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
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Revision 1
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REVISIONS

Revision Number	Date	Major Sections Affected	Description
0	June 2010		Original issue
1	September 2010	- Tables 2.2-1 and 2.2-2 - Section 2.2.2 and 2.2.3 - Tables C.3.0-3, C.3.0-4, C.4.0-1 and C.4.0-2 - Tables D.3.0-3, D.3.0-4, D.4.0-3 and D.4.0-4 - Tables E.3.0-3, E.3.0-4, E.4.0-3 and E.4.0-4 - Tables F.3.0-3, F.3.0-4, F.4.0-3 and F.4.0-4 - Sections 2.4 and 2.5 - Sections 3.4 and 3.5 - Appendices I, J, K and L	- Revised the volume of metal waste for the aqueous recycling waste estimates for light water reactor used fuel based on the Engineering Alternative Studies (EAS) to be in agreement with the metal waste estimates provided by the study, FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*. - Added mixed waste values for the EAS West Valley estimate - Added equations for the curves in Tables 2.2-5 through 2.2-8 - Added waste estimates for aqueous and electrochemical recycling of sodium fast reactor used fuel

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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

Revision 1 of this study provides additional waste estimates for aqueous recycling of sodium fast reactor used fuel and electrochemical recycling of sodium fast reactor used fuel.

Low level waste generation for operations at a geologic repository ranges from 0.8 m^3/MTHM of used fuel disposed to 3.7 m^3/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^3/MTHM to the values shown in Figure EX-1. Repository operations are not expected to generate GTCC waste, mixed LLW or mixed GTCC waste.

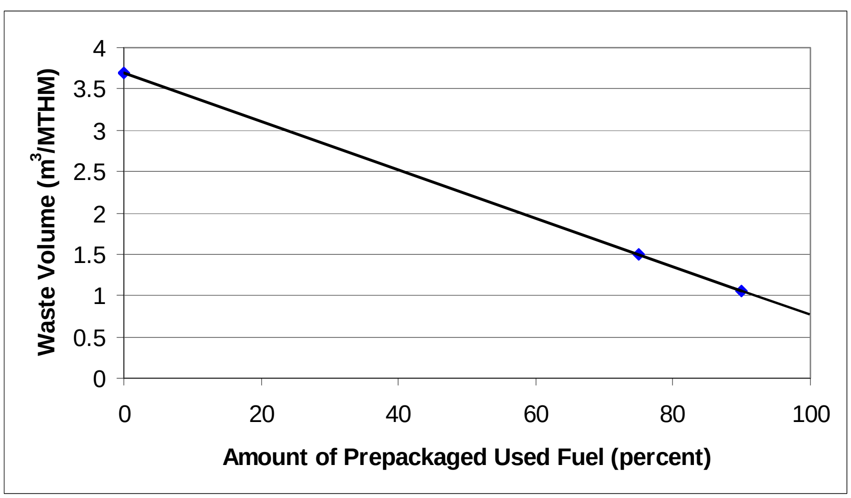


Figure EX-1
Low Level Waste Generation Rates For Geologic Repository Operations

Waste generation rates for aqueous recycling were derived for various aqueous recycling technologies based on data from industry (AREVA and Energy*Solutions*), West Valley and the Engineering Alternative Studies (EAS) for Separations. The technologies considered include co-extraction (AREVA), NUEX (Energy*Solutions*) 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.

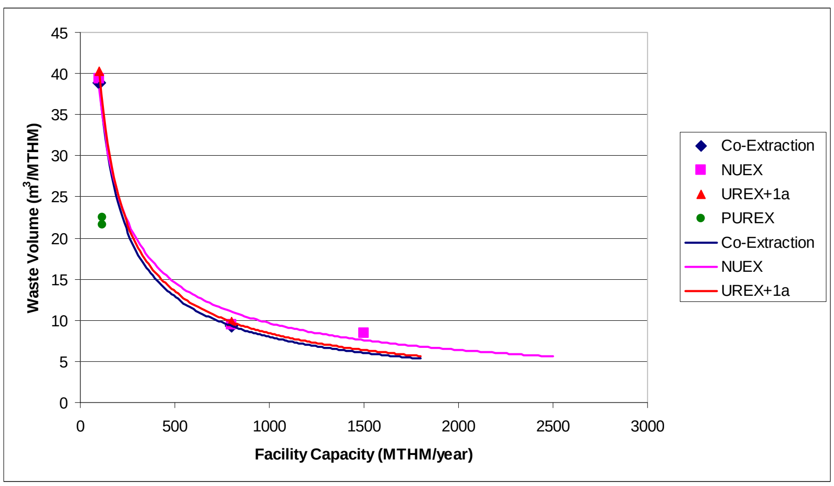


Figure EX-2
Low Level Waste Volume For Aqueous Recycling

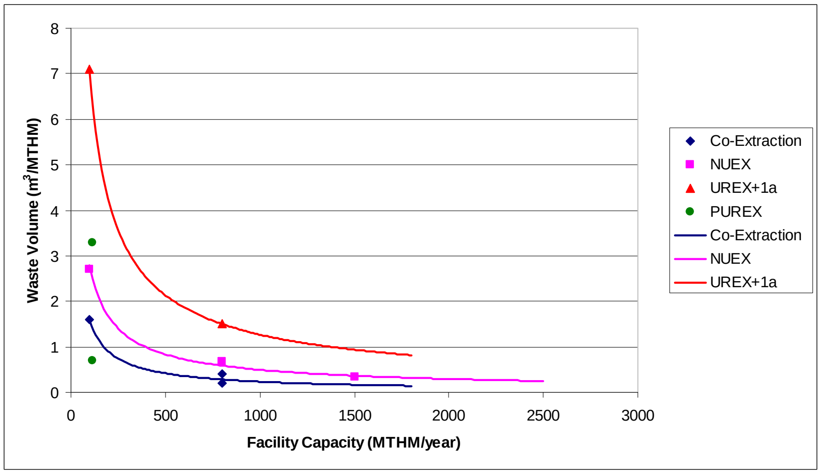


Figure EX-3
GTCC Waste Volume For Aqueous Recycling

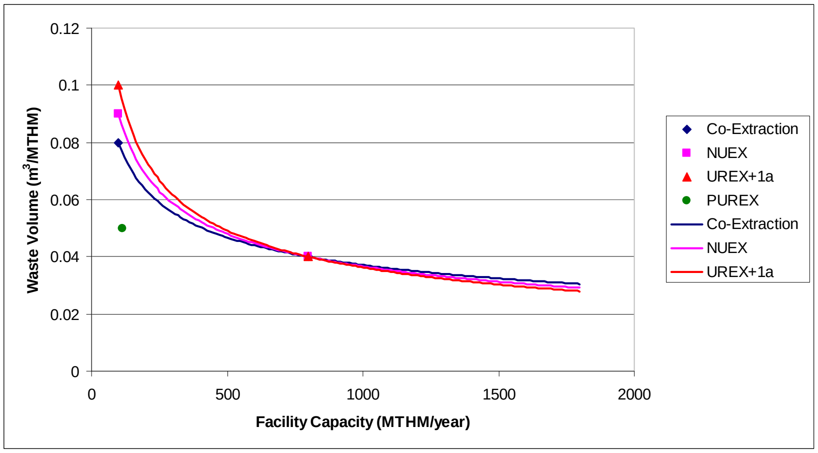


Figure EX-4
Mixed Low Level Waste Volume For Aqueous Recycling

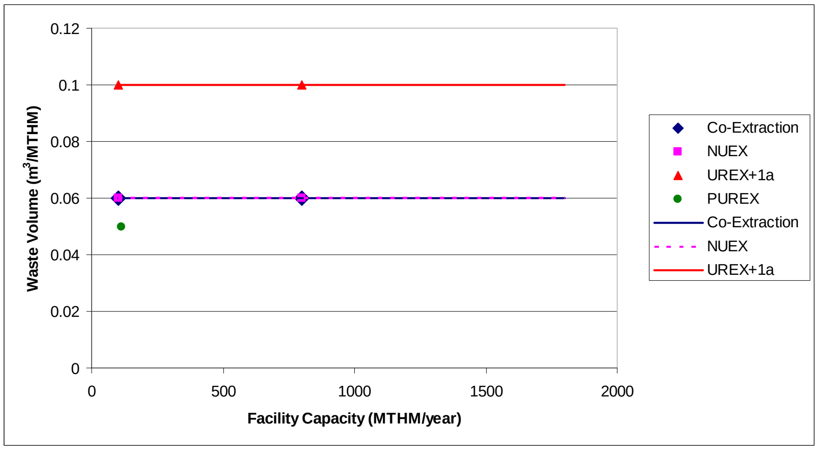


Figure EX-5
Mixed GTCC For Aqueous Recycling

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^3/MTHM of used fuel recycled. GTCC waste is expected to be generated at the rate of 3.1 m^3/MTHM, mixed LLW at 0.1 m^3/MTHM and mixed GTCC at 0.15 m^3/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.

Table EX-1
Comparison of Estimated LLW Generation Rates from Recycling Facilities to Current Class A LLW Disposal Rates

Recycling Method	Number of Plants	Recycling Facility Capacity (MTHM/year)	Estimated Total LLW Generated from Recycling (m^3/year)	Percentage of Annual Total LLW Generated [1]	Percentage of Annual Nuclear LLW Generated [2]
Co-extraction	2	1,200	16,800	25.2 %	32.3 %
	3	800	22,320	33.4 %	42.9 %
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.

Table 4.0-3
Comparison of Estimated LLW Generation Rates from Geologic Disposal to Current Disposal Rates

Percentage of Used Fuel Pre-Packaged in Disposable Canisters	Monitoring Period (years)	LLW Generation Rate (m^3/year)	Estimated Total LLW Generated from Geologic Disposal (m^3/year)	Percentage of Annual Total LLW Generated [1]	Percentage of Annual Nuclear LLW Generated [2]
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 %
90	50	50	1.06	2,544	3.8%
	250	250	1.26	3,024	4.5%

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 (Energy*Solutions*) 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.

1.1 Initial Issue (Revision 0)

The original issue (Revision 0) of this study provides waste estimates for the fuel cycles and recycling processes as described above. The original issue also provides a comparison of the low level waste generated from these fuel cycles and recycling operations to the current disposal rate of low level waste in the United States.

1.2 Revision 1

Revision 1 of this study provides additional waste estimates for aqueous recycling of sodium fast reactor used fuel and electrochemical recycling of sodium fast reactor used fuel. Revision 1 also incorporates minor corrections to the material provided by Revision 0. These revisions can be summarized as follows:

- The volume of metal waste for the waste estimates based on the Engineering Alternative Studies (EAS) was revised to be in agreement with the metal waste estimates provided by the study, FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition.*
- Mixed waste estimates were added to the EAS West Valley waste estimates based on the Engineering Alternative Studies data in Tables 2.2-1 and 2.2-2.
- Equations for the curves provided in Figures 2.2-5 through 2.2-8 are added.

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).[1] 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.

Table 2.1-1
Low Level Waste Volume Estimates For The Proposed Yucca Mountain Repository Operations

Source	Waste Volume (m^3)
Solidified low level liquid waste [1]	25,000
Dual-purpose canisters	9,800
Other operational and maintenance activities	39,200
Total (m^3)	74,000
Total (m^3/MTHM) [2]	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 m^3 ÷ 70,000 MTHM = 1.06 m^3/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^3/year of low level waste. Elimination of one Canister Receipt and Closure Facility avoids the generation of 76 m^3/year of low level waste. The net increase in low level waste volume is 504 m^3/year or approximately 29,000 m^3 over the 57 year emplacement period; therefore, the total low level waste volume becomes 103,000 m^3 (74,000 + 29,000 = 103,000). This equates to 1.5 m^3 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^3 [(580 x 5) - (76 x 2) = 2,748] or approximately 157,000 m^3 over the 57 year emplacement period. The total low level waste volume then becomes 260,000 m^3 (103,000 + 157,000 = 260,000) or 3.7 m^3 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^3/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^3/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^3/MTHM at a 100% prepackaging level.

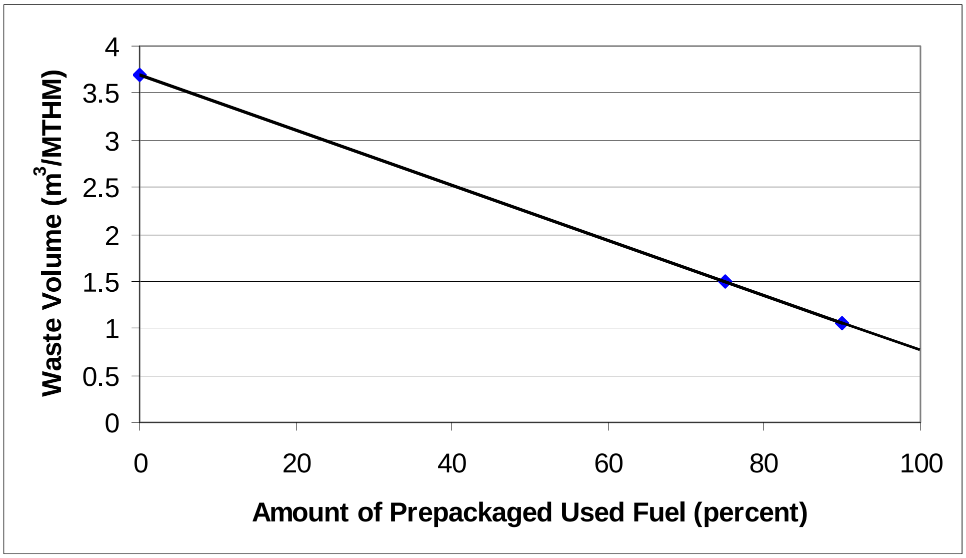


Figure 2.1-1
Low Level Waste Volume

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^3 (or 0.2 m^3/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 of Light Water Reactor Used Fuel

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 Energy*Solutions*, 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®) as depicted in Figure 2.2-1. Energy*Solutions* 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.

