1. D – drums, E – engineered containers

<b>Table F.3.0-6</b>			
<b>Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process</b>			
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Drum	11.4	114	22.8
Engineered container	3.5	Undetermined	7.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>14.9</b>		<b>29.8</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.02</b>		<b>0.04</b>

1. From Table F.3.0-5
2. Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $3.5 \div 0.50 = 7.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1 with a packing efficiency of 50%.

<b>Table F.3.0-7</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process</b>					
<b>System</b>	<b>Container <sup>1</sup></b>	<b>Annual Waste Volume (m<sup>3</sup>)</b>			<b>Subtotal</b>
		<b>Operational</b>	<b>Job Control</b>	<b>Maintenance</b>	
Fuel Receipt					
Shearing/Dissolving					
Offgas					
UREX					
U/Tc Separation		Not Applicable			
Tc Solidification		Not Applicable			
U Solidification					
CCD/PEG		Not Applicable			
Cs/Sr Solidification		Not Applicable			
TRUEX					
FP Solidification	E			34.1	34.1
TALSPEAK					
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>34.1</b>	<b>34.1</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>34.1</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>0.04</b>			

1. E – engineered containers

<b>Table F.3.0-8</b>			
<b>Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process</b>			
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	34.1	Undetermined	44.8
<b>TOTAL (m<sup>3</sup>)</b>	<b>34.1</b>		<b>44.8</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.04</b>		<b>0.06</b>

1. From Table F.3.0-7
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $34.1 \div 0.80 \times 1.05 = 44.8$ ).

#### **F.4.0 EAS Packaged Waste Volume Estimates for a 100 MTHM/year Recycling Facility**

Tables F.4.0-1 through F.4.0-8 below provide waste estimates for a 100 MTHM/year NUEX facility based on the EAS data for the UREX+1a process provided in Appendix D, Tables D.4.0-1 through D.4.0-8. Relevant process functions have been deleted to determine these waste estimates as described in Section F.1.0 above.



System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	6.0			6.0
	H	4.2		1.0	5.2
	L	18.1	447.5	1.8	467.4
Shearing/Dissolving	E		0	3.4	3.4
	L		310.7	0.4	311.1
Offgas	E		0	0.3	0.3
	L		21.7	0	21.7
UREX	E		0	4.9	4.9
	L		130.6	0	130.6
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	E		0	3.4	3.4
	L		251.7	1.6	253.3
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX	E		0	2.1	2.1
	L		130.6	0	130.6
FP Solidification	E		0	7.2	7.2
	L		374.6	1.4	376.0
TALSPEAK	E		0	2.1	2.1
	L		49.5	0	49.5
U/TRU Solidification	E		0	0.2	0.2
	L	0.4	132.1	0.9	133.4
Acid Recovery	E		0	2.7	2.7
	L		68.4	1.3	69.7
Solvent Recovery	E		0	10.3	10.3
	L		464.4	0	464.4
HAW	E		0	6.3	6.3
	L		117.5	0	117.5
LAW	E		0	3.5	3.5
	L		117.5	0	117.5
Waste Handling	L	16.8	803.3	0.6	820.7
Analytical	L		1,206.7	0.9	1,207.6
Chemical Receipt			0	0	0
Balance of Plant	E		0	17.2	17.2
	L		5,068.4	5,015.5	10,083.9
	S	150.0	0	0	150.0
<b>Subtotal</b>		<b>195.5</b>	<b>9,695.2</b>	<b>5,089.0</b>	<b>14,979.7</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>14,979.7</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>149.8</b>			

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

<b>Table F.4.0-2</b>					
<b>Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates</b>					
<b>From A 100 MTHM/year Recycling Facility Using The NUEX Process</b>					
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Packaging Scenario Without Compaction</b>		<b>Packaging Scenario With Compaction</b>	
		<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	69.6	Undetermined	87.0	Undetermined	87.0
High integrity container	5.2	33	8.3	33	8.3
Low level waste disposal box <sup>3,5</sup>	14,754.9	7,378	18,445	1,476	3,690
Solidified low level waste disposal box	150	125	150	125	150
<b>TOTAL (m<sup>3</sup>)</b>	<b>14,979.7</b>		<b>18,690.3</b>		<b>3,935.3</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>30.4</b>		<b>186.9</b>		<b>39.4</b>

1. From Table F.4.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $69.6 \div 0.80 = 87.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.
5. Package Quantity for the uncompacted waste scenario is determined by application of an 80% packing efficiency, i.e.  $14,754.9 \div 0.80 \div 2.5$  (internal volume from Appendix D, Table D.2.0-1).

<b>Table F.4.0-3</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates</b>					
<b>From A 100 MTHM/year Recycling Facility Using The NUEX Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	7.3			7.3
	G			0.1	0.1
Offgas	E			0.1	0.1
UREX					0
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification					0
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX	E			3.4	3.4
FP Solidification					0
TALSPEAK	E			6.8	6.8
	G		72.8		72.8
U/TRU	E			0.5	0.5
Solidification	G	1.0	109.3	1.3	111.6
Acid Recovery					0
Solvent Recovery					0
HAW					0
LAW					0
Waste Handling	G	0.6			0.6
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>		<b>8.9</b>	<b>182.1</b>	<b>12.2</b>	<b>203.2</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>203.2</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>2.0</b>			

1. A – universal containers, E – engineered containers, G – GTCC disposal containers

<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Universal container	7.3	9	8.1
Engineered container	10.8	Undetermined	13.5
GTCC waste disposal container <sup>3</sup>	185.1	145	246.5
<b>TOTAL (m<sup>3</sup>)</b>	<b>203.2</b>		<b>268.1</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>2.0</b>		<b>2.7</b>

1. From Table F.4.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $10.8 \div 0.80 = 13.5$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1.
3. Package Quantity is determined by application of an 80% packing efficiency, i.e.  $185.1 \div 0.80 \div 1.6$  (internal volume from Appendix D, Table D.2.0-1).

<b>Table F.4.0-5</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.1	0.1
Shearing/Dissolving	D			0.1	0.1
	E			0.5	0.5
Offgas	D			0.1	0.1
UREX	D			0.1	0.1
U/Tc Separation		Not Applicable			0
Tc Solidification		Not Applicable			0
U Solidification	D			0.1	0.1
CCD/PEG		Not Applicable			0
Cs/Sr Solidification		Not Applicable			0
TRUEX	D			0.1	0.1
FP Solidification	D			0.1	0.1
TALSPEAK	D			0.1	0.1
U/TRU Solidification	D			0.1	0.1
Acid Recovery	D			0.1	0.1
Solvent Recovery	D			0.1	0.1
HAW	D			0.1	0.1
LAW	D			0.1	0.1
Waste Handling	D			0.2	0.2
Analytical	D			0.3	0.3
Chemical Receipt				0	0
Balance of Plant	D			2.1	2.1
<b>Subtotal</b>				<b>4.4</b>	<b>4.4</b>
<b>TOTAL (m<sup>3</sup>)</b>			<b>4.4</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>0.04</b>		

1. D – drums, E – engineered containers

<b>Container</b>	<b>Bulk Waste Volume<sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume<sup>2</sup> (m<sup>3</sup>)</b>
Drum	3.9	39	7.8
Engineered container	0.5	Undetermined	1.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>4.4</b>		<b>8.8</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.04</b>		<b>0.09</b>

1. From Table F.4.0-5
2. Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $0.5 \div 0.50 = 1.0$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Appendix D, Table D.2.0-1 with a packing efficiency of 50%.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving					
Offgas					
UREX					
U/Tc Separation		Not Applicable			
Tc Solidification		Not Applicable			
U Solidification					
CCD/PEG		Not Applicable			
Cs/Sr Solidification		Not Applicable			
TRUEX					
FP Solidification	E			4.3	4.3
TALSPEAK					
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>4.3</b>	<b>4.3</b>
<b>TOTAL (m<sup>3</sup>)</b>		<b>4.3</b>			
<b>TOTAL (m<sup>3</sup>/MTHM)</b>		<b>0.04</b>			

1. E – engineered containers

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	4.3	Undetermined	5.6
<b>TOTAL (m<sup>3</sup>)</b>	<b>34.1</b>		<b>5.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.04</b>		<b>0.06</b>

1. From Table F.4.0-7
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $4.3 \div 0.80 \times 1.05 = 5.6$ ).

#### **F.5.0 References**

1. WH-G-ESR-G-00051, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 800 MT/year UREX+1a*, August 4, 2008, Revision 2



## Appendix G

### Waste Estimates for the EAS Electrochemical Facility

### G.1.0 Introduction

The Engineering Alternatives Studies (EAS) for Separations provided a forecast of waste generated from a recycling facility utilizing the electrochemical process at a capacity of 300 MTHM/year.<sup>1</sup> The EAS study provides waste estimates for high level waste (HLW), Greater Than Class C (GTCC) waste, low level waste (LLW), mixed waste, hazardous waste and non-hazardous waste. The EAS study does not make a distinction between Class A, B or C waste types. Note that HLW, hazardous waste and non-hazardous waste are not within the scope of the LLW Disposition - Quantities and Inventories study; therefore, it is not addressed in this appendix.