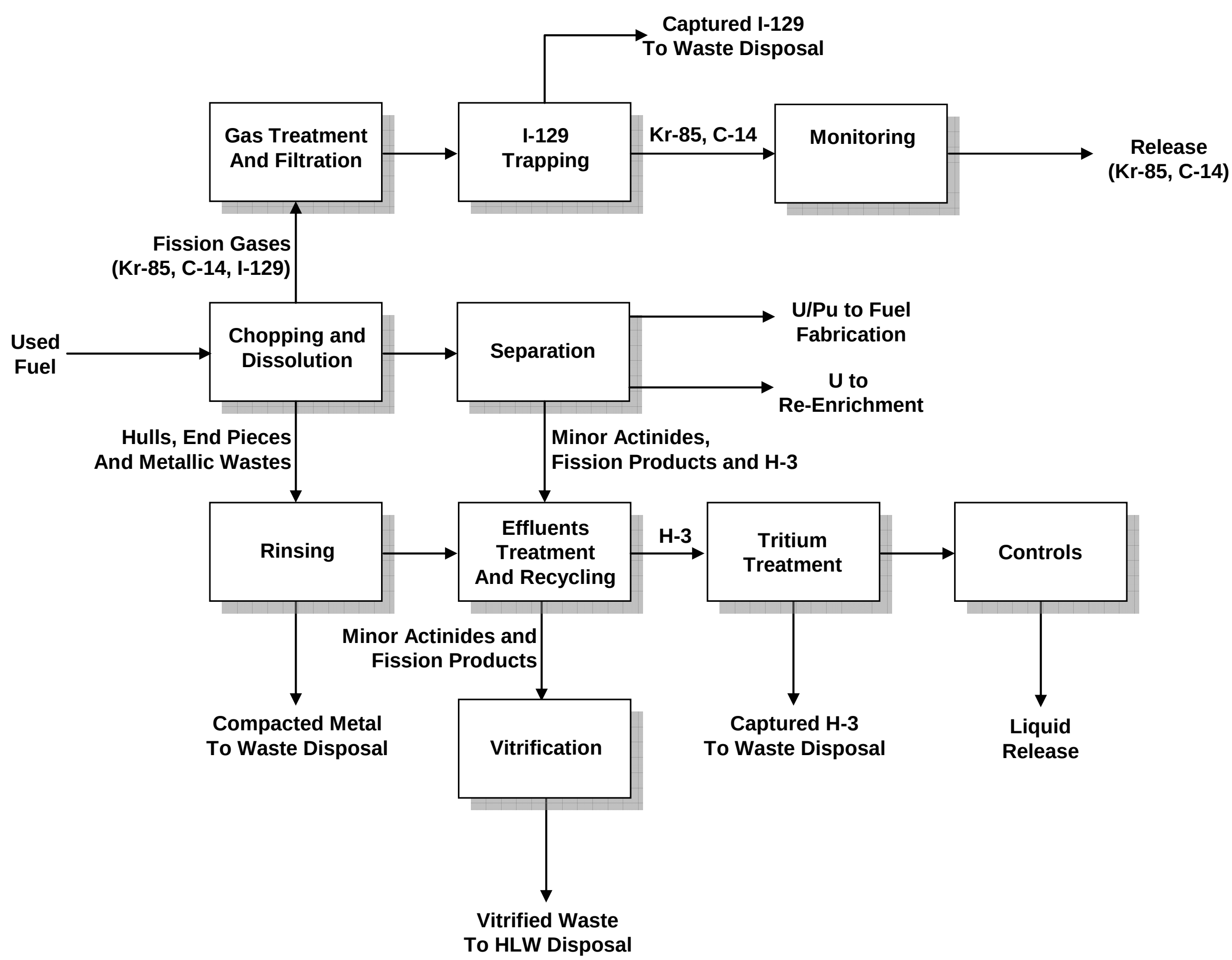


Figure 2.2-1
AREVA COEX® Recycling Process

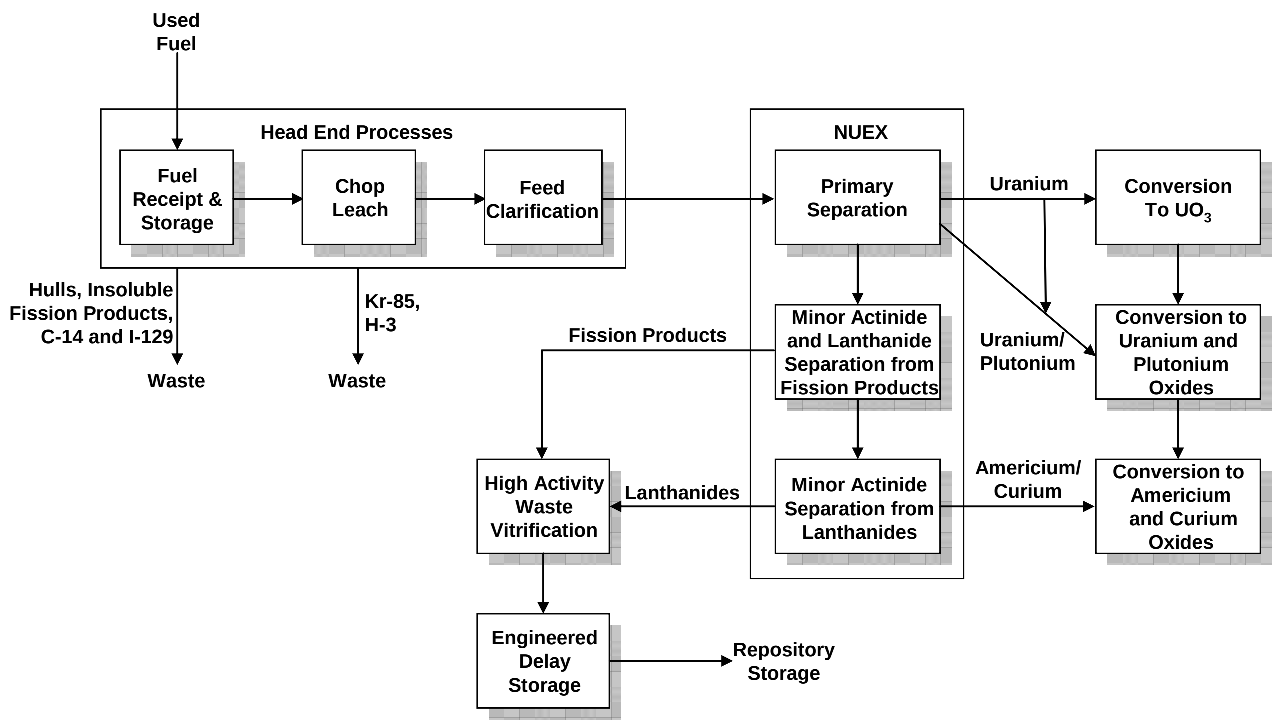


Figure 2.2-2
Energy*Solutions* NUEX Recycling Process

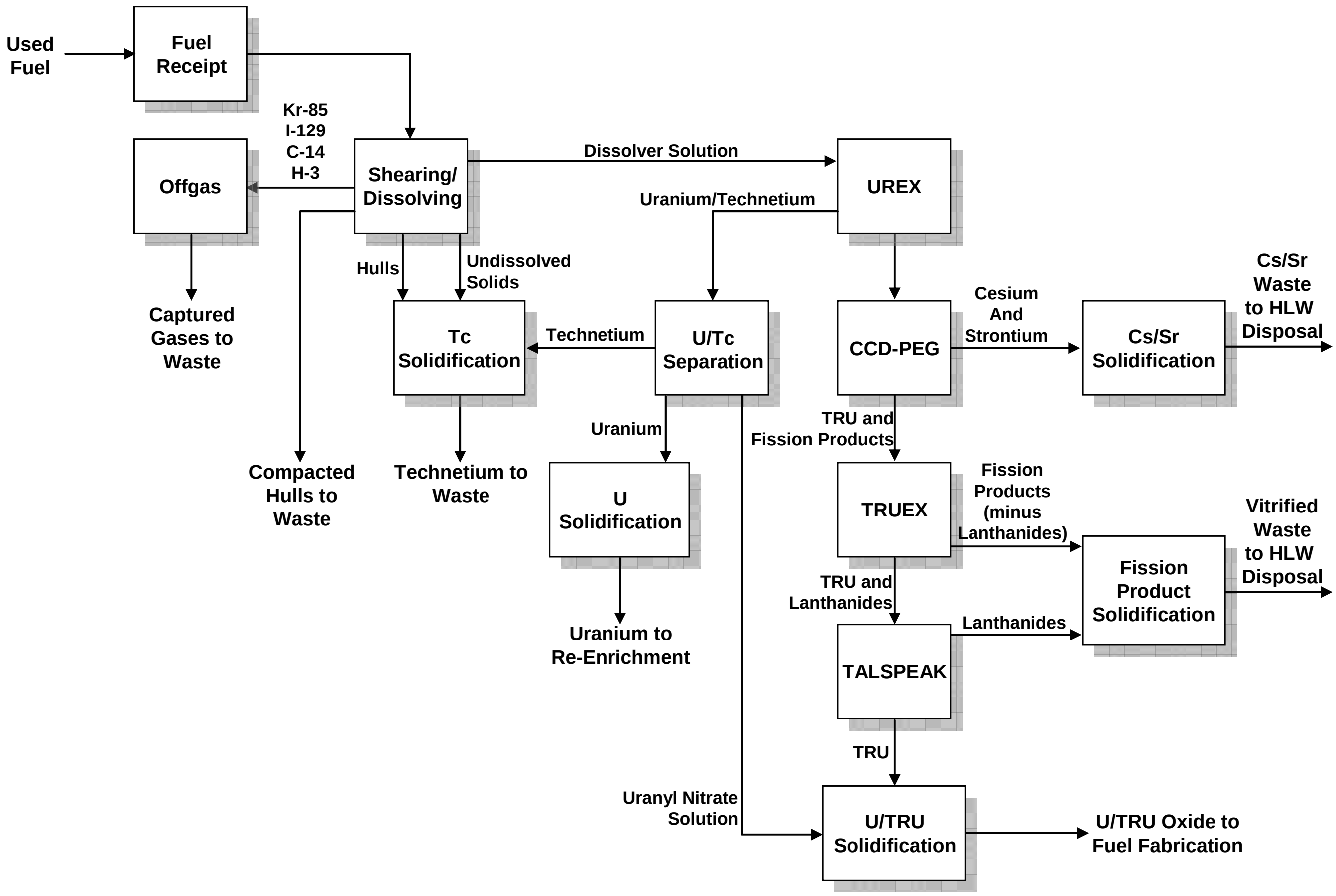


Figure 2.2-3
UREX+1a Recycling Process

Waste estimates from AREVA and Energy*Solutions* are provided in publicly available documents such as the presentations made to the Nuclear Waste Technical Review Board (NWTRB) on September 23, 2009.[3,4] The waste estimates provided by AREVA and Energy*Solutions* 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 Alternative 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.[5] 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 Energy*Solutions* 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^3/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.

Table 2.2-1
Summary of Annual Aqueous Recycling Waste Streams

Data Source [1]	Estimate Basis (MTHM/yr)	Volume	Low Level Waste Class A	Low Level Waste Class B	Low Level Waste Class C	Low Level Waste Total	GTCC Waste CH-TRU	GTCC Waste RH-TRU + GTCC	GTCC Waste Total	Mixed LLW	Mixed GTCC
AREVA	800	m^3/year				1,228			148		
		m^3/MTHM				1.5			0.2		
Energy Solutions	1,500	m^3/year	12,600		113	12,713	130	371	501		
		m^3/MTHM	8.4		0.08	8.5	0.09	0.25	0.33		
West Valley	115	m^3/year	2,420	9	83	2,511			384		
		m^3/MTHM	20.8	0.1	0.7	21.6			3.3		
EAS UREX+1a	800	m^3/year				7,801			1,251	32	76.9
		m^3/MTHM				9.8			1.6	0.04	0.1
	100	m^3/year				4,026			708	9.6	9.7
		m^3/MTHM				40.3			7.1	0.1	0.1
EAS Co-Extraction	800	m^3/year				7,479			347	28.6	44.8
		m^3/MTHM				9.3			0.43	0.04	0.06
	100	m^3/year				3,884			161	8.4	5.6
		m^3/MTHM				38.8			1.6	0.08	0.06
EAS "NUEX"	800	m^3/year				7,590			564	29.8	44.8
		m^3/MTHM				9.5			0.70	0.04	0.06
	100	m^3/year				3,935			271	8.8	5.6
		m^3/MTHM				39.4			2.7	0.09	0.06
EAS West Valley	115	m^3/year				2,590			88	6.0	5.6
		m^3/MTHM				22.5			0.8	0.05	0.05

1. AREVA - Appendix A
   EnergySolutions - 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

Table 2.2-2
Comparison of Waste Volume Estimates by Category

Data Source	Estimate Basis (MTHM/yr)	Volume	Low Level Waste				GTCC Waste			Mixed LLW	Mixed GTCC
			Class								
			A	B	C	Total	CH-TRU	RH-TRU + GTCC	Total		
AREVA	800	m^3/year				1,228			148		
		% of total				89.2			10.8		
Energy Solutions	1,500	m^3/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^3/year	2,420	9	83	2,511			384		
		% 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^3/year				7,801			1,251	32	76.9
		% of total				85.2			13.7	0.3	0.8
	100	m^3/year				4,026			708	9.6	9.7
		% of total				84.7			14.9	0.2	0.2
EAS Co-Extraction	800	m^3/year				7,479			347	28.6	44.8
		% of total				94.7			4.4	0.4	0.6
	100	m^3/year				3,884			161	8.4	5.6
		% of total				95.7			4.0	0.2	0.1
EAS "NUEX"	800	m^3/year				7,590			564	29.8	44.8
		% of total				92.2			6.9	0.4	0.5
	100	m^3/year				3,935			271	8.8	5.6
		% of total				93.2			6.4	0.2	0.1
EAS West Valley	115	m^3/year				2,590			88	6.0	5.6
		% of total				96.3			3.3	0.2	0.2

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^3 to 40.3 m^3 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^3 to 9.8 m^3 (~7-48 55 gallon drums) per MTHM of material processed. Without the AREVA estimate, the LLW generation is 8.5 m^3 to 9.8 m^3 (~42 to 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 ÷ 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 2.3 times greater than the AREVA estimates (347 ÷ 148 = 2.3).
   - The ratio of LLW volume to GTCC waste volume for the EAS Co-Extraction facility is approximately 21.6 (7,479 ÷ 347 = 21.6) and approximately 8.3 for the AREVA facility (1,228 ÷ 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 + 347) ÷ (1,228 + 148) = 5.7], the disparity driven primarily by the difference in LLW volumes.
2. Energy*Solutions* waste estimates compared to the EAS NUEX waste estimates:
   - LLW volume estimates for the EAS NUEX facility are in very close agreement with the Energy*Solutions* estimates, approximately 1.1 times greater than the Energy*Solutions* estimates after adjusting for capacity [(7,590 ÷ 800) ÷ (12,713 ÷ 1,500) = 1.1].
   - GTCC waste volume estimates for the EAS NUEX facility are approximately 2.1 times greater than the Energy*Solutions* estimates [(564 ÷ 800) ÷ (501 ÷ 1,500) = 2.1].
   - The ratio of LLW volume to GTCC waste volume for the EAS NUEX facility is approximately 14.1 (7,590 ÷ 564 = 13.5) and approximately 25.4 for the Energy*Solutions* facility (12,713 ÷ 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 Energy*Solutions* estimates, approximately 1.2 times greater than the Energy*Solutions* estimates [((7,590 + 564) ÷ 800) ÷ ((12,713 + 501) ÷ 1,500) = 1.2].
   - Note that the above calculations are based on the "per MTHM" waste volumes since the EAS and the Energy*Solutions* 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) ÷ 7,479) x 100 = 4.3] and approximately 1.5% for NUEX vs. Co-Extraction [((7,590 – 7,479) ÷ 7,479) x 100 = 1.5].
   - GTCC waste volume varies significantly, approximately 261% for UREX+1a vs. Co-Extraction [((1,251 – 347) ÷ 347) x 100 = 261] and approximately 63% for NUEX vs. Co-Extraction [((564 – 347) ÷ 347) x 100 = 63]. 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) ÷ 28.6) x 100 = 12] and approximately 3.6% for NUEX vs. Co-Extraction [((29.8 – 28.6) ÷ 28.6) x 100 = 3.6].

- Mixed GTCC waste volume varies significantly for UREX+1a vs. Co-Extraction, approximately 72% [((76.9 – 44.8) ÷ 44.8) x 100 = 72] but none for NUEX vs. Co-Extraction [((44.8 – 44.8) ÷ 44.8) x 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 ÷ 7,801 x 100 = 52%), approximately 52% for the Co-Extraction process (3,884 ÷ 7,479 x 100 = 52%) and approximately 52% for the "NUEX" process (3,935 ÷ 7,590 x 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 (708 ÷ 1,251 x 100 = 57%), approximately 46% for the Co-Extraction process (161 ÷ 347 x 100 = 46%) and approximately 48% for the "NUEX" process (271 ÷ 564 x 100 = 48%). 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 ÷ 32 x 100 = 30%), approximately 29% for the Co-Extraction process (8.4 ÷ 28.6 x 100 = 29%) and approximately 30% for the "NUEX" process (8.8 ÷ 29.8 x 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 ÷ 76.9 x 100 = 12.5%), approximately 12.5% for the Co-Extraction process (5.6 ÷ 44.8 x 100 = 12.5%) and approximately 12.5% for the "NUEX" process (5.6 ÷ 44.8 x 100 = 12.5%).