The EAS study utilizes a bottoms up methodology to estimate annual waste quantities from each of the major process functions of the electrochemical process (e.g. fuel receipt, electro reduction, offgas, U/TRU electrolysis, etc.). Waste from the major process operations is categorized as either operational waste, job control waste or maintenance waste. Waste is characterized based on its source and category (i.e. operational, job control, maintenance) as follows:

#### Low level waste

- operational and maintenance waste from process operations that do not handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55 (e.g. maintenance waste from the Cs/Sr Solidification process is generally considered GTCC waste)
- job control waste from routine operations and minor maintenance activities, even those associated with process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55
- 25% of the job control waste from major maintenance activities associated with process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55 (25% is an allowance for successful decontamination of GTCC waste to below low level limits)

#### GTCC waste

- operational and maintenance waste from process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55 (e.g. maintenance waste from the Cs/Sr Solidification process is considered GTCC waste)
- some allowance is made for decontamination of GTCC waste (such as some failed equipment) to low levels based on engineering judgment
- 75% of the job control waste from major maintenance activities associated with process operations that handle or process transuranic (TRU) waste or other radionuclides subject to the restrictions of 10CFR61.55

#### Mixed waste

- any low level or GTCC waste also containing hazardous constituents

### G.2.0 EAS Waste Packages

The radioactive waste packages considered for use in the EAS study include:

- 55 gallon drums
- low level waste disposal boxes
- solidified low level waste disposal boxes
- high integrity containers
- GTCC disposal containers
- engineered containers of undetermined size

Details of the containers are shown in Table G.2.0-1 below.

<b>Container</b>	<b>Description</b>	<b>Exterior Dimensions</b>	<b>Exterior Volume</b>	<b>Interior Volume</b>	<b>Weight</b>	<b>Usage</b>
Drum			55 gallons (0.2 m <sup>3</sup> )	55 gallons (0.2 m <sup>3</sup> )		- mixed waste - bulk loaded into drum (not compacted)
Low level waste disposal box		6' long x 4' deep x 4' high	2.5 m <sup>3</sup>	2.5 m <sup>3</sup>		- solid low level waste - bagged waste loaded directly into container - compacted waste reduced to 25% of the original volume
Solidified low level waste disposal box		6' long x 4' deep x 2' high	1.2 m <sup>3</sup>	1.2 m <sup>3</sup>		- solidified liquid low activity waste - solidified waste placed directly into container
High integrity containers			0.25 m <sup>3</sup>	0.2 m <sup>3</sup>		- low level waste requiring greater containment
GTCC disposal containers	- similar to Waste Isolation Pilot Plant (WIPP) standard waste boxes (SWB)		1.7 m <sup>3</sup>	1.6 m <sup>3</sup>		- GTCC waste - bulk loaded into container - can be used to overpack 55 gallon drums
Engineered containers	- specifically designed to accommodate the waste item such as large failed equipment	unspecified	unspecified	unspecified		- used for waste that is not suitable for packaging into other standard containers

### G.3.0 EAS Packaged Waste Volume Estimates for a 300 MTHM/year Recycling Facility Using the Electrochemical Process

The waste estimates provided in the EAS study are stated in terms of the annual quantity of bulk (unpacked) waste and packaged waste with no allowance for volume reduction (e.g. compaction). Additionally, an estimate of packaged low level waste volume is provided with an allowance for compaction. The packaged waste volume estimates (both with compaction and without compaction) include estimates of waste container quantities. The waste estimates for a 300 MTHM/year recycling facility using an electrochemical process provided in the EAS study are shown below in Tables G.3.0-1 through G.3.0-8.

<b>Table G.3.0-1</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates</b>					
<b>From A 300 MTHM/year Recycling Facility Using The Electrochemical Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	E	23.4			23.4
	H	14.2		6.0	20.2
	L	56.1	641.8	13.0	710.9
Shearing/Voloxidation	E		0	13.1	13.1
	L		363.9	2.9	366.8
Offgas	E		0	2.1	2.1
	L		20.8	0	20.8
Electro Reduction	E		0	49.3	49.3
	L		196.9	0	196.9
Cs/Sr Solidification	E		0	3.9	3.9
	L		68.1	5.5	73.6
Electro Refining	E		0	22.3	22.3
	L	14.4	26.6	0	41.0
Metal Processing	E		0	2.2	2.2
	L	0.9	53.1	5.5	59.5
U Processing	E		0	18.8	18.8
	L	1.5	180.9	0	182.4
U/TRU Electrolysis	E		0	22.3	22.3
	L		26.6	0	26.6
U/TRU Processing	E		0	5.4	5.4
	L	0.6	53.1	6.5	60.2
Ln Recovery	E		0	5.6	5.6
	L		26.6	0	26.6
Ln Solidification	E		0	3.9	3.9
	L		180.9	5.5	186.4
Oxidant Production	E		0	1.8	1.8
	L		23.4	0	23.4
Waste Handling	L	44.4	634.7	4.7	683.8
Analytical	L		1,586.7	7.0	1,593.7
Chemical Receipt			0	0	0
Balance of Plant	E		0	43.6	43.6
	L		995.4	3,197.0	4,192.4
	S	200		0	200.0
<b>Subtotal</b>		<b>355.5</b>	<b>5,079.5</b>	<b>3,447.9</b>	<b>8,882.9</b>
<b>TOTAL</b>			<b>8,882.9</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>29.6</b>		

1. E – engineered containers, H – high integrity containers, L – low level waste disposal box, S- solidified low level waste disposal box

<b>Table G.3.0-2</b>					
<b>Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process</b>					
<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Packaging Scenario Without Compaction</b>		<b>Packaging Scenario With Compaction</b>	
		<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	217.7	Undetermined	272.1	Undetermined	272.1
High integrity container	20.2	126	31.5	126	31.5
Low level waste disposal box <sup>3</sup>	8,445.0	4,223	10,557.5	845	2,112.5
Solidified low level waste disposal box	200	167	200	167	200
<b>TOTAL (m<sup>3</sup>)</b>	<b>8,882.9</b>		<b>11,061.1</b>		<b>2,616.1</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>29.6</b>		<b>36.9</b>		<b>8.7</b>

1. From Table G.3.0-1
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume ( $217.7 \div 0.80 = 774.6$ ). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table G.2.0-1.
3. Only waste disposed of in low level waste disposal boxes is considered for compaction. A volume reduction factor of 4 (i.e. compacted waste volume is 25% of the original bulk waste volume) with a 100% packing efficiency is assumed.
4. Shaded areas (i.e. ) indicate compacted waste.

<b>Table G.3.0-3</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates</b>					
<b>From A 300 MTHM/year Recycling Facility Using The Electrochemical Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Voloxidation	G			0.1	0.1
Offgas	E			0.2	0.2
Electro Reduction					0
Cs/Sr Solidification					0
	G		112.8		112.8
Electro Refining	E			45.7	45.7
	G		56.4		56.4
Metal Processing	E			2.0	2.0
	G		112.8		112.8
U Processing					0
U/TRU Electrolysis	E			45.7	45.7
	G	1.8	56.4		58.2
U/TRU Processing	E			4.0	4.0
	G	3.6	112.8	10.0	126.4
Ln Recovery	E			11.4	11.4
	G	0.5	56.4		56.9
Ln Solidification					0
Oxidant Production	E			6.2	6.2
	G		56.4		56.4
Waste Handling	G	3.5			3.5
Analytical					0
Chemical Receipt					0
Balance of Plant					0
<b>Subtotal</b>		<b>9.4</b>	<b>564.0</b>	<b>125.3</b>	<b>698.7</b>
<b>TOTAL</b>			<b>698.7</b>		
<b>TOTAL (m<sup>3</sup>/MTHM)</b>			<b>2.3</b>		

1. E – engineered containers, G – GTCC disposal containers

<b>Container</b>	<b>Bulk Waste Volume <sup>1</sup> (m<sup>3</sup>)</b>	<b>Package Quantity</b>	<b>Packaged Volume <sup>2</sup> (m<sup>3</sup>)</b>
Engineered container	115.2	Undetermined	144.0
GTCC waste disposal container	583.5	456	775.2
<b>TOTAL (m<sup>3</sup>)</b>	<b>699</b>		<b>919</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>2.3</b>		<b>3.1</b>

1. From Table G.3.0-3
2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume (115.2 ÷ 0.80 = 144.0). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table G.2.0-1.

System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt	D			0.3	0.3
Shearing/Voloxidation	D			0.8	0.8
	E			3.5	3.5
Offgas	D			0.3	0.3
Electro Reduction	D			0.3	0.3
Cs/Sr Solidification	D			0.3	0.3
Electro Refining	D			0.3	0.3
Metal Processing	D			0.3	0.3
U Processing	D			0.3	0.3
U/TRU Electrolysis	D			0.3	0.3
U/TRU Processing	D			0.3	0.3
Ln Recovery	D			0.3	0.3
Ln Solidification	D			0.3	0.3
Oxidant Production	D			0.3	0.3
Waste Handling	D			1.5	1.5
Analytical	D			2.5	2.5
Chemical Receipt				0	0
Balance of Plant	D			2.7	2.7
<b>Subtotal</b>				<b>14.6</b>	<b>14.6</b>
<b>TOTAL</b>				<b>14.6</b>	
<b>TOTAL (m<sup>3</sup>/MTHM)</b>				<b>0.05</b>	

1. D – drums, E – engineered containers

Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Drum	11.1	111	22.2
Engineered container	3.5	Undetermined	7.0
<b>TOTAL (m<sup>3</sup>)</b>	<b>15</b>		<b>29</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.05</b>		<b>0.1</b>

- From Table G.3.0-5
- Packaged volume for waste contained in engineered containers is estimated by application of a 50% packing efficiency and an assumption that the container itself adds a negligible amount to the final packaged waste volume (3.5 ÷ 0.50 = 7.0). All other packaged waste volumes are estimated by multiplying the Package Quantity by the Exterior Volumes listed in Table G.2.0-1 with a packing efficiency of 50%.



<b>Table G.3.0-7</b>					
<b>Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process</b>					
System	Container <sup>1</sup>	Annual Waste Volume (m <sup>3</sup> )			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Voloxidation					
Offgas					
Electro Reduction					
Cs/Sr Solidification	E			15.9	15.9
Electro Refining					
Metal Processing	E			1.4	1.4
U Processing					
U/TRU Electrolysis					
U/TRU Processing					
Ln Recovery					
Ln Solidification	E			15.9	15.9
Oxidant Production					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
<b>Subtotal</b>				<b>33.2</b>	<b>33.2</b>
<b>TOTAL</b>				<b>33.2</b>	
<b>TOTAL (m<sup>3</sup>/MTHM)</b>				<b>0.11</b>	

1. E – engineered containers

<b>Table G.3.0-8</b>			
<b>Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process</b>			
Container	Bulk Waste Volume <sup>1</sup> (m <sup>3</sup> )	Package Quantity	Packaged Volume <sup>2</sup> (m <sup>3</sup> )
Engineered container	33.2	Undetermined	43.6
<b>TOTAL (m<sup>3</sup>)</b>	<b>33.2</b>		<b>43.6</b>
<b>TOTAL (m<sup>3</sup>/MTHM)</b>	<b>0.11</b>		<b>0.15</b>

1. From Table G.3.0-7

2. Packaged volume for waste contained in engineered containers is estimated by application of an 80% packing efficiency and an assumption that the container itself adds 5% to the final packaged waste volume ( $33.2 \div 0.80 \times 1.05 = 43.6$ ).

#### **G.4.0 References**

1. WH-G-ESR-G-00054, *Engineering Alternative Studies for Separations Waste Generation Forecast and Characterization Study 300 MT/year Electrochemical Processing*, August 4, 2008, Revision 2

## Appendix H

Low Level Radioactive Waste Generation: 1986 - 2008

## H.1.0 Introduction

This appendix presents a compilation of low level radioactive waste (LLW) generation and disposal over the period of 1986 through 2008. This information was obtained from the U.S. DOE Office of Environmental Management's Manifest Information Management System (MIMS). Data is available from MIMS for academic, government, industry, medical, undefined, and utility LLW generators. MIMS reports the volume and activity of Class A, B, and C LLW from each generator and disposed at the sites shown in Table H.1.0-1:

<b>Site</b>	<b>From</b>	<b>Through</b>
Barnwell	01/02/1986	07/27/2009
Beatty	04/21/1986	12/31/1992
Clive	07/31/1992	03/31/2009
Richland	01/02/1986	12/30/2008

LLW reported from utility generators is solely from nuclear power plants. LLW reported from industry is from a variety of generators including fuel cycle facilities and LLW brokers/processors. Brokers and processors provide a variety of services including storage, sizing, compaction, separation, incineration, immobilization, stabilization, evaporation, and physical/chemical treatment.

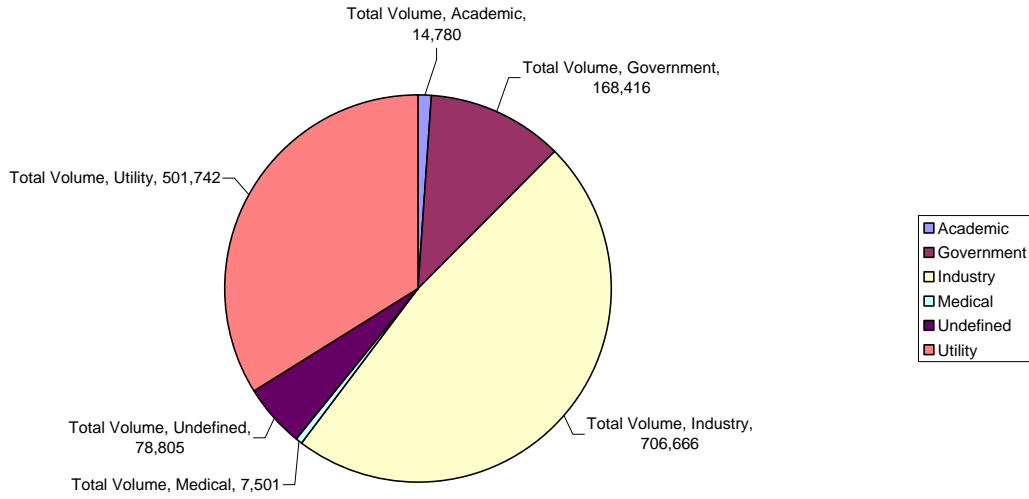
## H.2.0 Results

The volume and activity of LLW generated and disposed over the period from 1986 to 2008 are shown in Table H.2.0-1 and Figures H.2.0-1 through H.2.0-4. These results show that the largest amount of Class A LLW disposed, both in terms of volume and activity, is generated from nuclear utilities and industrial generators. Class B and C LLW volume and activity are dominated by wastes generated from the nuclear utilities.

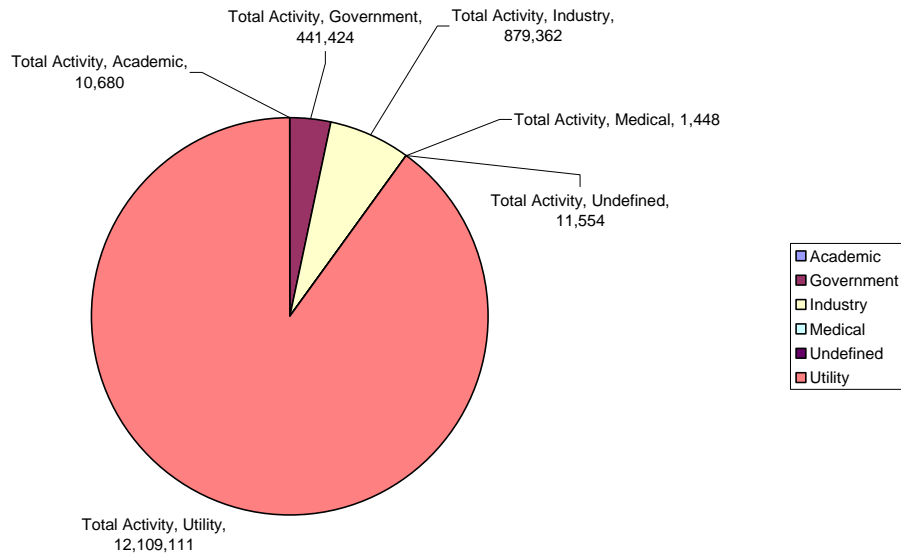
<b>Table H.2.0-1</b>								
Total Volume and Activity of Low Level Waste Disposed: 1986 - 2008								
<b>Generator</b>	<b>Total</b>		<b>Class A</b>		<b>Class B</b>		<b>Class C</b>	
	<b>Volume (m<sup>3</sup> / ft<sup>3</sup>)</b>	<b>Activity (Ci)</b>	<b>Volume (m<sup>3</sup> / ft<sup>3</sup>)</b>	<b>Activity (Ci)</b>	<b>Volume (m<sup>3</sup> / ft<sup>3</sup>)</b>	<b>Activity (Ci)</b>	<b>Volume (m<sup>3</sup> / ft<sup>3</sup>)</b>	<b>Activity (Ci)</b>
Academic	14,780	10,680	6,216	238	11	760	36	1,357
	521,937		219,500		382		1,261	
Government	168,416	441,424	156,529	4,819	128	135,624	177	15,024
	5,947,555		5,527,783		4,504		6,244	
Medical	7,501	1,448	2,750	16	1	27	17	104
	264,905		97,113		50		589	
Undefined	78,805	11,554	73,071	9,962	3	53	30	224
	2,782,985		2,580,475		103		1,075	
Industry	706,666	879,362	665,326	11,093	751	205,615	607	16,354
	24,955,663		23,495,767		26,509		21,433	
Utility	501,742	12,109,111	426,605	78,082	13,529	197,123	7,111	6,790,121
	17,718,847		15,065,412		477,759		251,139	
Total	1,477,910	13,453,579	1,330,497	104,211	14,422	539,203	7,978	6,823,184
	52,191,892		46,986,050		509,307		281,742	