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

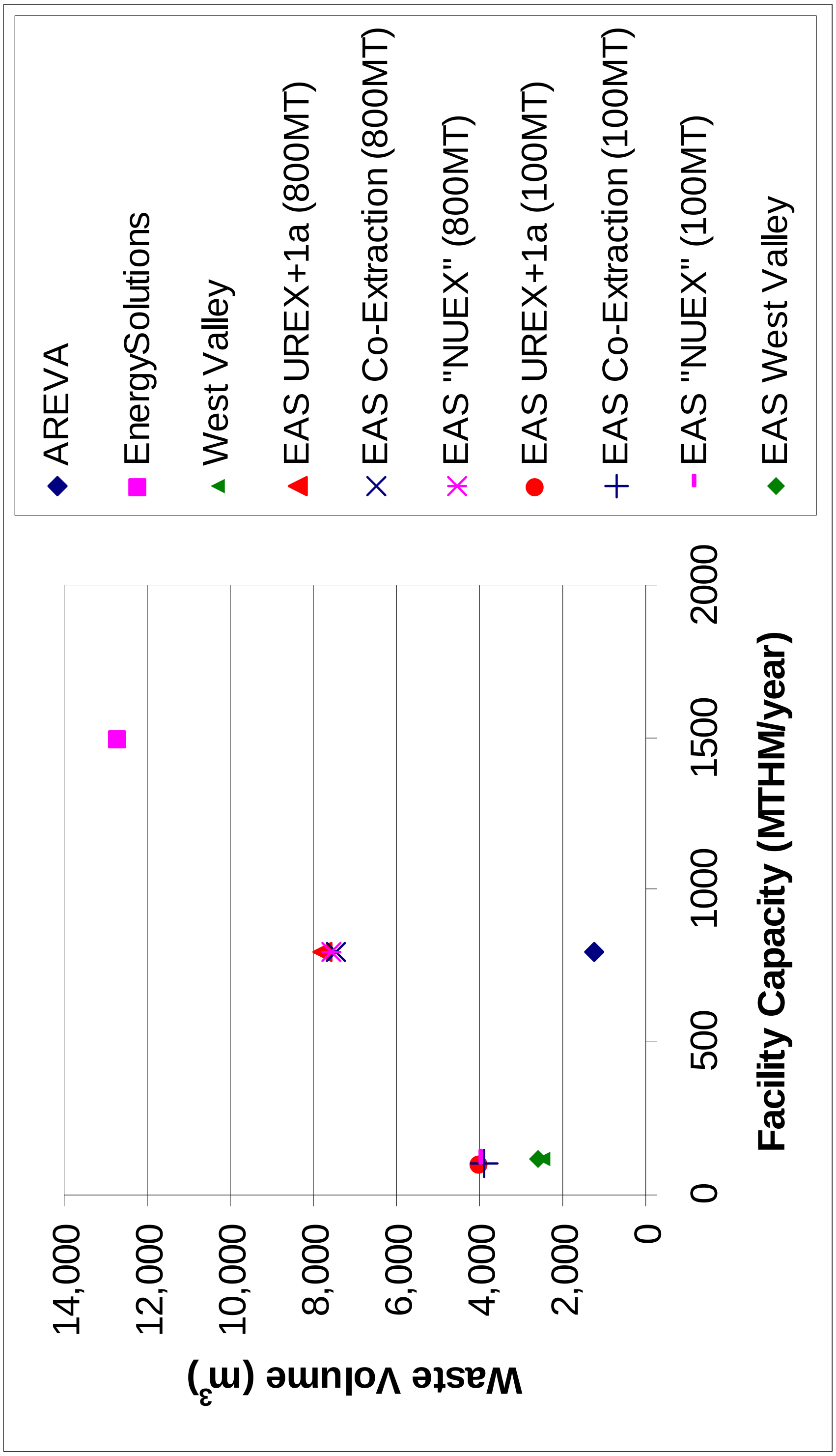


Figure 2.2-1
Annual Low Level Waste Volume

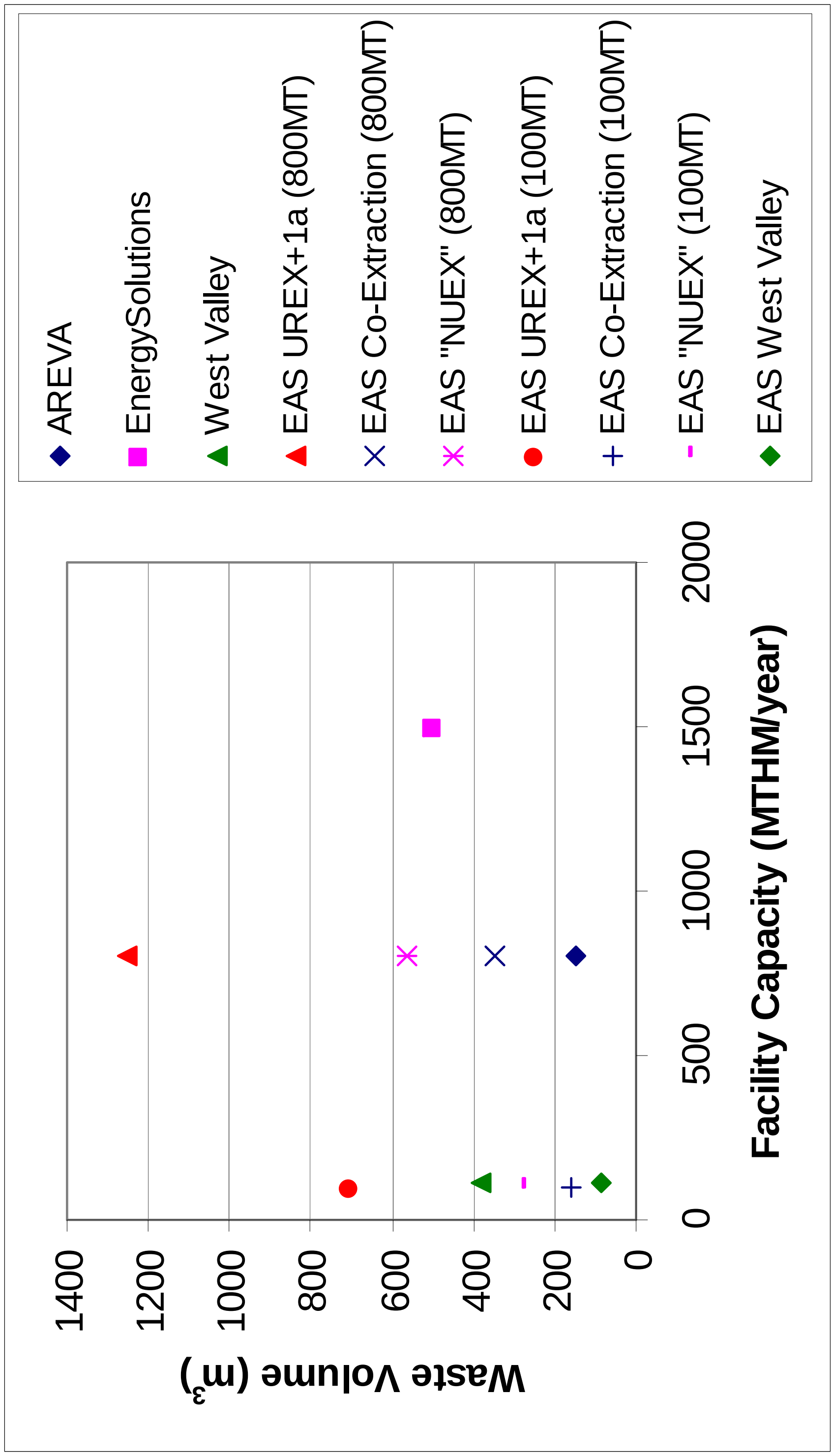


Figure 2.2-2
Annual GTCC Waste Volume

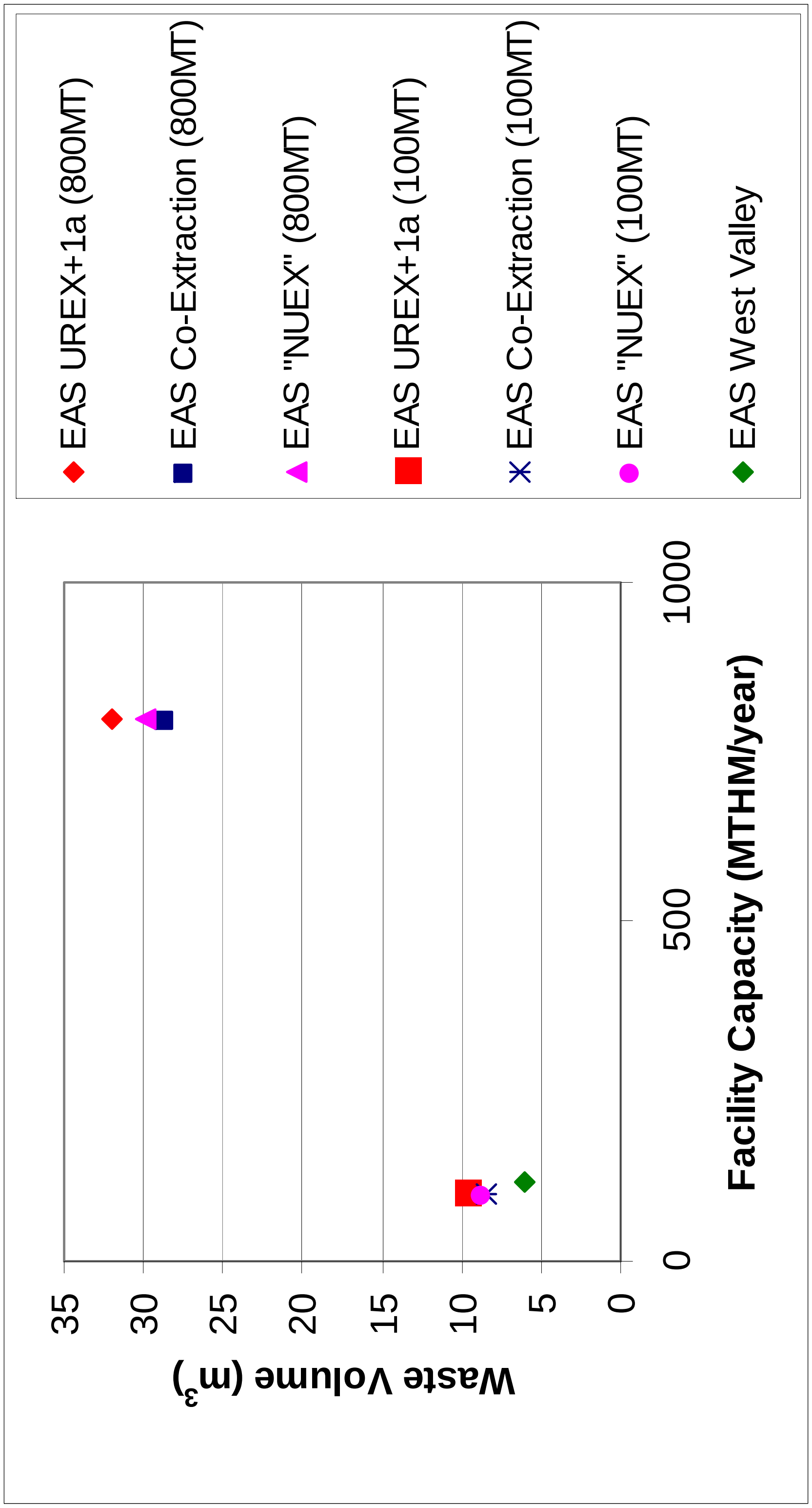


Figure 2.2-3
Annual Mixed Low Level Waste Volume

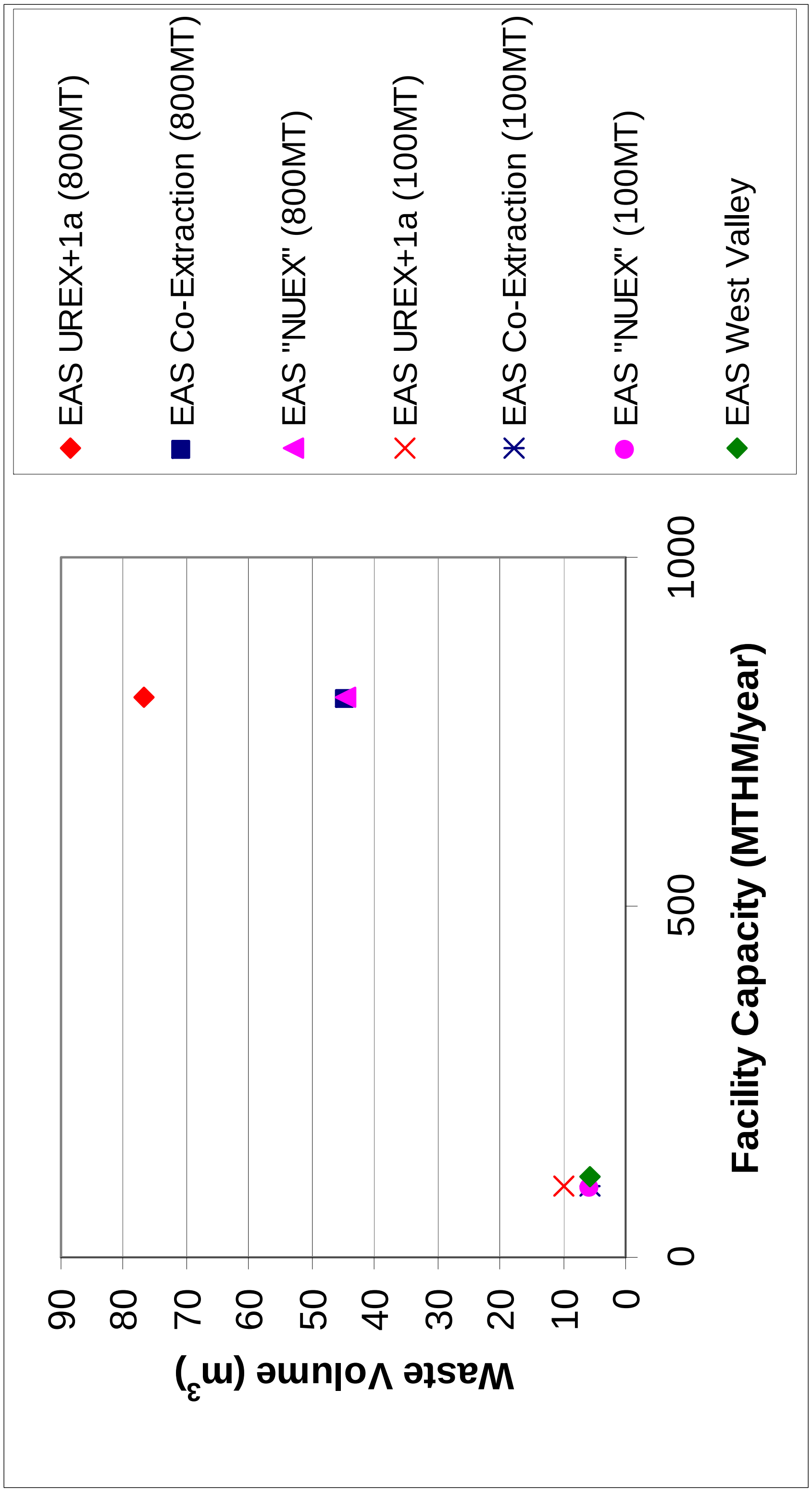
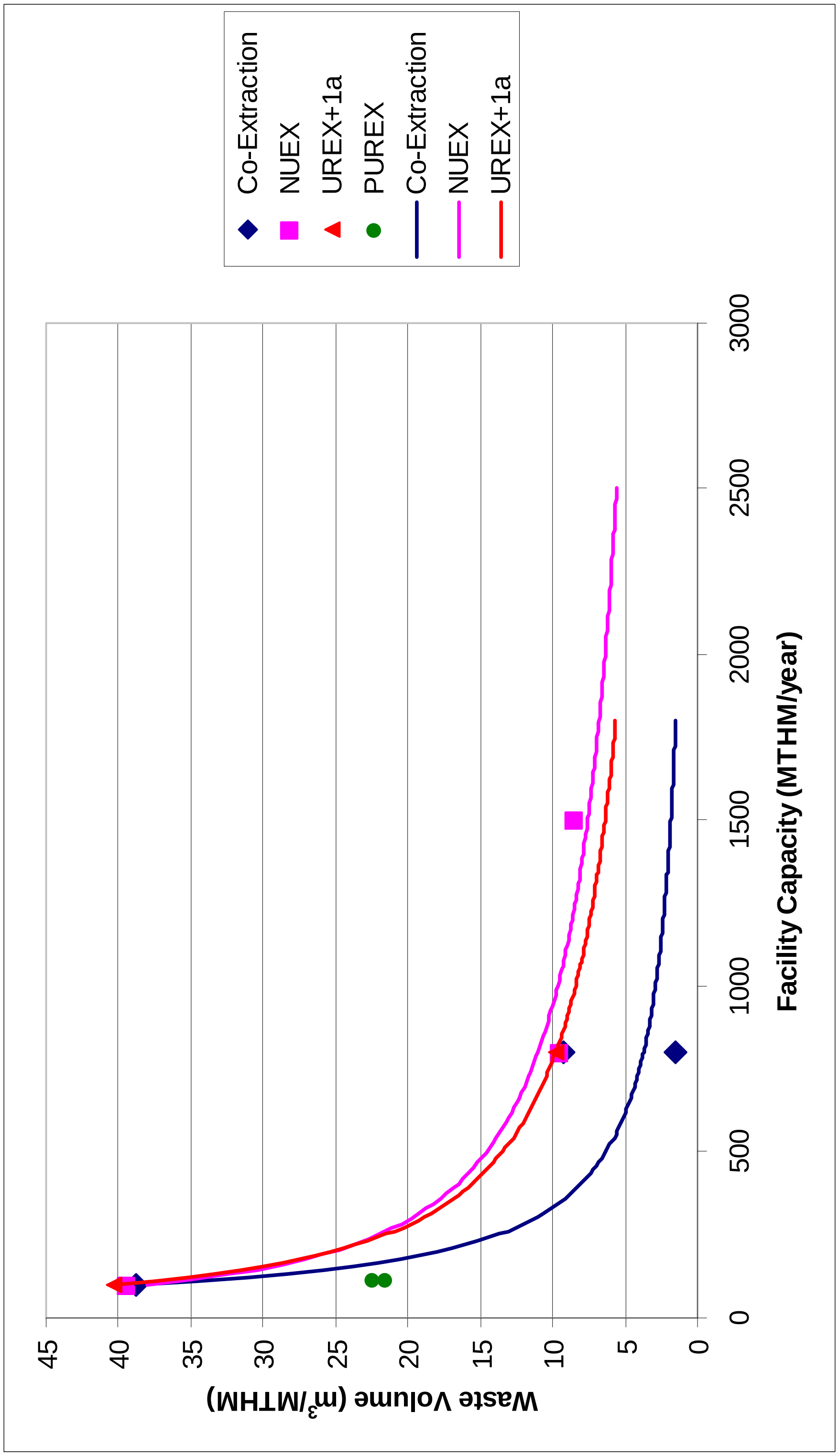


Figure 2.2-4
Annual Mixed GTCC Waste Volume

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.

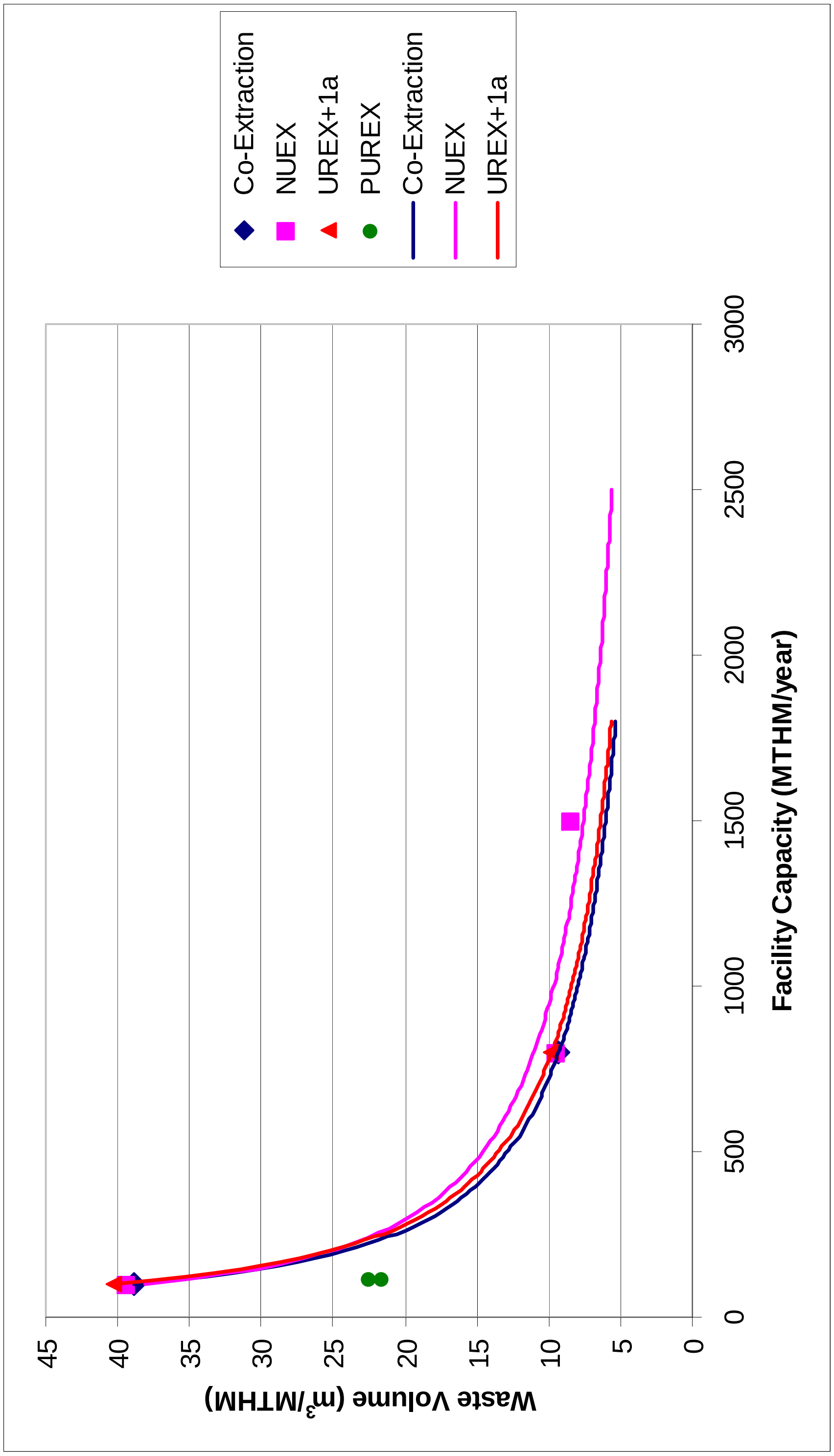
A variation of the low level waste curve is provided (Figure 2.2-6) that eliminates the AREVA data point which does not appear to be in good agreement with the other data points in Table 2.2-1. AREVA has verbally stated that they are in the process of reviewing their waste estimates and that the estimates could possibly be revised based on the results of the review.[6] 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.



<u>Equations</u>

Co-extraction	$y = 6919.8x^{-1.1256}$
NUEX	$y = 591.71x^{-0.5958}$
UREX+1a	$y = 923.12x^{-0.68}$

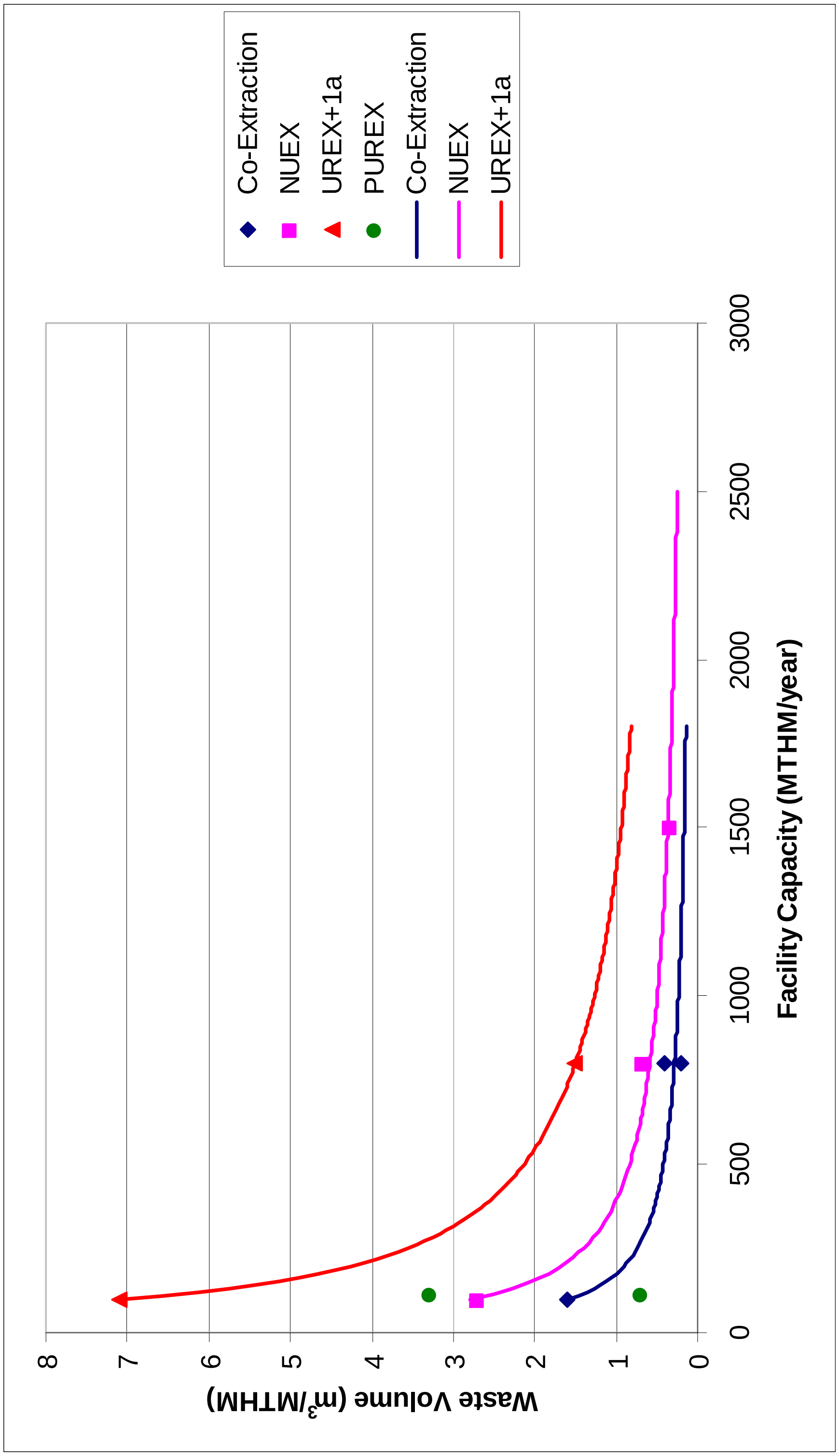
Figure 2.2-5
Normalized Low Level Waste Volume



Equations

Co-extraction	$y = 917.63x^{-0.6869}$
NUEX	$y = 591.71x^{-0.5958}$
UREX+1a	$y = 923.12x^{-0.68}$

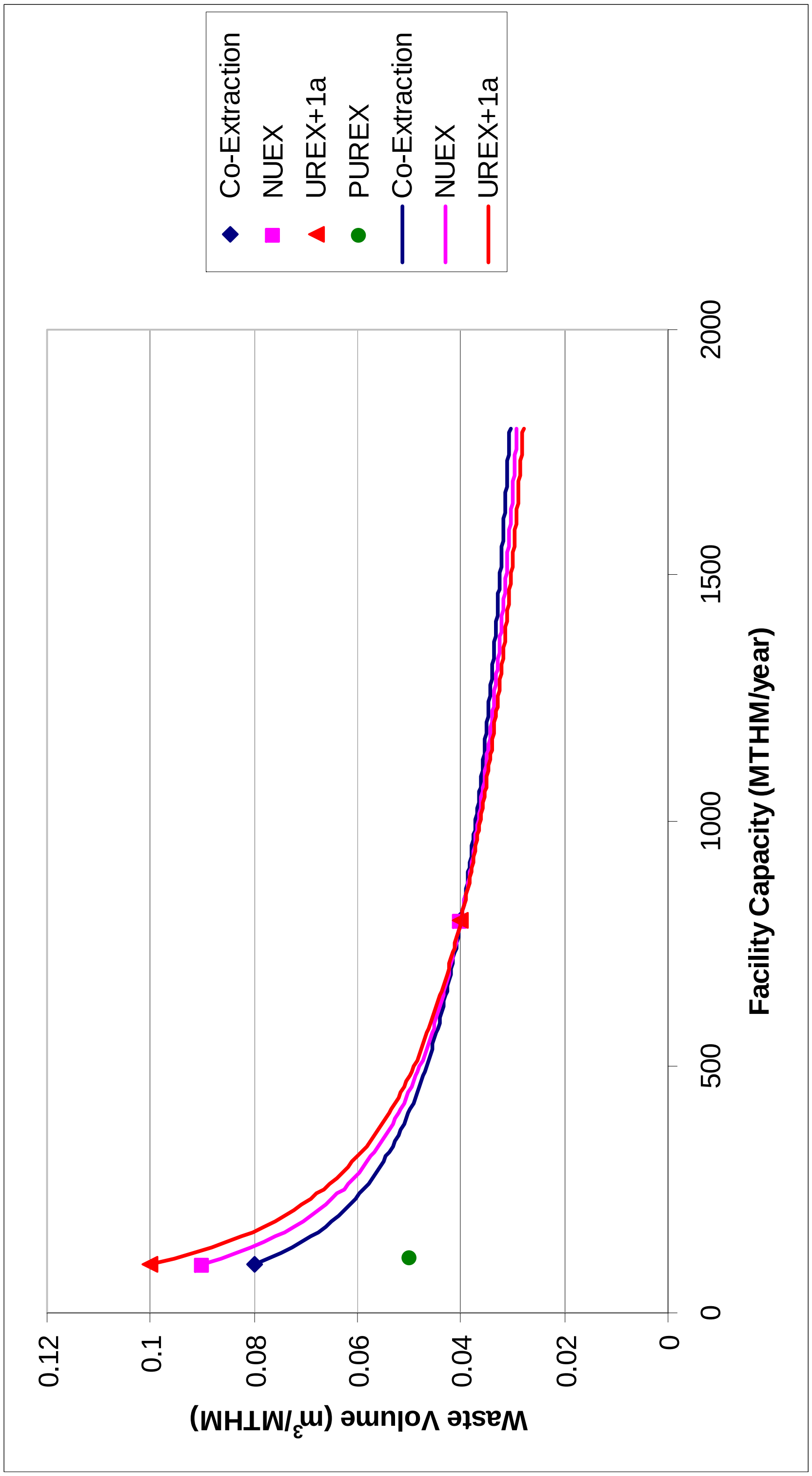
Figure 2.2-6
Normalized Low Level Waste Volume
(Excluding the AREVA Data Point)



Equations

Co-extraction	$y = 68.55x^{-0.8159}$
NUEX	$y = 86.364x^{-0.7444}$
UREX+1a	$y = 192.5x^{-0.7166}$

Figure 2.2-7
Normalized GTCC Waste Volume



<u>Equations</u>

Co-extraction	$y = 0.3713x^{-0.3333}$
NUEX	$y = 0.5422x^{-0.39}$
UREX+1a	$y = 0.7608x^{-0.4406}$

Figure 2.2-8
Normalized Mixed Low Level Waste Volume

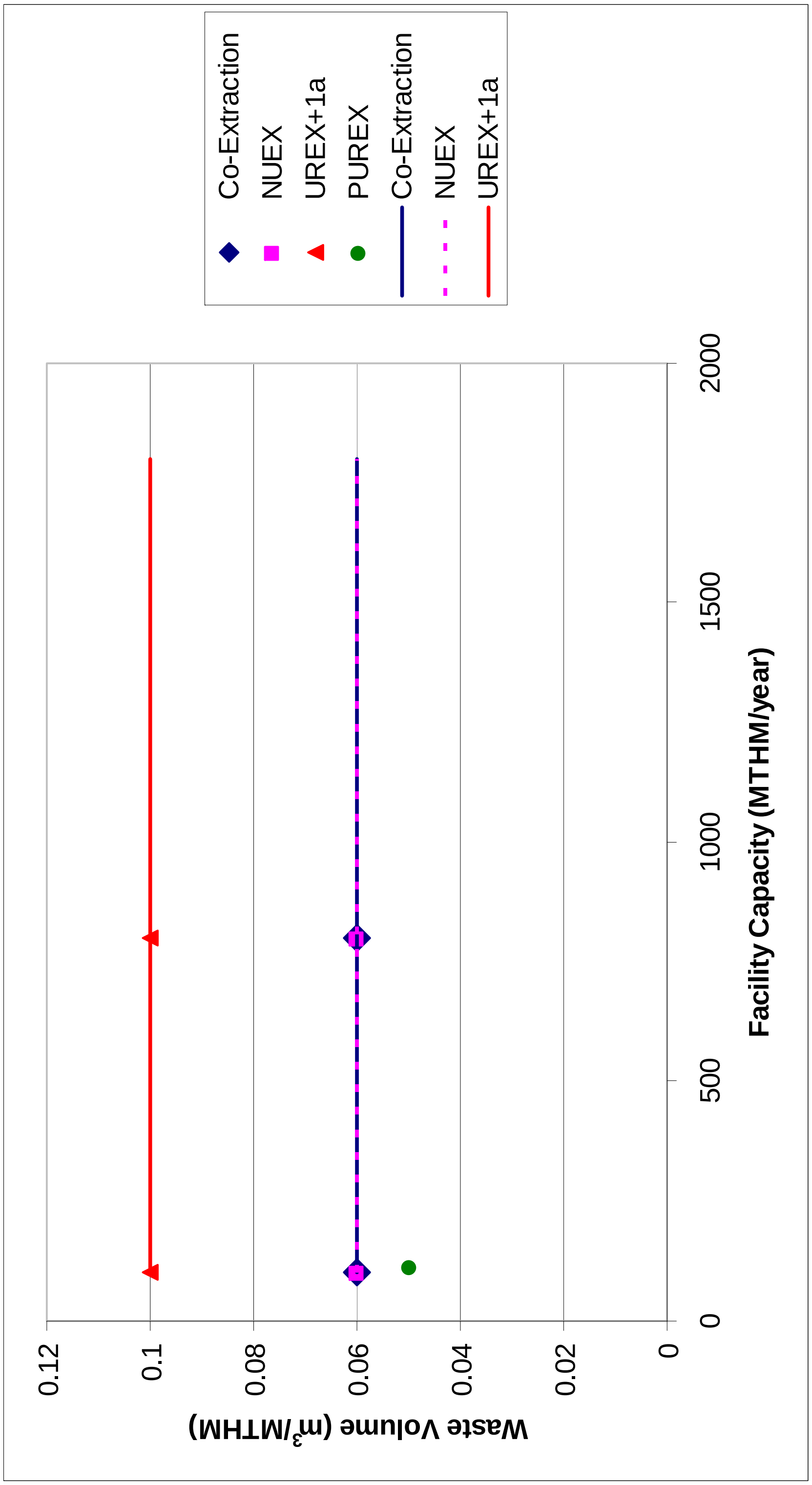


Figure 2.2-9
Normalized Mixed GTCC Waste Volume

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 2.2-6, a single facility (1,500 MTHM/year) co-extraction scenario will generate about 6 m^3 of LLW per MTHM processed for an annual total of 9,000 m^3. The two facility co-extraction scenario (750 MTHM/year each) will generate about 9.7 m^3 of LLW per MTHM processed for an annual total of 14,550 m^3 or 1.6 times the single facility scenario. A three facility co-extraction scenario (500 MTHM/year each) will generate about 12.8 m^3 of LLW per MTHM processed for an annual total of 19,200 m^3 or 2.1 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, Energy*Solutions*, 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 of Light Water Reactor Used Fuel

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.[7] The Engineering Alternative 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.[8] 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.

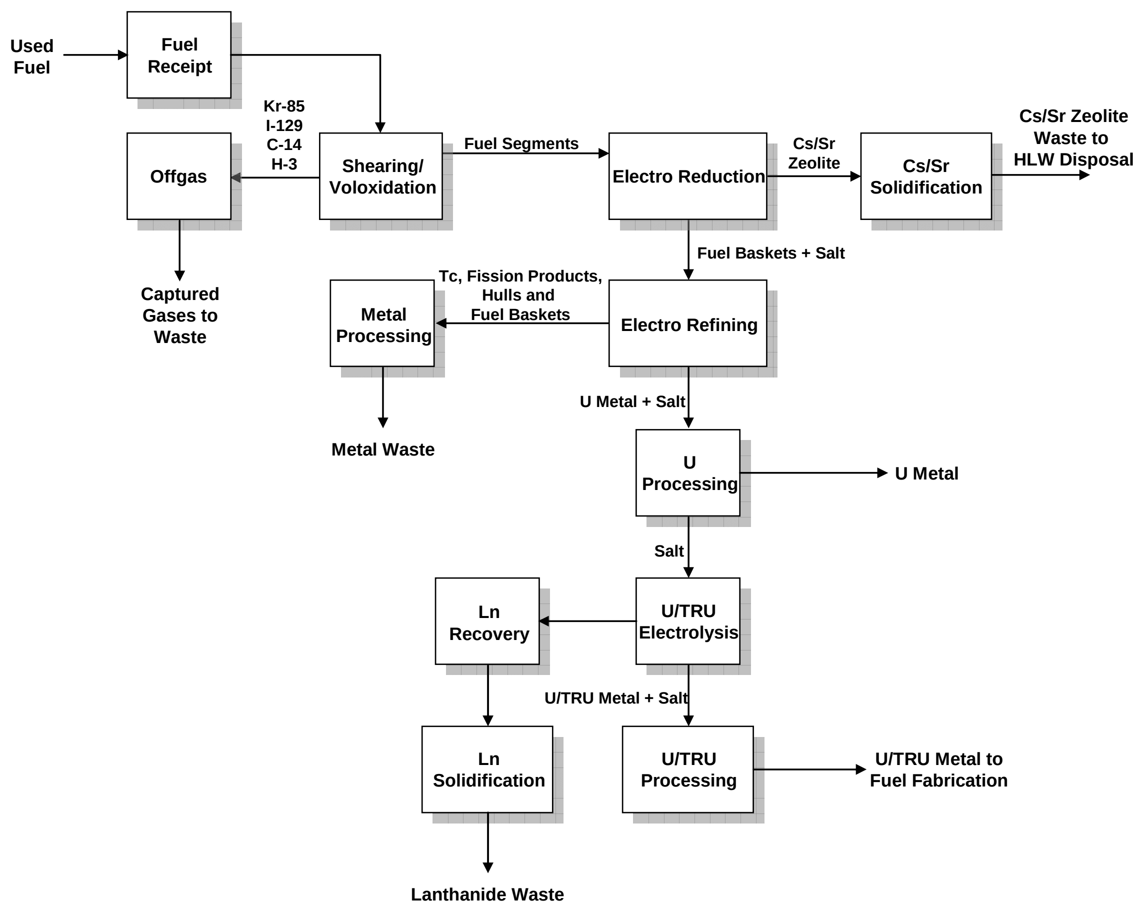


Figure 2.3-1
Electrochemical Recycling Process

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^3/year) and a normalized value expressed as waste per metric ton of heavy metal processed.