1. Source: U.S. DOE Manifest Information Management System (MIMS), March 11, 2010. Report – Waste Classification and Generator Class (All States/Compacts, All Disposal Sites, 01/01-1986 – 12/31/2008)
2. Note: Volumes and activities do not sum to total and were computed (sorting and summing) from data obtained directly from MIMS.

**Total Volume LLW Disposed (m<sup>3</sup>): 1986-2008**

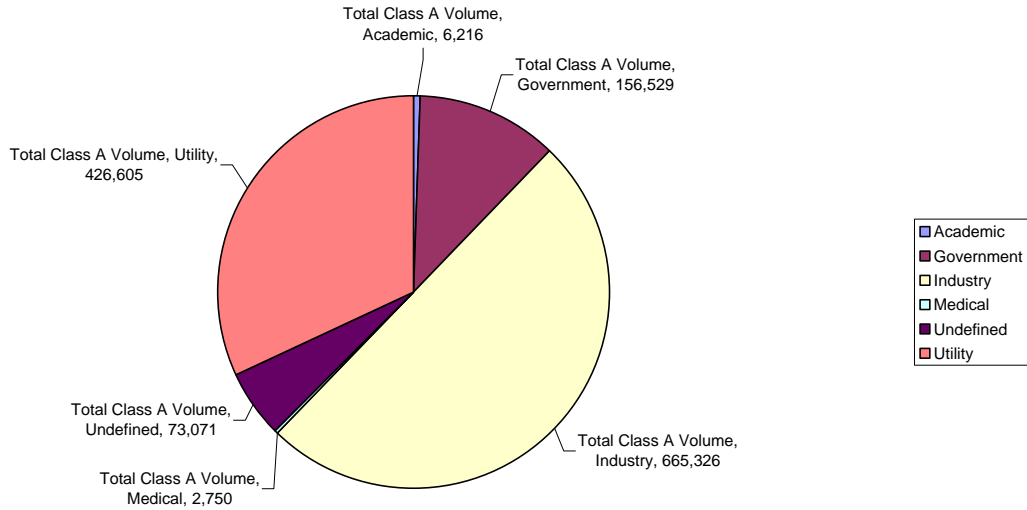


**Total Activity LLW Disposed (Ci): 1986-2008**

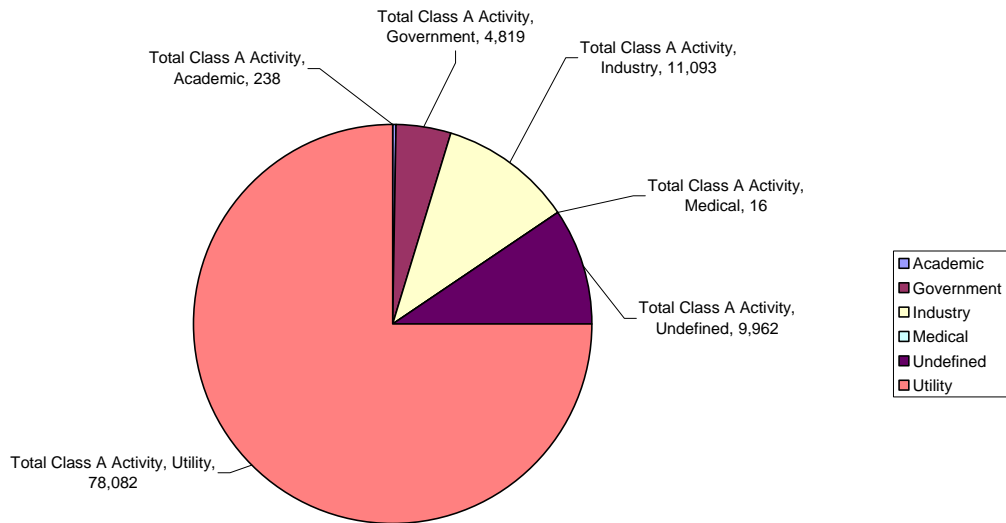


**Figure H.2.0-1  
 Total LLW Volume and Activity Disposed**

**Total Volume Class A LLW Disposed (m<sup>3</sup>): 1986-2008**



**Total Activity Class A LLW Disposed (Ci): 1986-2008**



**Figure H.2.0-2**  
 Total Class A LLW Volume and Activity Disposed

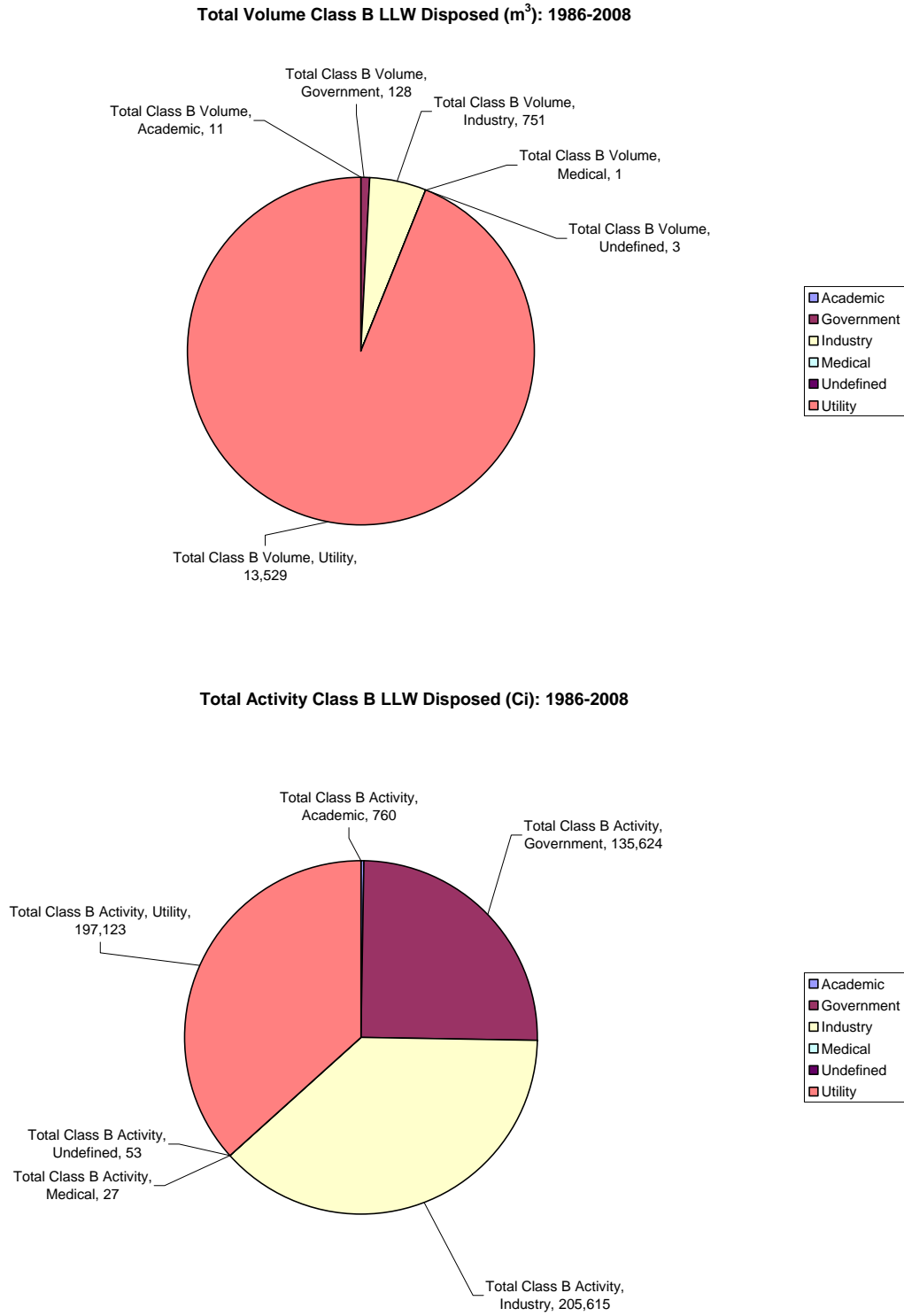


Figure H.2.0-3  
 Total Class B LLW Volume and Activity Disposed



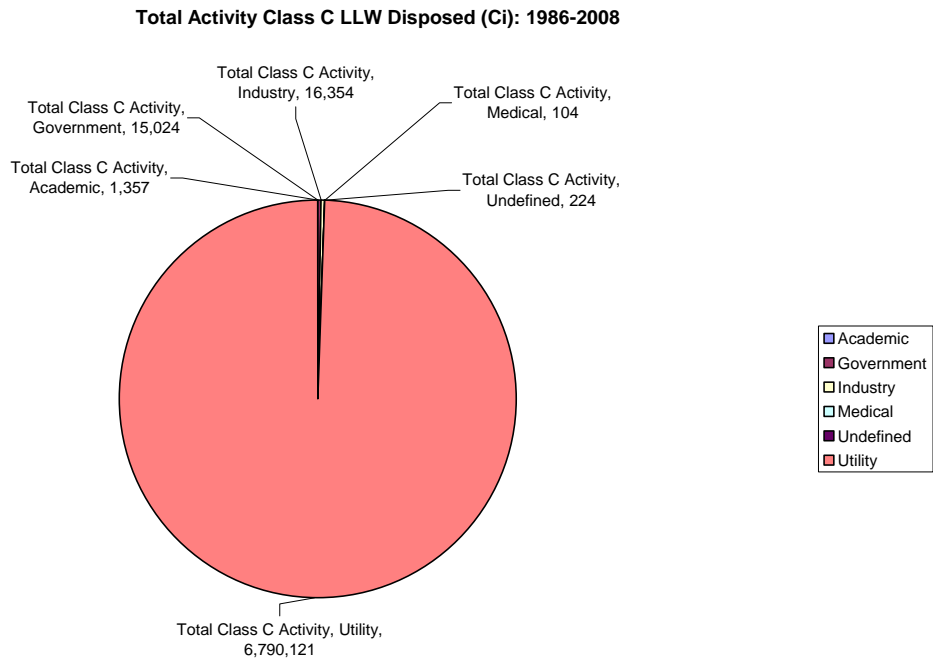
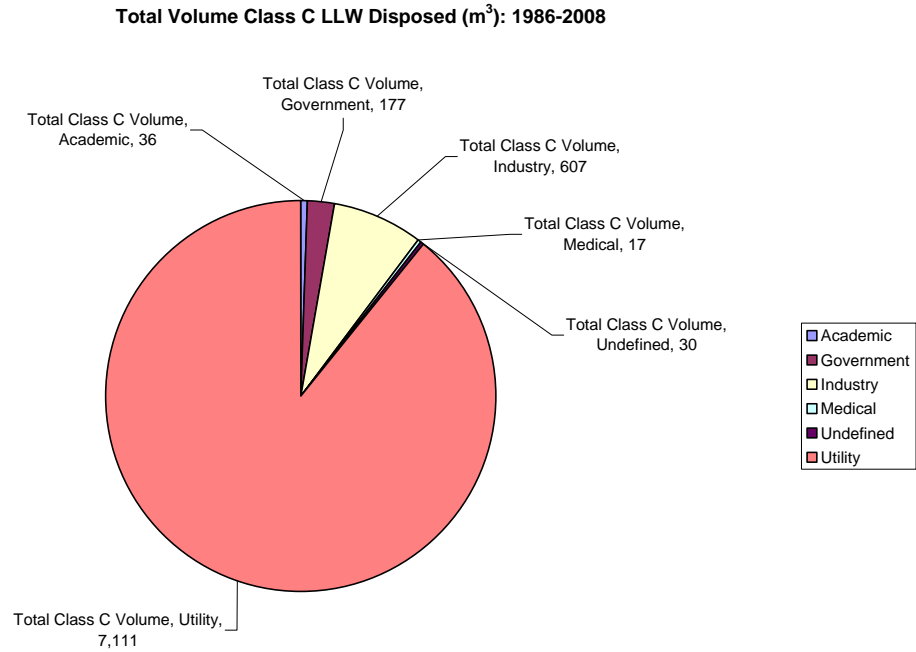


Figure H.2.0-4  
 Total Class C LLW Volume and Activity Disposed

## H.2.1 Utility and Industry Generation

Figure H.2.1-1 shows annual disposal of utility generated LLW over the period from 1986 to 2008. The data shows that the disposal of utility generated Class C LLW is relatively constant over this period, at about 10,000 ft<sup>3</sup>/year. The volume of utility generated Class B waste disposed is trending downward, from approximately 50,000 ft<sup>3</sup>/year in 1986 to approximately 10,000 ft<sup>3</sup>/year in 2008. The volume of utility generated Class A also followed a decreasing trend from 1986 through 2000, when a