Table 2.3-1
Summary of Annual Electrochemical Recycling Waste Streams

Data Source[1]	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						
EAS Electrochemical	300	m^3/year				2,616.1			919	29	43.6
		m^3/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.

2.4 Aqueous Recycling of Sodium Fast Reactor Used Fuel

Aqueous recycling of used fuel from sodium fast reactors (SFR) is expected to be essentially the same as aqueous recycling of light water reactor (LWR) used fuel. Only the minor differences listed below that have the potential to affect low level waste (LLW) generation have been identified.

1. Metal waste from hulls and hardware will be increased due to the different configuration of SFR fuel. This difference will impact the greater than Class C (GTCC) waste generated by the Disassembly and Shearing operations. Waste volumes for other waste types are not expected to be affected.
2. Sodium fast reactor fuel is expected to have a smaller quantity of heavy metal per assembly than LWR fuel. This difference will impact the quantity of fuel casks received which in turn will impact the volume of waste generated from Fuel Receipt operations.

Table 2.4-1 provides a summary of the waste estimates provided in Appendices I through K for aqueous recycling of SFR used fuel. Waste volume estimates are provided in terms of total annual waste generation (m^3/year) and a normalized value expressed as waste per metric ton of heavy metal (MTHM) recycled. Table 2.4-2 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.

Table 2.4-1
Summary of Annual Waste Volume Estimates For Aqueous Recycling Of Sodium Fast Reactor Used Fuel

Estimate Reference [1]	Estimate Basis (MTHM/yr)	Fuel Burn-Up (GWD/MTHM)	Volume	Low Level Waste				GTCC Waste			Mixed LLW	Mixed GTCC
				Class			Total	CH-TRU	RH-TRU + GTCC	Total		
				A	B	C						
AREVA	800	131	m^3/year				1,449			629		
			m^3/MTHM				1.8			0.8		
		166	m^3/year				1,449			845		
			m^3/MTHM				1.8			1.1		
Energy *Solutions*	1,500	131	m^3/year	12,960		166	13,126	130	1,272	1,402		
			m^3/MTHM	8.6		0.1	8.8	0.09	0.85	0.9		
		166	m^3/year	12,960		166	13,126	130	1,677	1,807		
			m^3/MTHM	8.6		0.1	8.8	0.09	1.12	1.2		
EAS UREX+1a	800	131	m^3/year				8,022			1,731	32	76.9
			m^3/MTHM				10.0			2.2	0.04	0.1
		166	m^3/year				8,022			1,948	32	76.9
			m^3/MTHM				10.0			2.4	0.04	0.1
	100	131	m^3/year				4,055			768	9.6	9.7
			m^3/MTHM				40.5			7.7	0.1	0.1
		166	m^3/year				4,055			795	9.6	9.7
			m^3/MTHM				40.5			8.0	0.1	0.1
EAS Co-Extraction	800	131	m^3/year				7,700			828	28.6	44.8
			m^3/MTHM				9.6			1.0	0.04	0.06
		166	m^3/year				7,700			1,044	28.6	44.8
			m^3/MTHM				9.6			1.3	0.04	0.06
	100	131	m^3/year				3,913			221	8.4	5.6
			m^3/MTHM				39.1			2.2	0.08	0.06
		166	m^3/year				3,913			248	8.4	5.6
			m^3/MTHM				39.1			2.5	0.08	0.06
EAS NUEX	800	131	m^3/year				7,811			1,045	29.8	44.8
			m^3/MTHM				9.8			1.3	0.04	0.06
		166	m^3/year				7,811			1,261	29.8	44.8
			m^3/MTHM				9.8			1.6	0.04	0.06
	100	131	m^3/year				3,964			331	8.8	5.6
			m^3/MTHM				39.6			3.3	0.09	0.06
		166	m^3/year				3,964			358	8.8	5.6
			m^3/MTHM				39.6			3.6	0.09	0.06

1. AREVA and EAS Co-extraction - Appendix I
   Energy*Solutions* and EAS NUEX - Appendix J
   EAS UREX+1a - Appendix K
2. Shaded areas (i.e. [shaded box]) indicate values not changed due to recycling of SFR used fuel relative to LWR used fuel. Compare the changed values to the values for LWR used fuel in Table 2.2-1.

Table 2.4-2
Comparison of Annual Waste Volume Estimates For Aqueous Recycling Of Sodium Fast Reactor Used Fuel

Estimate Reference	Estimate Basis (MTHM/yr)	Fuel Burn-Up (GWD/MTHM)	Volume	Low Level Waste Class A	B	C	Total	GTCC Waste CH-TRU	RH-TRU + GTCC	Total	Mixed LLW	Mixed GTCC
AREVA	800	131	m^3/year				1,449			629		
			% of total				69.7			30.3		
		166	m^3/year				1,449			845		
			% of total				63.2			36.8		
Energy *Solutions*	1,500	131	m^3/year	12,960		166	13,126	130	1,272	1,402		
			% of category	98.7		1.3		9.3	90.7			
			% of total	89.2		1.1	90.3	0.9	8.8	9.7		
		166	m^3/year	12,960		166	13,126	130	1,677	1,807		
			% of category	98.7		1.3		7.2	92.8			
			% of total	86.8		1.1	87.9	0.9	11.2	12.1		
EAS UREX+1a	800	131	m^3/year				8,022			1,731	32	76.9
			% of total				81.3			17.6	0.3	0.8
		166	m^3/year				8,022			1,948	32	76.9
			% of total				79.6			19.3	0.3	0.8
	100	131	m^3/year				4,055			768	9.6	9.7
			% of total				83.7			15.9	0.2	0.2
		166	m^3/year				4,055			795	9.6	9.7
			% of total				83.3			16.3	0.2	0.2
EAS Co-Extraction	800	131	m^3/year				7,700			828	28.6	44.8
			% of total				89.5			9.6	0.3	0.5
		166	m^3/year				7,700			1,044	28.6	44.8
			% of total				87.3			11.8	0.3	0.5
	100	131	m^3/year				3,913			221	8.4	5.6
			% of total				94.3			5.3	0.2	0.1
		166	m^3/year				3,913			248	8.4	5.6
			% of total				93.7			5.9	0.2	0.1
EAS NUEX	800	131	m^3/year				7,811			1,045	29.8	44.8
			% of total				87.5			11.7	0.3	0.5
		166	m^3/year				7,811			1,261	29.8	44.8
			% of total				85.4			13.8	0.3	0.5
	100	131	m^3/year				3,964			331	8.8	5.6
			% of total				92.0			7.7	0.2	0.1
		166	m^3/year				3,964			358	8.8	5.6
			% of total				91.4			8.3	0.2	0.1

1. Shaded areas (i.e. [shaded box]) indicate values not changed due to recycling of SFR used fuel relative to LWR used fuel. Compare the changed values to the values for LWR used fuel in Table 2.2-2.

Figure 2.4-1 shows scatter plots of the annual low level waste volume (m^3/year) for each data source. Low level waste estimates are the same for used fuel of 131 GWD/MTHM and 166 GWD/MTHM burn up. Figures 2.4-2 and 2.4-3 show scatter plots of the annual GTCC waste volume (m^3/year) for each data source for 131 GWD/MTHM and 166 GWD/MTHM used fuel respectively. The plots for Mixed LLW and Mixed GTCC waste are the same as those derived for aqueous recycling of LWR used fuel as shown in Section 2.2.2.

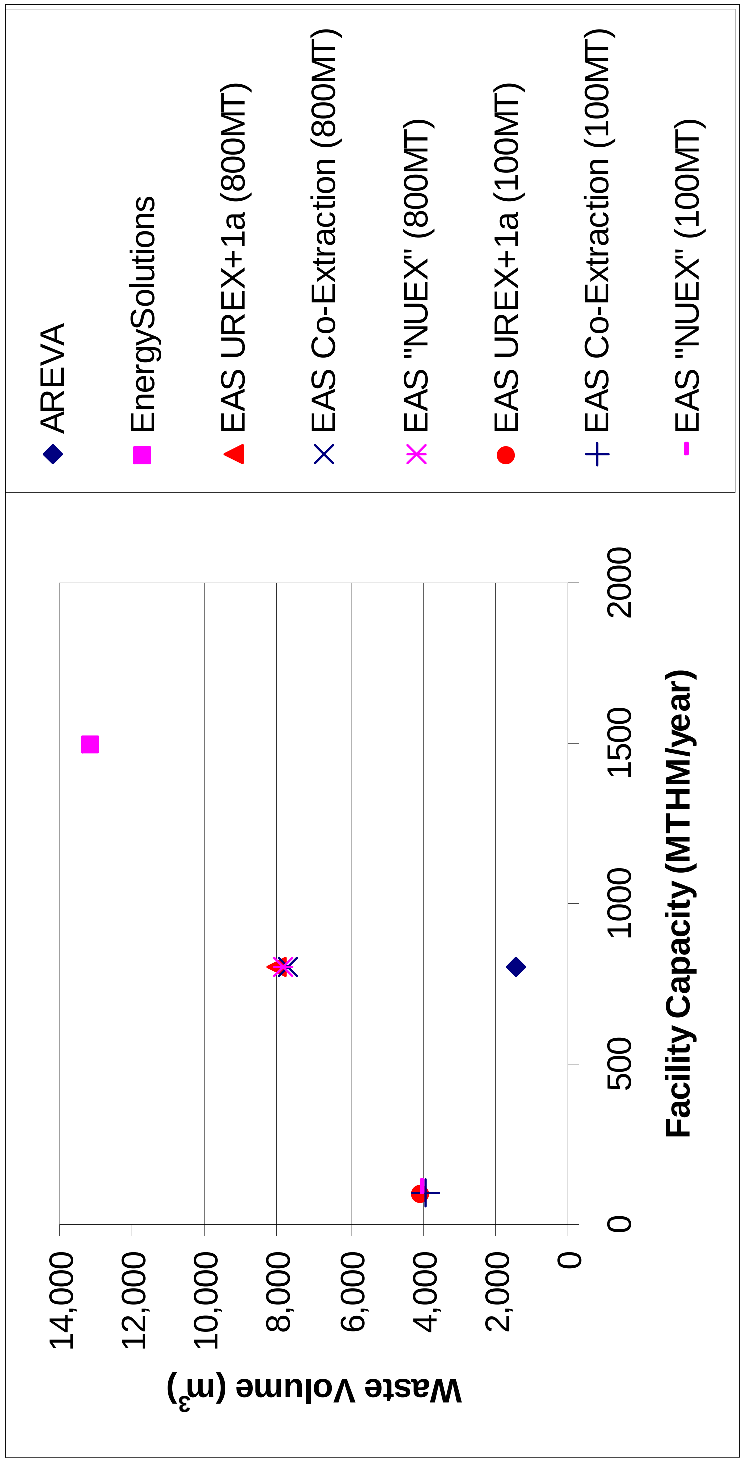


Figure 2.4-1
Annual Low Level Waste Volume

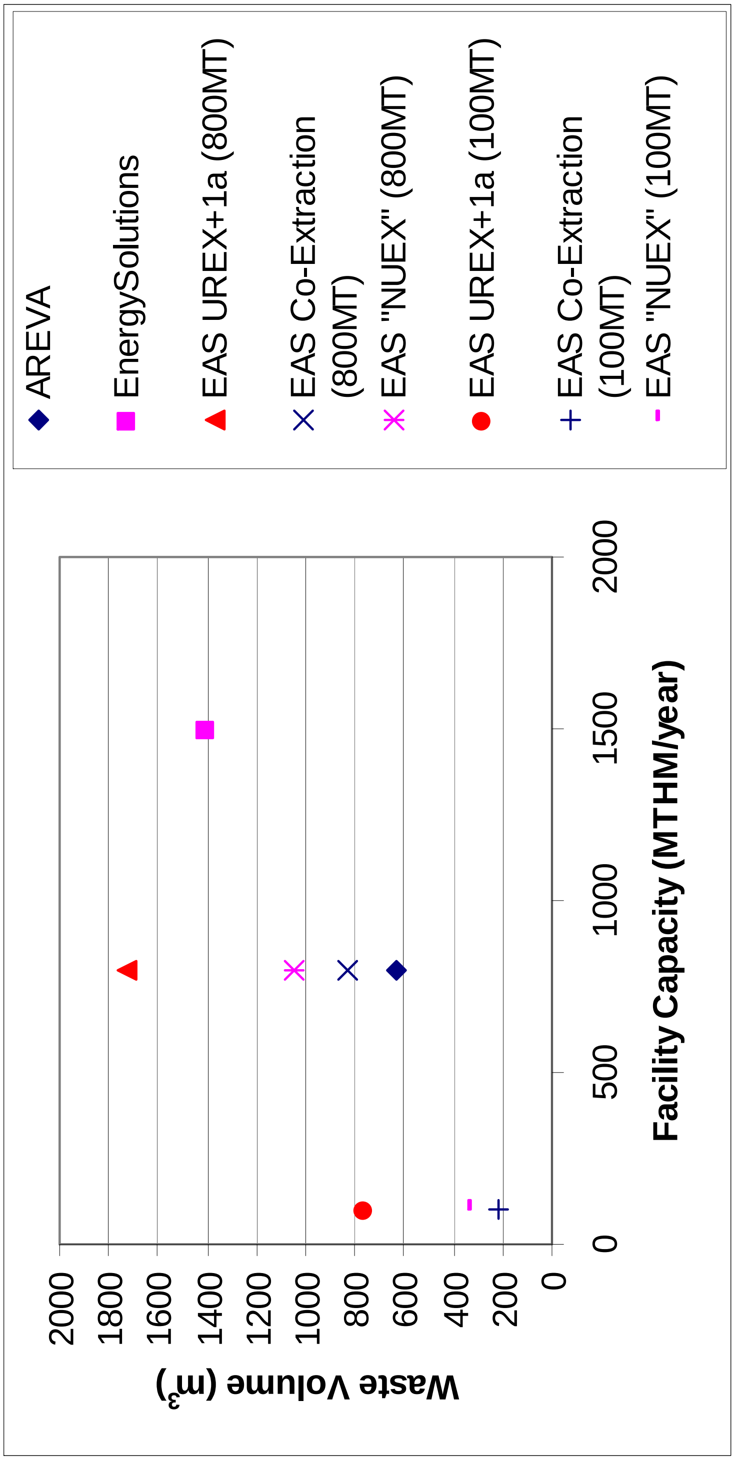


Figure 2.4-2
Annual GTCC Waste Volume (131 GWD/MTHM)

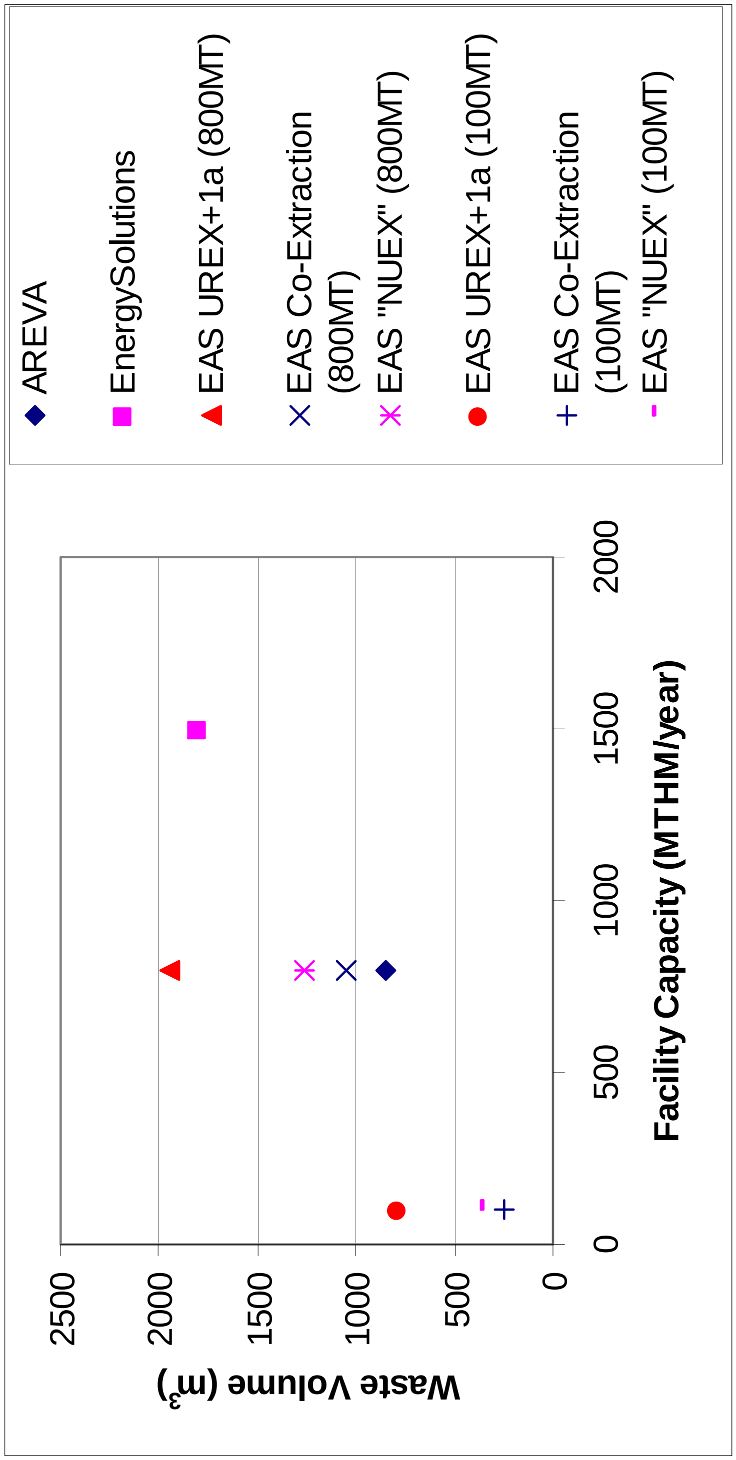
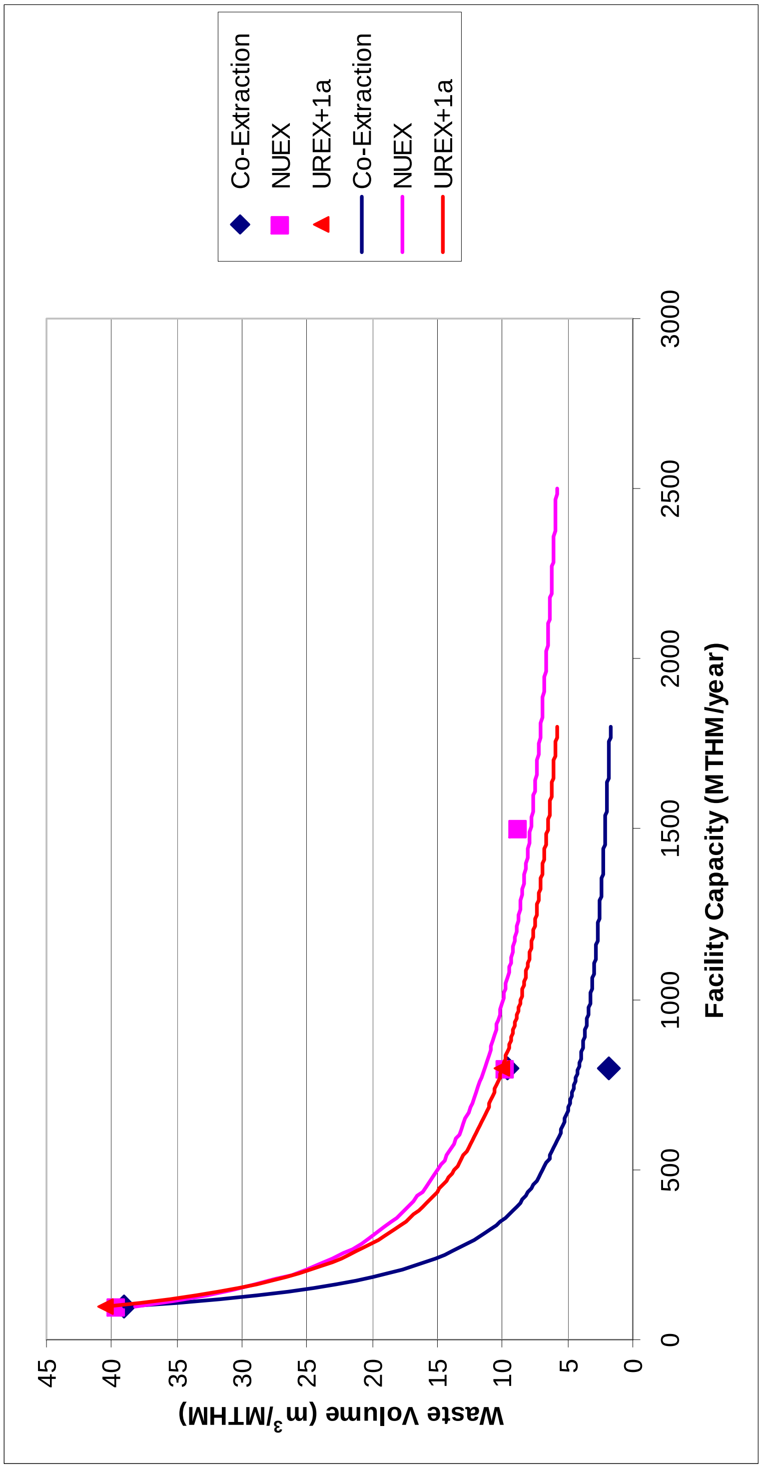


Figure 2.4-3
Annual GTCC Waste Volume (166 GWD/MTHM)

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 2.4-4 through 2.4-7. 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.

A variation of the low level waste curve is provided (Figure 2.4-5) that eliminates the AREVA data point which does not appear to be in good agreement with the other data points in Table 2.4-1. 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.[6] Elimination of the AREVA data point produces a curve as shown in Figure 2.4-5 that provides a more conservative estimate of LLW from a co-extraction facility. Figure 2.4-4 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.

The plots for Mixed LLW and Mixed GTCC waste are the same as those derived for aqueous recycling of LWR used fuel as shown in Section 2.2.3.



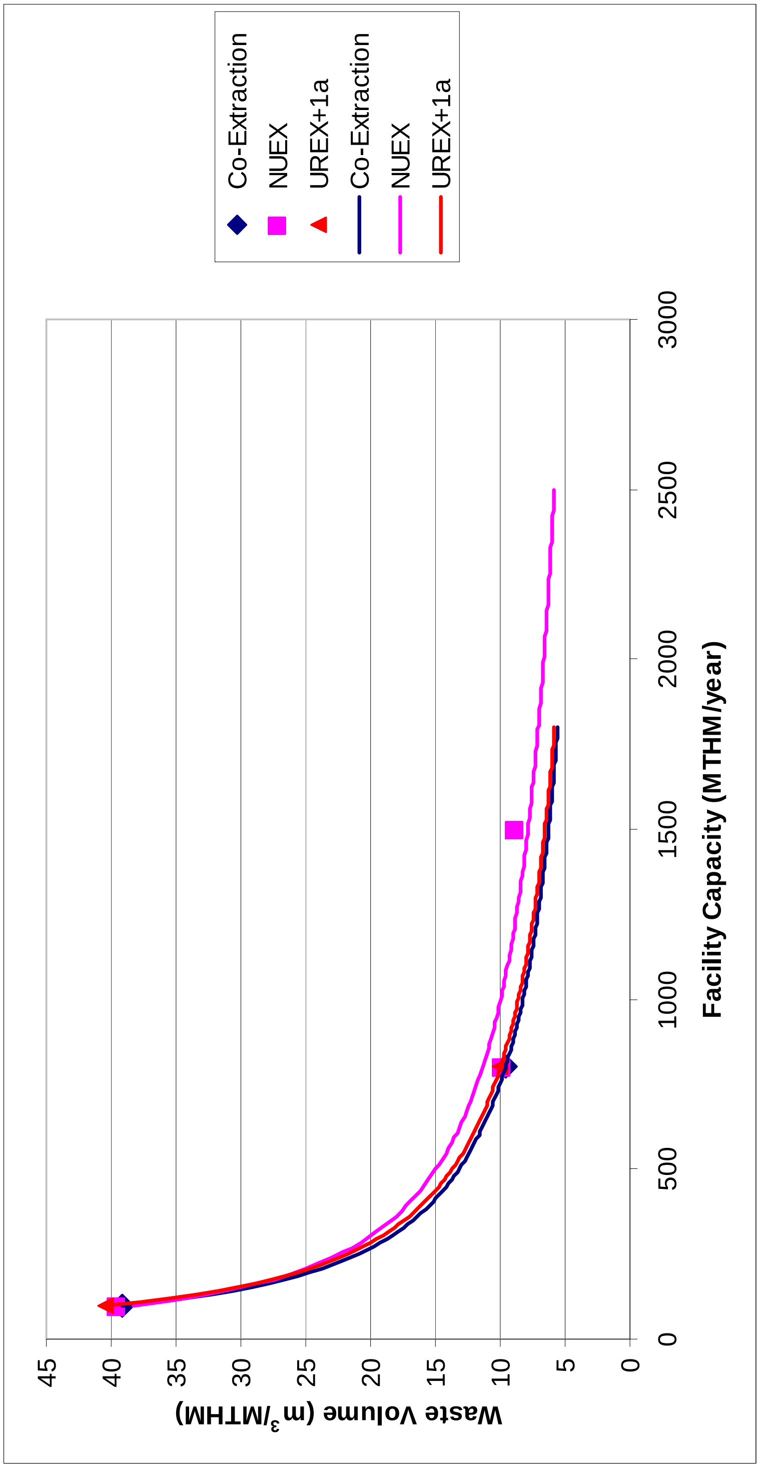
<u>Equations</u>

Co-extraction $y = 5596.3x^{-1.0779}$

NUEX $y = 564.73x^{-0.5845}$

UREX+1a $y = 896.88x^{-0.6726}$

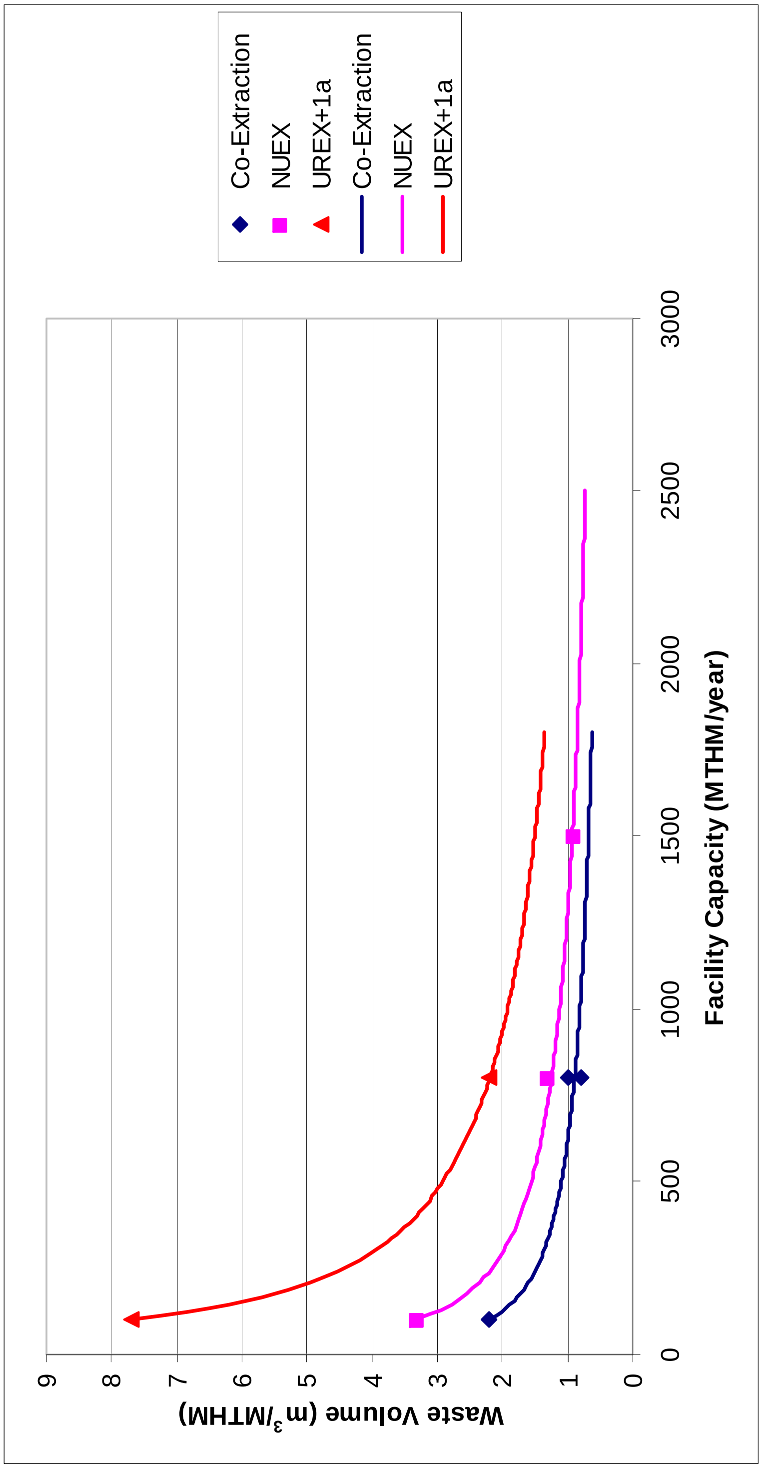
Figure 2.4-4
Normalized Low Level Waste Volume



Equations

Co-extraction	$y = 876.77x^{-0.6754}$
NUEX	$y = 564.73x^{-0.5845}$
UREX+1a	$y = 896.88x^{-0.6726}$

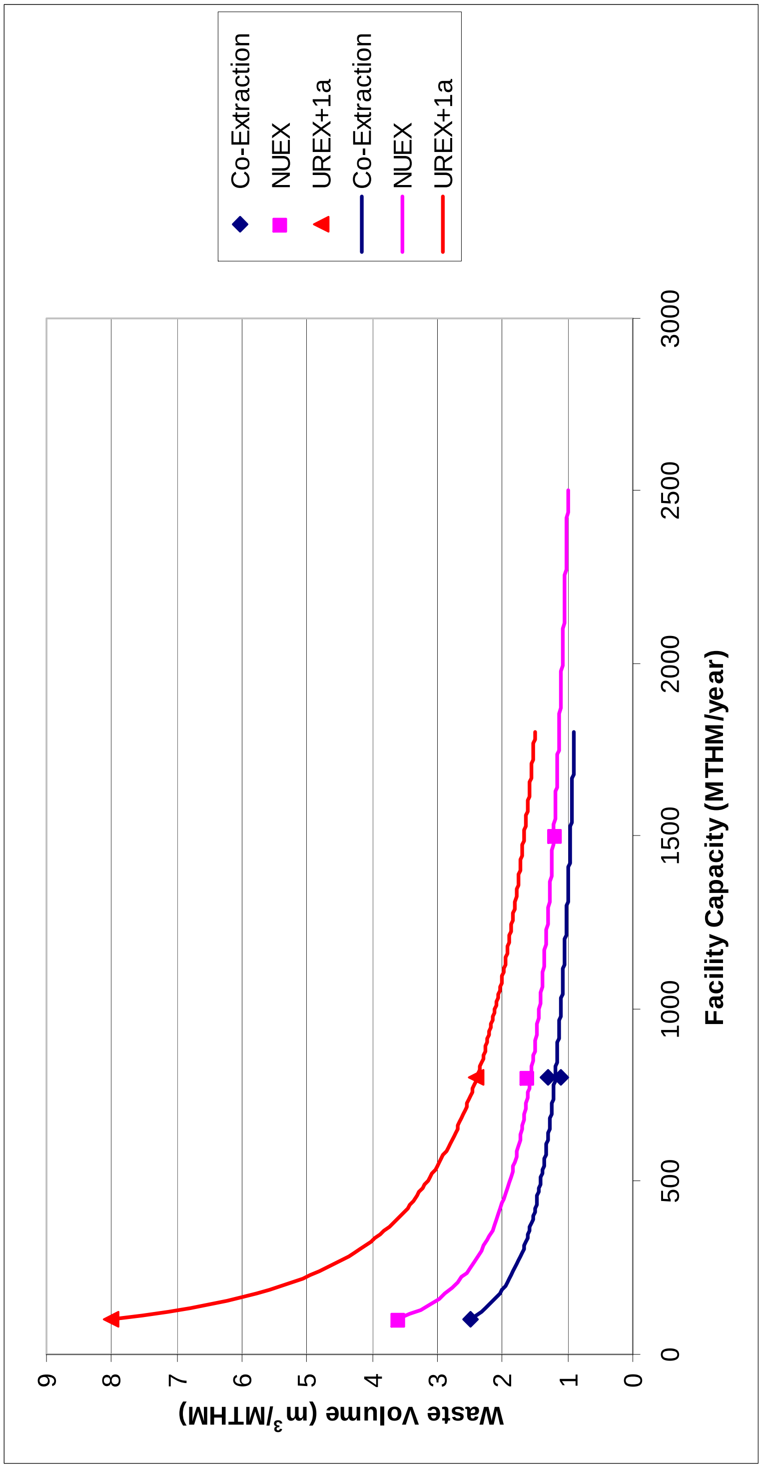
Figure 2.4-5
Normalized Low Level Waste Volume
(Excluding the AREVA Data Point)



Equations

Co-extraction	$y = 16.146x^{-0.4328}$
NUEX	$y = 29.256x^{-0.4718}$
UREX+1a	$y = 123.42x^{-0.6025}$

Figure 2.4-6
Normalized GTCC Waste Volume (131 GWD/MTHM)



Equations

Co-extraction	$y = 12.8x^{-0.3546}$
NUEX	$y = 23.004x^{-0.4018}$
UREX+1a	$y = 115.1x^{-0.579}$

Figure 2.4-7
Normalized GTCC Waste Volume (166 GWD/MTHM)

2.5 Electrochemical Recycling of Sodium Fast Reactor Used Fuel

Table 2.5-1 provides a summary of the waste estimates provided in Appendix L for recycling of sodium fast reactor used fuel using an electrochemical process. Waste volume estimates are provided in terms of total annual waste generation (m^3/year) and a normalized value expressed as waste per metric ton of heavy metal processed.

Table 2.5-1
Summary of Annual Waste Volume Estimates For
Electrochemical Recycling Of Sodium Fast Reactor Used Fuel

Data Reference	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						
EAS Electrochemical	300	m^3/year				2,715.6			919	29	43.6
		m^3/MTHM				9.1			3.1	0.1	0.15

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 2.5-1 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 prepackaging scenarios from 0-100 percent can be determined.

3.2 Aqueous Recycling of Light Water Reactor Used Fuel

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 of Light Water Reactor Used Fuel

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.

3.4 Aqueous Recycling of Sodium Fast Reactor Used Fuel

The volume of low level waste (Class A/B/C) from aqueous recycling of used fuel from sodium fast reactors (SFR) is expected to be similar to that generated from aqueous recycling of light water reactor (LWR) used fuel. Only a minor increase in waste volume driven by the design and configuration of the SFR fuel is expected. Increases in low level (Class A/B/C) waste volume is driven by the increased amount of fuel receipts required for SFR used fuel relative to LWR used fuel for a given amount of heavy metal recycled.

The volume of GTCC waste from aqueous recycling of used fuel from sodium fast reactors is expected to be significantly higher than that generated from aqueous recycling of LWR used fuel. The significance decreases as facility capacity decreases and process complexity increases (e.g. UREX+1a versus co-extraction). GTCC waste volume is driven by the design of the SFR fuel which has a much higher hardware to heavy metal ratio than LWR fuel. GTCC waste volume is also dependent on the fuel burn-up and the fuel design necessary to achieve those burn-ups. Table 3.4-1 compares the waste volume from recycling SFR used fuel to LWR used fuel for several process examples.