significant increase occurred. A similar, but not as drastic, a trend is observed in the industrial generation as shown in Figure H.2.1-2. The increase in Class A utility generated waste is attributed to reactor decommissioning projects, in particular:

- Maine Yankee (Maine): 2002 – 2005
- Connecticut Yankee (Connecticut): 1998 – 2007
- Yankee Rowe (Massachusetts): 1993 – 2007
- San Onofre 1 (California): 1999 - 2008

Figure H.2.1-3 shows the volume of Class A LLW disposed from Maine, Massachusetts, Connecticut, and California from both industry and utility generators over the period of 1995 to 2008. The data indicates a significant increase in the utility generated Class A LLW during the periods when the nuclear power plants shown above were being decommissioned. The data shown in Figure H.2.1-3 indicates that approximately 1,000,000 cubic feet of Class A LLW can be generated annually over a two to three year period when a nuclear power plant is being decommissioned.

In order to determine an estimate for the utility generation of LLW without decommissioning, the utility generation data shown in Figure H.2.1-1 was adjusted by removing the LLW volumes from:

Maine:	2002 – 2007
Massachusetts:	2004 – 2006
Connecticut:	2004 – 2006
California:	2006 – 2008

Figure H.2.1-4 shows the adjusted annual disposal of LLW for utility generated LLW over the period from 1986 to 2008. It is recognized that Massachusetts, Connecticut, and California had additional nuclear power plants that were in operation over these periods; however, the impact on the overall estimates of LLW generation is expected to be small.