Table 3.4-1
Comparison of Aqueous Recycling of Sodium Fast Reactor Used Fuel to Aqueous Recycling of Light Water Reactor Used Fuel

Process	Plant Capacity (MTHM/year)	Fuel Burn-Up (GWD/MTHM)	Low Level Waste			GTCC Waste		
			LWR Volume (m^3) [1]	SFR Volume (m^3) [2]	Increase (%) [3]	LWR Volume (m^3) [4]	SFR Volume (m^3) [5]	Increase (%) [3]
Co-extraction	800	131	7,441	7,678	3.2	235	716	205
		166					957	307
	100	131	3,880	3,909	0.7	160	220	38
		166					250	56
NUEX	1,500	131	11,373	11,790	3.7	560	1393	149
		166					1,827	226
	800	131	8,821	9,080	2.9	477	999	109
		166					1,254	163
	100	131	3,806	3,827	0.6	280	333	19
		166					362	29
UREX+1a	800	131	7,839	8,002	2.1	1,280	1,759	37
		166					1,920	50
	100	131	4,030	4,051	0.5	710	770	8
		166					800	13

1. Based on the equations associated with Figure 2.2-6
2. Based on the equations associated with Figure 2.4-5
3. Increase = (SFR Volume - LWR Volume) ÷ LWR Volume x 100
4. Based on the equations associated with Figure 2.2-7
5. Based on the equations associated with Figures 2.4-6 and 2.4-7

3.5 Electrochemical Recycling of Sodium Fast Reactor Used Fuel

The volume of low level waste (Class A/B/C) from electrochemical recycling of used fuel from sodium fast reactors (SFR) is expected to be similar to that generated from electrochemical recycling of light water reactor (LWR) used fuel. Only a minor increase in waste volume driven by the design and configuration of the SFR fuel is expected. Increases in low level (Class A/B/C) waste volume is driven by the increased amount of fuel receipts required for SFR used fuel relative to LWR used fuel for a given amount of heavy metal recycled.

The volume of GTCC waste from electrochemical recycling of used fuel from sodium fast reactors is not expected to be any different than that generated from electrochemical recycling of LWR used fuel. All of the metal waste which drove the increase in GTCC waste for aqueous recycling is incorporated into the high level, fission product waste form produced by electrochemical recycling. High level waste is beyond the scope of this study. For estimates of metal waste associated with electrochemical recycling of SFR used fuel, see Reference 10.

Table 3.5-1 compares the waste volume from recycling SFR used fuel to LWR used fuel.

Table 3.5-1
Comparison of Aqueous Recycling of Sodium Fast Reactor Used Fuel to Aqueous Recycling of Light Water Reactor Used Fuel

Process	Plant Capacity (MTHM/year)	Fuel Burn-Up (GWD/MTHM)	Low Level Waste			GTCC Waste		
			LWR Volume (m^3) [1]	SFR Volume (m^3) [2]	Increase (%) [3]	LWR Volume (m^3) [4]	SFR Volume (m^3)	Increase (%)
Electrochemical	300	131	2,616	2,716	3.8	919	919	0
		166					919	0

1. From Section 2.3
2. From Section 2.5
3. Increase = (SFR Volume - LWR Volume) ÷ LWR Volume x 100
4. From Section 2.3

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.

Table 4.0-1
Summary of LLW Disposal Rates: 1986 - 2008

Source	Class A (m^3/year)	Class B (m^3/year)	Class C (m^3/year)	Total (m^3/year)
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
TOTAL	66,730	347.4	314.1	67,391.5

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 involving light water reactors (LWR) that determine the amount of used LWR 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 LWR 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 the equations provided in Figure 2.2-6, approximately 7.0 m^3/MTHM of used fuel recycled is generated from a 1,200 MTHM/year co-extraction recycling facility. Likewise, approximately 9.3 m^3/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^3/MTHM of used fuel recycled. Table 4.0-2 summarizes the amount of LLW generated from recycling 2,400 MTHM of used LWR fuel based on these facility assumptions and its relationship to the current rate of Class A LLW disposal.

Table 4.0-2
Comparison of Estimated LLW Generation Rates from Recycling Used Fuel From Light Water Reactors to Current Class A LLW Disposal Rates

Recycling Method	Number of Facilities	Recycling Facility Capacity (MTHM/year)	Estimated Total LLW Generated from Recycling (m^3/year) [1]	Percentage of Annual Total LLW Generated [2]	Percentage of Annual Nuclear LLW Generated [3]
Co-extraction	2	1,200	16,800	25.2 %	32.3 %
	3	800	22,320	33.4 %	42.9 %
Electrochemical	8	300	20,880	31.3 %	40.2 %

1. LLW volume for co-extraction is determined by using the normalized waste generation rates for each facility given above (i.e. 800 MTHM/year - 9.3 m^3/MTHM, 1,200 MTHM/year - 7.0 m^3/MTHM). The total LLW volume for each scenario is calculated by multiplying the waste volume based on individual facility capacity times the number of facilities (e.g. 1,200 MTHM/year x 7.0 m^3/MTHM/facility x 3 facilities = 16,800 m^3/year).
2. Estimated Annual Total Class A LLW Generated from Table 4.0-1: 66,730 m^3/year.
3. Estimated Annual Nuclear LLW Generated by Industry and Utility sources from Table 4.0-1: 45,000 m^3/year + 7,000 m^3/year = 52,000 m^3/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.

Table 4.0-3
Comparison of Estimated LLW Generation Rates from Geologic Disposal to Current Disposal Rates

Percentage of Used Fuel Pre-Packaged in Disposable Canisters	Monitoring Period (years)	LLW Generation Rate (m^3/year) [1]	Estimated Total LLW Generated from Geologic Disposal (m^3/year)	Percentage of Annual Total LLW Generated [2]	Percentage of Annual Nuclear LLW Generated [3]
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 %
90	50	1.06	2,544	3.8%	4.9%
	250	1.26	3,024	4.5%	5.8%

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

10. Joe T. Carter, Alan J. Luptak, FCR&D-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, September 2010, Revision 2

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.[1] 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.

Table A.2.0-1
AREVA Radioactive Waste Packages

Container	Description	Exterior Dimensions	Exterior Volume	Interior Volume	Weight	Usage
120L	- steel drum		120 liters (0.120 m^3)	~120 liters (0.120 m^3)		- Class A, B or C waste - non-compactable waste - bulk loaded into drum
C0	- steel drum		213 liters (0.213 m^3)	~213 liters (0.213 m^3)		- 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^3	340 liters (0.340 m^3)	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^3	670 liters (0.670 m^3)	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^3)	213 liters (0.213 m^3)		- 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^3 (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.

CBF-C1 CBF-C2 S5 UC-C

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 [1]	Container	Process		Maintenance and Operational		Subtotal (m^3)
		Container Quantity	Volume (m^3)	Container Quantity	Volume (m^3)	
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
Subtotal			**46.43**		**1,181.5**	**1,227.9**
TOTAL (m^3)	**1,227.9**					
TOTAL (m^3/MTHM) [2]	**1.5**					

1. 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.
2. The AREVA presentation to the NWTRB gives a value of 50 ft^3/MTHM or 1.416 m^3/MTHM. The value in the table above (i.e. 1.535 m^3 or 54 ft^3) 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.
3. Shaded areas (i.e. [shaded box]) indicate compacted waste.

Table A.3.0-2
Summary of AREVA Packaged Greater Than Class C Radioactive Waste Volume Estimates

System [1]	Container	Process		Maintenance and Operational		Subtotal (m^3)
		Container Quantity	Volume (m^3)	Container Quantity	Volume (m^3)	
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
Subtotal			**109.2**		**38.97**	**148.2**
TOTAL (m^3)	**148.2**					
TOTAL (m^3/MTHM) [3]	**0.2**					

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^3/MTHM or 0.283 m^3/MTHM. The value in the NWTRB presentation includes vitrified high level waste; therefore, a comparison of this value (i.e. 0.283 m^3) with the value in Table A.3.0-2 (i.e. 0.2 m^3) 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

Appendix B

Waste Estimates for the Proposed Energy*Solutions* Recycling Facility

B.1.0 Introduction

Energy*Solutions* 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.[1] 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 ^{85}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 Energy*Solutions* Waste Packages

The radioactive waste packages proposed for use by Energy*Solutions* 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 ^{85}Kr waste. Details of the containers are shown in Table B.2.0-1 and Figure B.2.0-1 below.

Table B.2.0-1
Energy*Solutions* Radioactive Waste Packages

Container	Description	Exterior Dimensions	Exterior Volume	Interior Volume	Weight	Usage
Drum	- assumed to be carbon steel		55 gallon drum: 0.212 m^3 100 gallon drum: 0.386 m^3 (see Note 1)	55 gallons (0.208 m^3) 100 gallons (0.379 m^3)		- 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 [3]	- half-height cargo container - top loading - steel floor	- 19'-10" long - 4'-3" high - 8' wide	674 ft^3 (19.1 m^3)	535 ft^3 (15.15 m^3)	- 7,000 lbs tare weight - 48,150 lbs capacity - 55,150 lbs gross weight	- Class A waste (grouted tritiated water, ^{14}C slurry and salt concentrate)
210-Liners [4]	- 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 [6]	- 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^3 (1.71m^3)	- inner vessel volume 54.2 ft^3 (1.53m^3)	- 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 ^{85}Kr gas

1. Reference 2 lists the displacement volume (i.e. external volume) for 55 gallon drums as 7.50 ft^3 or 0.212 m^3 and for 110 gallon drums as 15.00 ft^3 or 0.425 m^3. The external volume of 100 gallon drums is determined (prorated) based on the ratio determined from these external volumes relative to the internal volume.
2. 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.
3. Data for the half-height cargo container is obtained from Reference 4.
4. Data for the 210-liners is obtained from Reference 5.
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 Energy*Solutions* in the NWTRB presentation indicates an individual waste package volume of approximately 185 ft^3. A liner such as the PL14-195 or the L14-170 would provide a burial volume close to this value.
6. 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^3)	Maximum Internal Volume (ft^3)	Usable Volume (ft^3)	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
Energy*Solutions* Radioactive Waste Packages

B.3.0 Energy*Solutions* Packaged Waste Volume Estimates

The waste estimates provided by Energy*Solutions* 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.

Table B.3.0-1
Summary of Energy*Solutions* Packaged Low Level Class A Radioactive Waste Volume Estimates

System	Container	Process		Maintenance and Operational		Subtotal (m^3)
		Container Quantity	Volume (m^3)	Container Quantity	Volume (m^3)	
All systems [1]	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
Subtotal			**11,265**		**1,335**	**12,600**
TOTAL (m^3)	**12,600**					
TOTAL (m^3/MTHM)	**8.4**					

1. The Energy*Solutions* 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^3) consists of waste from maintenance and clean up operations. Waste packaged in half-height 20' cargo containers consists of grouted tritiated water, ^{14}C slurry and salt concentrate. Waste packaged in 100 gallon drums (132 m^3) consists of pyrolized solvent ash. Waste packaged in 210-liners consists of spent ion exchange resin.
2. Shaded areas (i.e.) indicate waste streams that include compaction.

Table B.3.0-2
Summary of Energy*Solutions* Packaged Low Level Class C Radioactive Waste Volume Estimates

System	Container	Process		Maintenance and Operational		Subtotal (m^3)
		Container Quantity	Volume (m^3)	Container Quantity	Volume (m^3)	
All systems [1]	55/100 gal. drums			282	113	113
Subtotal					**113**	**113**
TOTAL (m^3)	**113**					
TOTAL (m^3/MTHM)	**0.08**					

1. The Energy*Solutions* 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^3) 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 Energy*Solutions* Packaged Contact Handled TRU Radioactive Waste Volume Estimates

System	Container	Process		Maintenance and Operational		Subtotal (m^3)
		Container Quantity	Volume (m^3)	Container Quantity	Volume (m^3)	
All systems [1]	55/100 gal. drums			326	130	130
Subtotal					**130**	**130**
TOTAL (m^3)	**130**					
TOTAL (m^3/MTHM)	**0.09**					

1. The Energy*Solutions* 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^3) 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 Energy*Solutions* Packaged Remote Handled TRU and GTCC Radioactive Waste Volume Estimates						
System	**Container**	**Process**		**Maintenance and Operational**		**Subtotal (m^3)**
		Container Quantity	**Volume (m^3)**	**Container Quantity**	**Volume (m^3)**	
All systems [1]	RH-72B			419	371	371
Subtotal					**371**	**371**
TOTAL (m^3)	**371**					
TOTAL (m^3/MTHM)	**0.25**					

1. The Energy*Solutions* 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 ^{129}I waste (captured on silver mordenite).
2. Shaded areas (i.e.) indicate waste streams that include compaction.

Table B.3.0-5 Summary of Energy*Solutions* Packaged ^{85}KrVolume Estimates						
System	**Container**	**Process**		**Maintenance and Operational**		**Subtotal (m^3)**
		Container Quantity	**Volume (m^3)**	**Container Quantity**	**Volume (m^3)**	
Offgas [1]	RH-72B			103	3	3
Subtotal					**3**	**3**
TOTAL (m^3)	**3**					
TOTAL (m^3/MTHM)	**0.002**					

1. Waste packaged in gas bottles consists of ^{85}Kr gas to be placed in decay storage prior to eventual release. Energy*Solutions* does not define ^{85}Kr gas as a specific waste type.

B.4.0 References

1. Presentation by Energy*Solutions* 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)
5. *Cask Book for Model 14/210 & 14/215H*, Energy*Solutions*, 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 Energy*Solutions* 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*.[2] 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.[3] These estimates are shown in Table C.2.0-1. Mixed waste volumes were not identified or quantified by the WVDP personnel.

Table C.2.0-1
Historical Waste Volume Estimates from West Valley Reprocessing Operations [1]

Estimate Basis (MTHM)	Disposal Area [2]	Volume and Radioactivity	Class A/B/C Low Level Waste				GTCC
			A	B	C	Total	
640 (Note 3)	SDA	m^3	9,108	0	6	9,114	0
		Curies	33.9	0	0.3	34.2	0
	NDA	m^3	885	37	430	1,352	2,081
		Curies	29.6	12.0	512.1	553.7	296,026
Total		m^3	9,993	37	436	10,466	2,081
		m^3/year	1,816.9	6.7	79.3	1,902.9	378.4
		m^3/MTHM	15.6	0.1	0.7	16.4	3.3
		Curies	63.5	12.0	512.4	587.9	296,026
		Curies/m^3	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.[3] These estimates are shown in Table C.2.0-2. Mixed waste volumes were not identified or quantified by the WVDP personnel.

Table C.2.0-2
Historical Waste Volume Estimates from West Valley Vitrification Operations [1]

Estimate Basis (MTHM)	Disposal Area [2]	Volume and Radioactivity	Class A/B/C Low Level Waste				GTCC
			A	B	C	Total	
640 (Note 3)	SDA	m^3	0	0	0	0	0
		Curies	0	0	0	0	0
	NDA	m^3	3,317	11	18	3,346	31
		Curies	26.9	5.8	6.6	39.3	1,159
Total		m^3	3,317	11	18	3,346	31
		m^3/year	603.1	2.0	3.2	608.4	5.6
		m^3/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^3	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.

Table C.2.0-3
Total Waste Volume Estimates from West Valley Reprocessing and Vitrification Operations

Operational Phase	Class A/B/C Low Level Waste				
	A	B	C	Total	GTCC
Reprocessing	9,993	37	436	10,466	2,081
Vitrification	3,317	11	18	3,346	31
Total (m^3)	13,310	48	454	13,812	2,112
Total (m^3/year) [1]	2,420.0	8.7	82.6	2,511.3	384.0
Total (m^3/MTHM) [2]	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.4.0-8. 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.

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

System	Container [1]	Annual Waste Volume (m^3)			
		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	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
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 [2]	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 [3]	E		0	8.6	8.6
	L		2,534.2	2,507.8	5,042.0
	S	75.0	0	0	75.0
Subtotal		**120.3**	**6,893.1**	**2,567.7**	**9,581.1**
TOTAL (m^3)	**9,581.1**				
TOTAL (m^3/MTHM) [4]	**83.3**				

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 [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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 [3,5]	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
TOTAL (m^3)	**9,581.1**		**12,036.3**		**2,589.9**
TOTAL (m^3/MTHM) [6]	**83.3**		**104.7**		**22.5**

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 ÷ 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 ÷ 0.80 ÷ 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 ÷ 5.5 years ≈ 115)

Table C.3.0-3
Summary Of Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates For The West Valley Reprocessing Facility Based On EAS Data

System	Container [1]	Annual Waste Volume (m^3)			
		Operational	**Job Control**	**Maintenance**	**Subtotal**
Fuel Receipt					0
Shearing/Dissolving [2]	A	11.7			11.7
	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 [3]	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		**12.8**	**54.7**	**1.1**	**68.5**
TOTAL (m^3)	**68.5**				
TOTAL (m^3/MTHM) [4]	**0.6**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste for Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 4 for the co-extraction process (i.e. 442.07 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table C.3.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc). A capacity of 115 MTHM/year is used as a basis.
3. 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.
4. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM ÷ 5.5 years ≈ 115 MTHM/year).

Table C.3.0-4
Summary Of Annual Packaged GTCC Solid Waste Volume Estimates For The West Valley Reprocessing Facility Based On EAS Data

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume (m^3)
Universal container [2]	11.7	15	12.6
Engineered container [3]	0.3	Undetermined	0.4
GTCC waste disposal container [4]	56.5	44	74.8
TOTAL (m^3)	**68.5**		**87.8**
TOTAL (m^3/MTHM) [5]	**0.6**		**0.8**

1. From Table C.3.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 442.07 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 4 for the co-extraction process (i.e. 3.86 ft^3/MTHM). A capacity of 115 MTHM/year is used as a basis.
3. 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 ÷ 0.80 = 0.4).
4. Package Quantity for GTCC waste disposal containers is determined by application of an 80% packing efficiency, i.e. 56.5 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 44. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.
5. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM ÷ 5.5 years ≈ 115 MTHM/year).