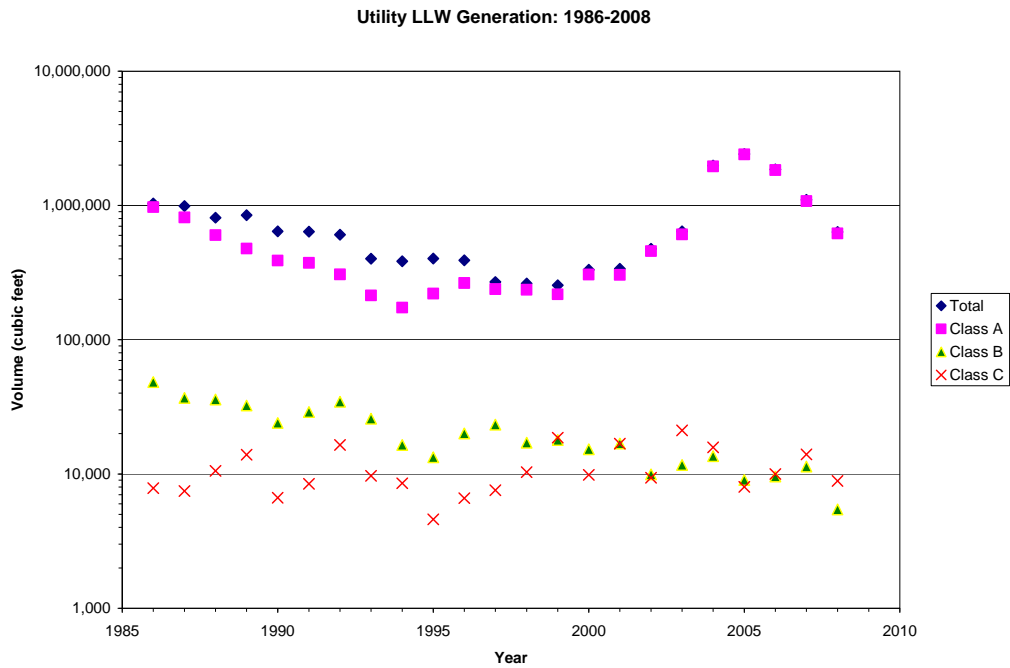


Figure H.2.1-1  
Utility Generated Low Level Waste Disposed: 1986 - 2008

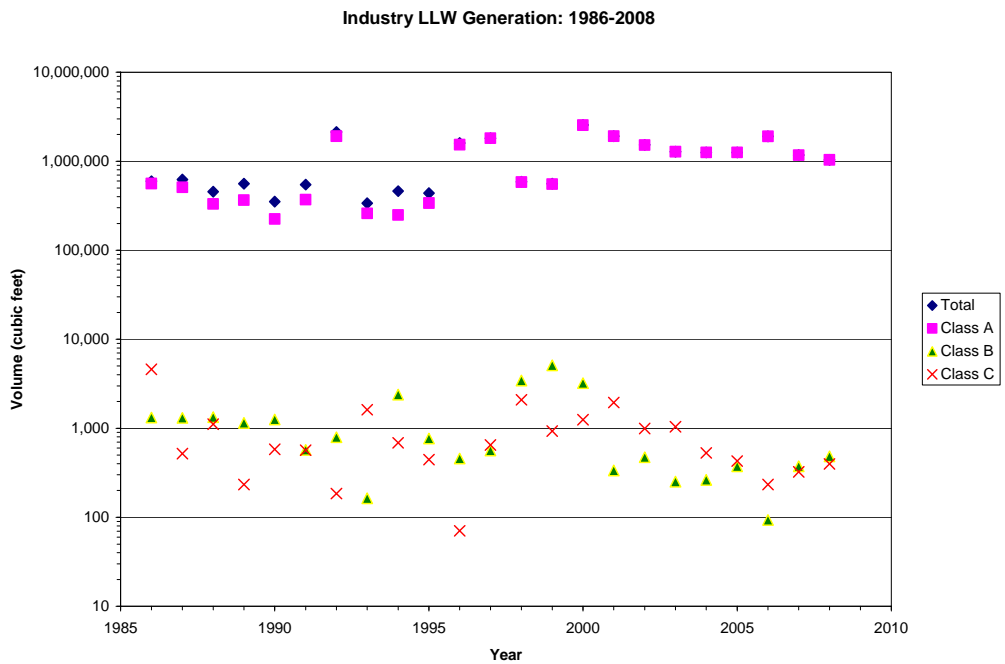


Figure H.2.1-2  
Industry Generated Low Level Waste Disposed: 1986 - 2008

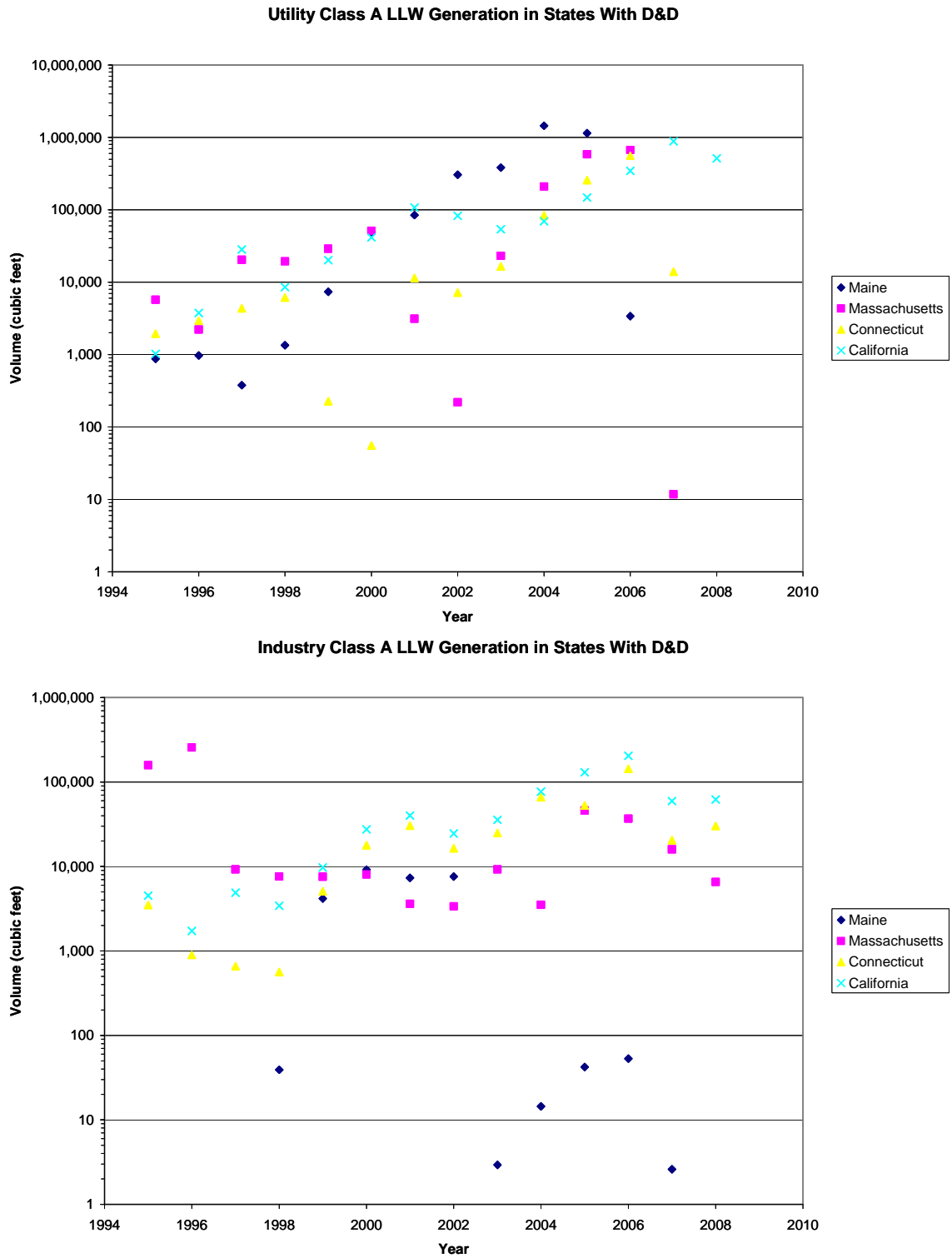


Figure H.2.1-3  
 Utility and Industry Generated Class A Low Level Waste Disposed in States with Active D&D

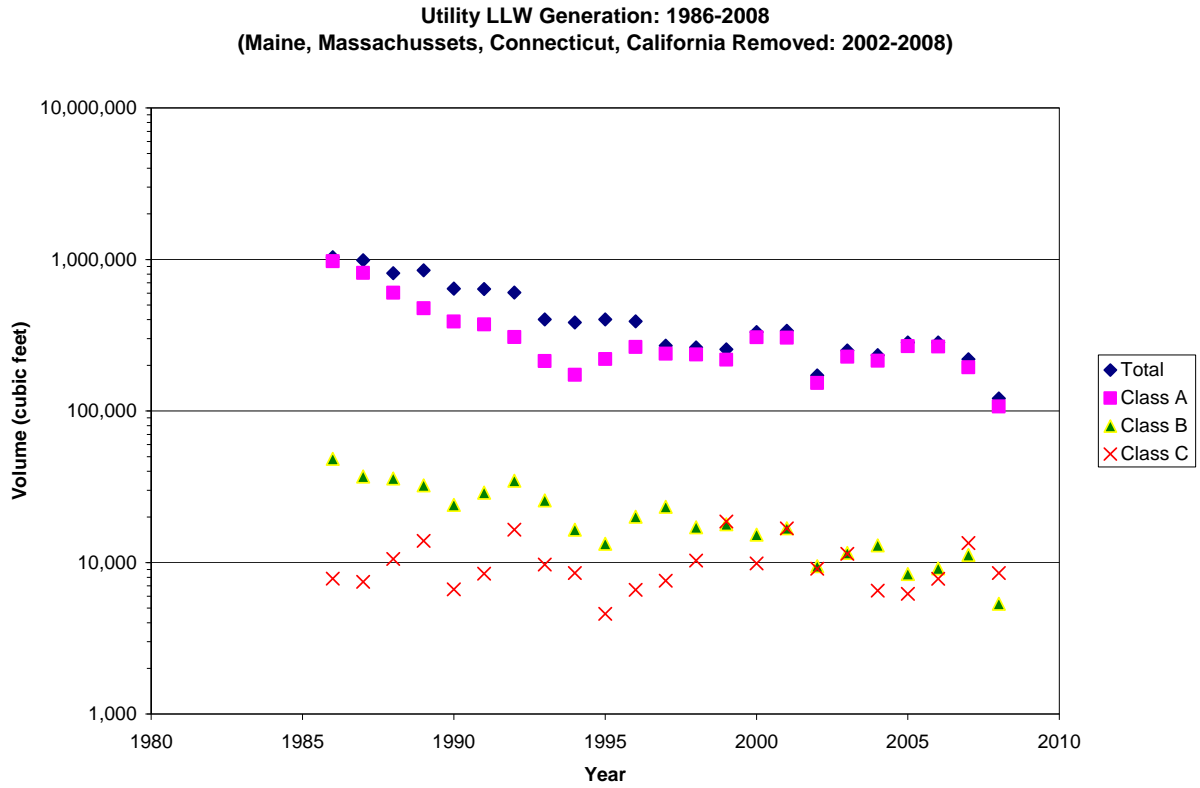


Figure H.2.1-4  
Utility Generated Low Level Waste Disposed, Adjusted for Plant Decommissioning: 1986 - 2008

## **H.2.2 Academic, Government, Medical, and Undefined Generation**

The volume of LLW disposed from academic, medical, government, and undefined generators over the period 1986 through 2008 is shown in Figures H.2.2-1 and H.2.2-2. The data obtained from MIMS is somewhat inconsistent in that the volumes of Class A, B, and C wastes do not always add up to the total volume reported and in some years only a total volume is reported. The data also shows considerable variability.

The volume of academic-generated Class A LLW disposed is observed to have decreased between 1986 and 1996, then remained relatively steady (except for 2007). The volume of academic-generated Class B LLW disposed is observed to be relatively steady, but variable. The volume of academic-generated Class C waste is observed to have increased after 1996 and has remained relatively steady.

Except for 2006 and 2007, the volume of medical-generated Class A LLW disposed is observed to have decreased. While variable from year-to-year, the volume of medical-generated Class B and C LLW disposed has remained relatively steady.

The Federal Government is the third largest generator of LLW disposed in commercial facilities. The LLW is generated primarily from environmental restoration within the DOE Office of Environmental Management (DOE-EM) complex. DOE-EM uses commercial disposal facilities when economically practical, in addition to DOE-owned disposal facilities. The data shows an increase in Government-generated LLW volumes beginning in the late 1990s and continuing as DOE-EM environmental restoration projects were initiated (i.e., Hanford River Corridor, Fernald, Rocky Flats). It is anticipated that DOE-EM will continue to utilize commercial disposal facilities to dispose of environmental restoration wastes through at least mid-century.

The volume of waste disposed from undefined generators reported in MIMS is small, in particular for Class B and C LLW, and variable.

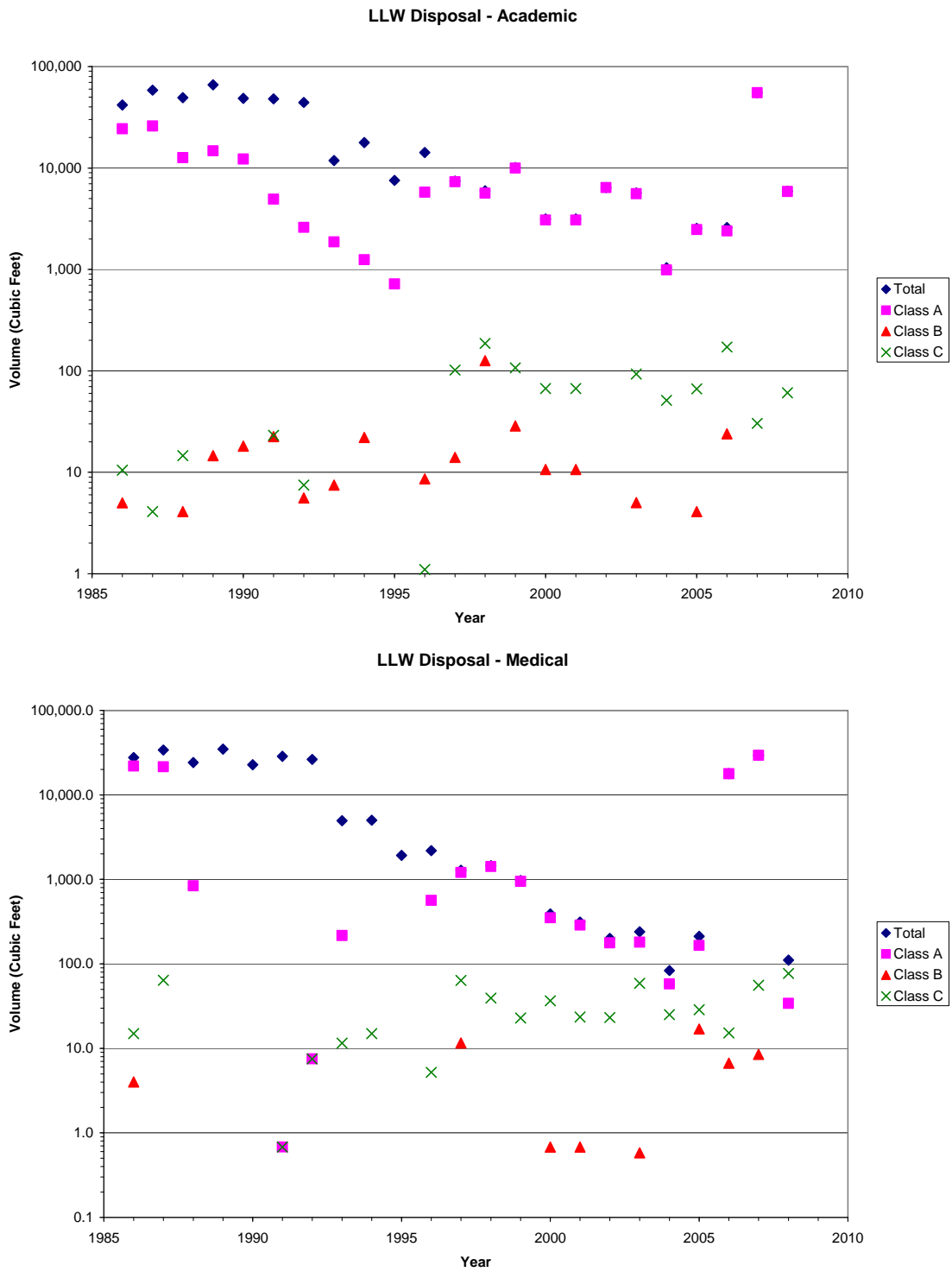


Figure H.2.2-1  
 Academic and Medical Generated Low Level Waste Disposed: 1986 - 2008.

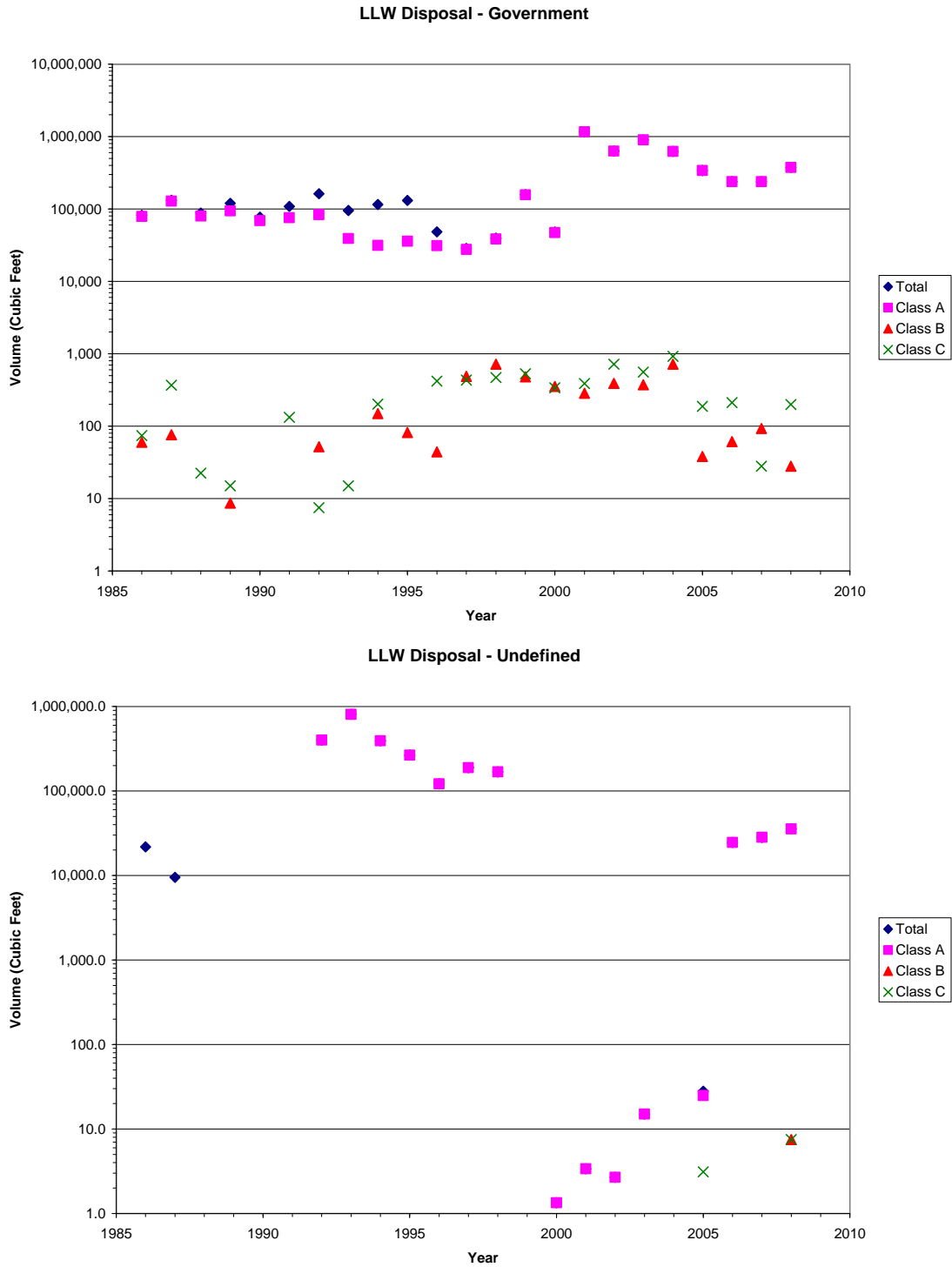


Figure H.2.2-2  
Government and Undefined Generated Low Level Waste Disposed: 1986 - 2008.



### H.3.0 Generation Estimates

The data reported from MIMS and presented above were used to develop estimates of LLW generation rates. It is recognized that these estimates are uncertain and actual disposal volumes could vary significantly from year to year. As such, the MIMS data shown above was used to develop projection estimates to two significant figures at most.

#### Academic

The estimates for LLW from undefined generators were determined from the MIMS data in Figure H.2.2-1 averaged over the period of 2000 – 2008 (converted to cubic meters).

Class A:	270 m <sup>3</sup> /year
Class B:	0.2 m <sup>3</sup> /year
Class C:	2 m <sup>3</sup> /year

#### Medical

The estimates for LLW from undefined generators were determined from the MIMS data in Figure H.2.2-1 averaged over the period of 2000 – 2008 (converted to cubic meters).

Class A:	150 m <sup>3</sup> /year
Class B:	0.1 m <sup>3</sup> /year
Class C:	1 m <sup>3</sup> /year

#### Government

The estimates for government generated LLW that will be disposed in a commercial facility were determined from the MIMS data in Figure H.2.2-2 averaged over the period of 2000 – 2008 (converted to cubic meters).

Class A:	14,000 m <sup>3</sup> /year
Class B:	7 m <sup>3</sup> /year
Class C:	11 m <sup>3</sup> /year

#### Undefined

The estimates for LLW from undefined generators were determined from the MIMS data in Figure H.2.2-2 averaged over the period of 2000 – 2008 (converted to cubic meters).

Class A:	310 m <sup>3</sup> /year
Class B:	0.1 m <sup>3</sup> /year
Class C:	0.1 m <sup>3</sup> /year

#### Industry and Utility

The estimates for LLW from industry generators were determined from the MIMS data in Figure H.2.1-2 averaged over the period of 2000 – 2008 (converted to cubic meters). The estimates for LLW from utility generators were determined from data shown in Figure H.2.1-4 (D&D activities removed), averaged over the period of 2000 – 2008 (converted to cubic meters). These estimates are shown in Table H.3.0-1.

An overall estimate for nuclear power generation is determined by summing the individual utility (without D&D) and industrial generated LLW estimates. This assumes that all industrial generated LLW is related to nuclear power and will thus lead to an overestimate in the estimated LLW generation rate because there are some industrial generators not related to nuclear power. The LLW generation rates from industry are also shown in Table H.3.0-1. Data obtained from the DOE Energy Information Agency indicates that the average annual amount of electricity generated by nuclear power was 780 TW-hr over the period of 2000-2008. This was used to normalize the LLW generation rate to power production, also shown in Table H.3.0-1.

<b>Table H.3.0-1 Estimated LLW Disposal Rates for Utility and Industry Generators</b>				
<b>Waste Class</b>	<b>Utility (w/o D&amp;D)</b>	<b>Industry</b>	<b>Total Nuclear</b>	
Class A	7,000 m <sup>3</sup> /year	45,000 m <sup>3</sup> /year	52,000 m <sup>3</sup> /year	66 m <sup>3</sup> /TW-hr
Class B	320 m <sup>3</sup> /year	20 m <sup>3</sup> /year	340 m <sup>3</sup> /year	0.4 m <sup>3</sup> /TW-hr
Class C	280 m <sup>3</sup> /year	20 m <sup>3</sup> /year	300 m <sup>3</sup> /year	0.4 m <sup>3</sup> /TW-hr

#### Nuclear Power Plant Decommissioning

The volume of LLW disposed from states having active D&D during the period of 2002 through 2008 is shown in Figure H.3.0-1 along with the number of reactor plants that were under D&D in each year. The LLW volumes shown in Figure H.3.0-1 were normalized to the number of reactor plants under D&D each year. The estimate of the volume of LLW that would be generated during the decommissioning of a nuclear power plant was then estimated by determining the average over this period. These estimates are on a per plant basis and applicable only during periods of active decommissioning.

Class A: 15,000 m<sup>3</sup>/year

Class B: 5 m<sup>3</sup>/year

Class C: 50 m<sup>3</sup>/year

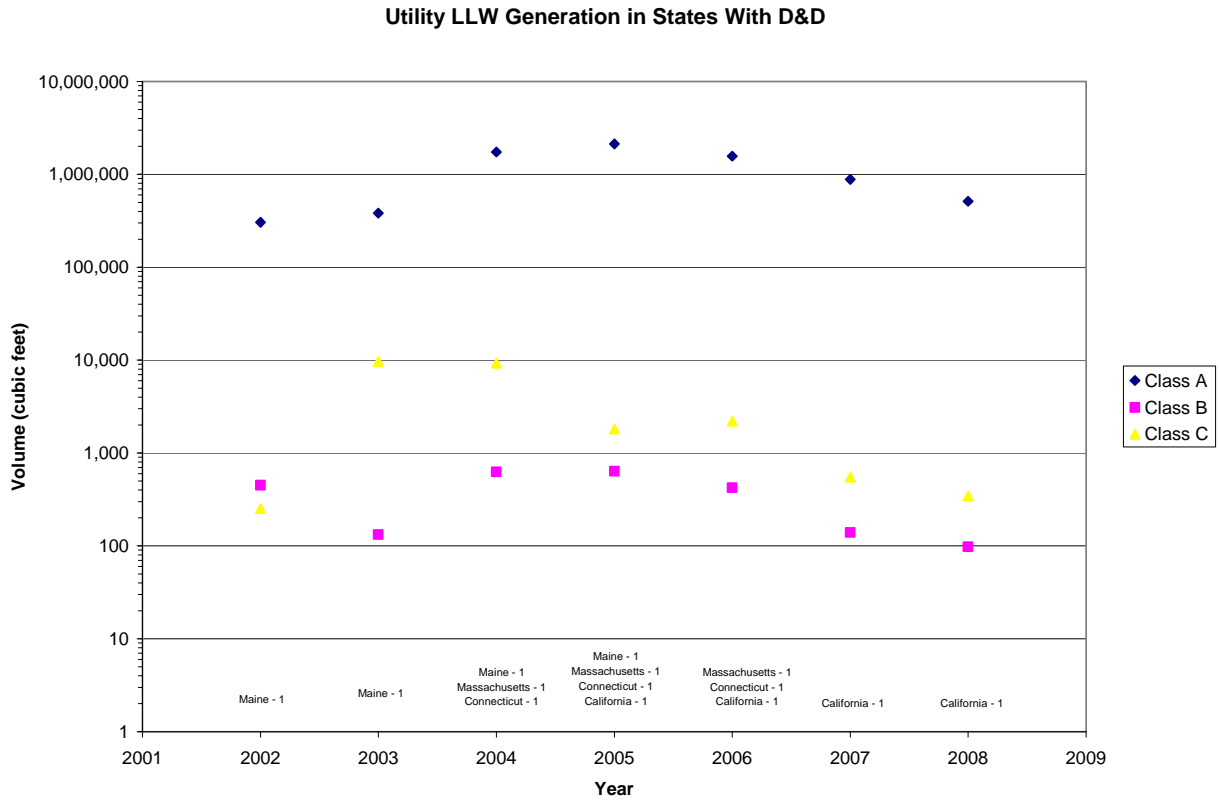


Figure H.3.0-1  
Utility Generated Low Level Waste Disposed, States with Active D&D: 2002 - 2008.