Table C.3.0-5
Summary Of Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates For The West Valley Reprocessing Facility Based On EAS Data

System	Container [1]	Annual Waste Volume (m^3)			
		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	Not Applicable				0
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 [2]	D			0.05	0.05
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 [3]	D			1.05	1.05
Subtotal				**3.0**	**3.0**
TOTAL (m^3)	**3.0**				
TOTAL (m^3/MTHM) [4]	**0.03**				

1. D – drums, E – engineered 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.
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 MTHM/year).

Table C.3.0-6
Summary Of Annual Packaged Mixed Low Level Solid Waste Volume Estimates
For The West Valley Reprocessing Facility Based On EAS Data

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	2.5	24	5.0
Engineered container	0.5	Undetermined	1.0
TOTAL (m^3)	**3.0**		**6.0**
TOTAL (m^3/MTHM) [3]	**0.03**		**0.05**

1. From Table C.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 ÷ 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%.
3. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM ÷ 5.5 years ≈ 115 MTHM/year).

Table C.3.0-7
Summary Of Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates For The West Valley Reprocessing Facility Based On EAS Data

System	Container[1]	Annual Waste Volume (m^3)			
		Operational	**Job Control**	**Maintenance**	**Subtotal**
Fuel Receipt					
Shearing/Dissolving					
Offgas	Not Applicable				
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					
Subtotal				**4.3**	**4.3**
TOTAL (m^3)	**4.3**				
TOTAL (m^3/MTHM) [2]	**0.04**				

1. E – engineered containers
2. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM ÷ 5.5 years ≈ 115 MTHM/year).

Table C.3.0-8
Summary Of Annual Packaged Mixed GTCC Solid Waste Volume Estimates
For The West Valley Reprocessing Facility Based On EAS Data

Container	Bulk Waste Volume[1] (m^3)	Package Quantity	Packaged Volume[2] (m^3)
Engineered container	4.3	Undetermined	5.6
TOTAL (m^3)	**4.3**		**5.6**
TOTAL (m^3/MTHM) [3]	**0.04**		**0.05**

1. From Table C.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 ÷ 0.80 x 1.05 = 5.6).
3. Based on a throughput of 115 MTHM/year to agree with the actual capacity of West Valley (640 MTHM ÷ 5.5 years ≈ 115 MTHM/year).

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.

Table C.4.0-1
Comparison of Actual West Valley Reprocessing Waste Volumes to Waste Volume Estimates Based On EAS Data

Waste Volume Basis	Volume	Class A/B/C Low Level Waste				GTCC
		A	B	C	Total	
Actual West Valley Waste Volume	m^3/year	2,420.0	8.7	82.6	2,511.3	384.0
	m^3/MTHM	20.8	0.1	0.7	21.6	3.3
Estimated West Valley Waste Volume Based on EAS Data	m^3/year				2,589.9	87.8
	m^3/MTHM				22.5	0.8

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.

Table C.4.0-2
Summary Of Annual Packaged GTCC Solid Waste Volume Estimates
For The West Valley Reprocessing Facility Based On EAS Data
(With 100% of the U/TRU Solidification Waste Volume)

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Universal container	11.7	15	12.6
Engineered container	0.6	Undetermined	0.8
GTCC waste disposal container [3]	112.3	88	149.6
TOTAL (m^3)	**124.6**		**163**
TOTAL (m^3/MTHM)[4]	**1.1**		**1.4**

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.
4. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 1, March 2010

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Appendix D

Waste Estimates for the EAS UREX+1a Facility

D.1.0 Introduction

The Engineering Alternative 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.[1] 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:

<u>Low level waste</u>

- 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)

<u>GTCC waste</u>

- 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

<u>Mixed waste</u>

- 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.

Table D.2.0-1
EAS Radioactive Waste Packages

Container	Description	Exterior Dimensions	Exterior Volume	Interior Volume	Weight	Usage
Drum			55 gallons ($0.2\ m^3$)	55 gallons ($0.2\ m^3$)		- mixed waste - bulk loaded into drum (not compacted)
Low level waste disposal box		6' long x 4' deep x 4' high	$2.5\ m^3$	$2.5\ m^3$		- 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	$1.2\ m^3$	$1.2\ m^3$		- solidified liquid low activity waste - solidified waste placed directly into container
High integrity containers			$0.25\ m^3$	$0.2\ m^3$		- low level waste requiring greater containment
GTCC disposal containers	- similar to Waste Isolation Pilot Plant (WIPP) standard waste boxes (SWB)		$1.7\ m^3$	$1.6\ m^3$		- 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	$0.9\ m^3$		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.

Table D.3.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container[1]	Annual Waste Volume (m^3)			
		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
Subtotal		**1,563.4**	**15,511.8**	**7,837.8**	**24,913.0**
TOTAL (m^3)	**24,913.0**				
TOTAL (m^3/MTHM)	**31.1**				

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

Table D.3.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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 [3]	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
TOTAL (m^3)	**24,913.0**		**30,853.6**		**7,801.1**
TOTAL (m^3/MTHM)	**31.1**		**38.6**		**9.8**

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 ÷ 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.

Table D.3.0-3
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	Annual Waste Volume (m^3)			
		Operational	**Job Control**	**Maintenance**	**Subtotal**
Fuel Receipt					
Shearing/Dissolving [2]	A	79.3			79.3
	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					
Subtotal		**91.6**	**789.6**	**80.1**	**961.3**
TOTAL (m^3)	**961.3**				
TOTAL (m^3/MTHM)	**1.2**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste for Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 2 (i.e. 430.91 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table D.3.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc).

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

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Universal container [2]	79.3	96	85.2
Engineered container [3]	69.8	Undetermined	87.3
GTCC waste disposal container [4]	812.2	634	1,078.7
TOTAL (m^3)	**961.3**		**1,251.2**
TOTAL (m^3/MTHM)	**1.2**		**1.6**

1. From Table D.3.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 430.91 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 2 (i.e. 3.76 ft^3/MTHM).
3. 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 ÷ 0.80 = 87.3).
4. Package Quantity for GTCC waste disposal containers is determined by application of an 80% packing efficiency, i.e. 812.2 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 634. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.

Table D.3.0-5
Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**16.1**	**16.1**
TOTAL (m^3)	**16.1**				
TOTAL (m^3/MTHM)	**0.02**				

1. D – drums, E – engineered containers

Table D.3.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	12.6	126	25.2
Engineered container	3.5	Undetermined	7.0
TOTAL (m^3)	**16.1**		**32.2**
TOTAL (m^3/MTHM)	**0.02**		**0.04**

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 ÷ 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%.

Table D.3.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	Annual Waste Volume (m^3)			
		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					
Subtotal				**58.6**	**58.6**
TOTAL (m^3)	**58.6**				
TOTAL (m^3/MTHM)	**0.07**				

1. E – engineered containers

Table D.3.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

Container	Bulk Waste Volume[1] (m^3)	Package Quantity	Packaged Volume[2] (m^3)
Engineered container	58.6	Undetermined	76.9
TOTAL (m^3)	**58.6**		**76.9**
TOTAL (m^3/MTHM)	**0.07**		**0.1**

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 ÷ 0.80 x 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.

Table D.3.0-9
Summary Of EAS Annual Bulk (Unpackaged) Low Activity Liquid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	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					
Subtotal				**2,156**	**2,156**
TOTAL (liters)	**2,156**				
TOTAL (liters/MTHM)	**2.7**				

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.

Table D.4.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal		**195.5**	**10,017.1**	**5,100.4**	**15,313.0**
TOTAL (m^3)	**15,313**				
TOTAL (m^3/MTHM)	**153.1**				

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

Table D.4.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process

Container	Bulk Waste Volume[1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume[2] (m^3)	Package Quantity	Packaged Volume[2] (m^3)
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[3]	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
TOTAL (m^3)	**15,313.0**		**19,105.6**		**4,025.6**
TOTAL (m^3/MTHM)	**153.1**		**191.1**		**40.3**

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 ÷ 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.

Table D.4.0-3
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 [1]	Annual Waste Volume (m^3)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving [2]	A	9.9			9.9
	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 Solidification	E			0.5	0.5
	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					
Subtotal		**11.6**	**509.8**	**13.8**	**535.2**
TOTAL (m^3)	**535.2**				
TOTAL (m^3/MTHM)	**5.4**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste for Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 2 (i.e. 430.91 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table D.4.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc).

Table D.4.0-4 Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process			
Container	**Bulk Waste Volume [1] (m^3)**	**Package Quantity**	**Packaged Volume (m^3)**
Universal container [2]	9.9	12	10.6
Engineered container [3]	12.4	Undetermined	15.5
GTCC waste disposal container [4]	512.9	401	681.7
TOTAL (m^3)	**535.2**		**707.8**
TOTAL (m^3/MTHM)	**5.4**		**7.1**

1. From Table D.4.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 430.91 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 2 (i.e. 3.76 ft^3/MTHM).
3. 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 ÷ 0.80 = 15.5).
4. Package Quantity for GTCC waste disposal containers is determined by application of an 80% packing efficiency, i.e. 512.9 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 401. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.

Table D.4.0-5
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

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**4.8**	**4.8**
TOTAL (m^3)	**4.8**				
TOTAL (m^3/MTHM)	**0.05**				

1. D – drums, E – engineered containers

Table D.4.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	4.3	43	8.6
Engineered container	0.5	Undetermined	1.0
TOTAL (m^3)	**4.8**		**9.6**
TOTAL (m^3/MTHM)	**0.05**		**0.1**

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^3 instead of the 4.3 m^3 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 ÷ 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%.

Table D.4.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	Annual Waste Volume (m^3)			
		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					
Subtotal				**7.4**	**7.4**
TOTAL (m^3)	**7.4**				
TOTAL (m^3/MTHM)	**0.07**				

1. E – engineered containers

Table D.4.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	7.4	Undetermined	9.7
TOTAL (m^3)	**7.4**		**9.7**
TOTAL (m^3/MTHM)	**0.07**		**0.1**

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 ÷ 0.80 x 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.

Table D.4.0-9
Summary Of EAS Annual Bulk (Unpackaged) Low Activity Liquid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The UREX+1a Process

System	Container [1]	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					
Subtotal				**274**	**274**
TOTAL (liters)	**274**				
TOTAL (liters/MTHM)	**2.7**				

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
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 1, March 2010

Appendix E

Waste Estimates for an EAS Co-Extraction Facility

E.1.0 Introduction

The Engineering Alternative 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.

Table E.3.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal		**1,563.4**	**14,734.7**	**7,715.8**	**24,013.9**
TOTAL (m^3)	**24,013.9**				
TOTAL (m^3/MTHM)	**30.0**				

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

Table E.3.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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 [3,5]	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
TOTAL (m^3)	**24,013.9**		**29,731.1**		**7,478.6**
TOTAL (m^3/MTHM)	**30.0**		**37.2**		**9.3**

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 ÷ 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 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1).

Table E.3.0-3
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates
From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container [1]	Annual Waste Volume (m^3)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving [2]	A	81.3			81.3
	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 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					
Subtotal		**93.5**	**169.2**	**13.9**	**276.6**
TOTAL (m^3)	**276.6**				
TOTAL (m^3/MTHM)	**0.35**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste from Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 2 (i.e. 442.07 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table E.3.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc).

Table E.3.0-4
Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume (m^3)
Universal container [2]	81.3	99	87.5
Engineered container [3]	3.6	Undetermined	4.5
GTCC waste disposal container [4]	191.7	150	255.0
TOTAL (m^3)	**276.6**		**347.0**
TOTAL (m^3/MTHM)	**0.35**		**0.43**

1. From Table E.3.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 442.07 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 2 (i.e. 3.86 ft^3/MTHM).
3. 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 ÷ 0.80 = 4.5).
4. Package Quantity for GTCC waste disposal containers is determined by application of an 80% packing efficiency, i.e. 191.7 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 150. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.

Table E.3.0-5
Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**14.3**	**14.3**
TOTAL (m^3)	**14.3**				
TOTAL (m^3/MTHM)	**0.02**				

1. D – drums, E – engineered containers

Table E.3.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	10.8	108	21.6
Engineered container	3.5	Undetermined	7.0
TOTAL (m^3)	**14.3**		**28.6**
TOTAL (m^3/MTHM)	**0.02**		**0.04**

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 ÷ 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%.

Table E.3.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container [1]	Annual Waste Volume (m^3)			
		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			34.1	34.1
TALSPEAK	Not Applicable				
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
Subtotal				**34.1**	**34.1**
TOTAL (m^3)	**34.1**				
TOTAL (m^3/MTHM)	**0.04**				

1. E – engineered containers

Table E.3.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	34.1	Undetermined	44.8
TOTAL (m^3)	**34.1**		**44.8**
TOTAL (m^3/MTHM)	**0.04**		**0.06**

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 ÷ 0.80 x 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.

Table E.4.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal		**195.5**	**9,515.1**	**5,084.8**	**14,795.4**
TOTAL (m^3)	**14,795.4**				
TOTAL (m^3/MTHM)	**148.0**				

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

Table E.4.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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[3,5]	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
TOTAL (m^3)	**14,795.4**		**18,460.1**		**3,883.9**
TOTAL (m^3/MTHM)	**148**		**184.6**		**38.8**

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 ÷ 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 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1).

Table E.4.0-3
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container [1]	Annual Waste Volume (m^3)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving [2]	A	10.2			10.2
	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 Solidification	E			0.5	0.5
	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					
Subtotal		**11.8**	**109.3**	**2.0**	**123.1**
TOTAL (m^3)	**123.1**				
TOTAL (m^3/MTHM)	**1.2**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste for Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 2 (i.e. 442.07 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table E.4.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc).

Table E.4.0-4
Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume (m^3)
Universal container [2]	10.2	13	10.9
Engineered container [3]	0.6	Undetermined	0.8
GTCC waste disposal container [4]	112.3	88	149.6
TOTAL (m^3)	**123.1**		**161.3**
TOTAL (m^3/MTHM)	**1.2**		**1.6**

1. From Table E.4.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 442.07 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 2 (i.e. 3.86 ft^3/MTHM).
3. 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 ÷ 0.80 = 0.8).
4. Package Quantity for GTCC waste disposal containers is determined by application of an 80% packing efficiency, i.e. 112.3 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 88. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.

Table E.4.0-5
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

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**4.2**	**4.2**
TOTAL (m^3)	**4.2**				
TOTAL (m^3/MTHM)	**0.04**				

1. D – drums, E – engineered containers

Table E.4.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume[1] (m^3)	Package Quantity	Packaged Volume[2] (m^3)
Drum	3.7	37	7.4
Engineered container	0.5	Undetermined	1.0
TOTAL (m^3)	**4.2**		**8.4**
TOTAL (m^3/MTHM)	**0.04**		**0.08**

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 ÷ 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%.

Table E.4.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

System	Container[1]	Annual Waste Volume (m^3)			
		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					
Subtotal				**4.3**	**4.3**
TOTAL (m^3)	**4.3**				
TOTAL (m^3/MTHM)	**0.04**				

1. E – engineered containers

Table E.4.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The Co-Extraction Process

Container	Bulk Waste Volume[1] (m^3)	Package Quantity	Packaged Volume[2] (m^3)
Engineered container	4.3	Undetermined	5.6
TOTAL (m^3)	**4.3**		**5.6**
TOTAL (m^3/MTHM)	**0.04**		**0.06**

1. From Table E.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 ÷ 0.80 x 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
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 1, March 2010

Appendix F

Waste Estimates for an EAS "NUEX" Facility

F.1.0 Introduction

The Engineering Alternative 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 Energy*Solutions*) 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.

Table F.3.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

System	Container[1]	Annual Waste Volume (m^3)			
		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
Subtotal		**1,563.4**	**15,013.5**	**7749.1**	**24,326**
TOTAL (m^3)	**24,326**				
TOTAL (m^3/MTHM)	**30.4**				

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

Table F.3.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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 [3,5]	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
TOTAL (m^3)	**24,326**		**30,120.3**		**7,590.3**
TOTAL (m^3/MTHM)	**30.4**		**37.7**		**9.5**

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 ÷ 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 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1).

Table F.3.0-3
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

System	Container [1]	Annual Waste Volume (m^3)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	81.3			81.3
	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 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					
Subtotal		**93.5**	**282.0**	**67.7**	**443.2**
TOTAL (m^3)	**443.2**				
TOTAL (m^3/MTHM)	**0.55**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste for Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 2 (i.e. 442.07 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table E.3.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc).

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

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume (m^3)
Universal container [2]	81.3	99	87.5
Engineered container [3]	57.4	Undetermined	71.8
GTCC waste disposal container [4]	304.5	238	404.4
TOTAL (m^3)	**443.2**		**563.7**
TOTAL (m^3/MTHM)	**0.55**		**0.70**

1. From Table F.3.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 442.07 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 2 (i.e. 3.86 ft^3/MTHM).
3. 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 ÷ 0.80 = 71.8).
4. Package Quantity is determined by application of an 80% packing efficiency, i.e. 304.5 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 238. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.

Table F.3.0-5
Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**14.9**	**14.9**
TOTAL (m^3)	**14.9**				
TOTAL (m^3/MTHM)	**0.02**				

1. D – drums, E – engineered containers

Table F.3.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	11.4	114	22.8
Engineered container	3.5	Undetermined	7.0
TOTAL (m^3)	**14.9**		**29.8**
TOTAL (m^3/MTHM)	**0.02**		**0.04**

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 ÷ 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%.

Table F.3.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

System	Container [1]	Annual Waste Volume (m^3)			
		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			34.1	34.1
TALSPEAK					
U/TRU Solidification					
Acid Recovery					
Solvent Recovery					
HAW					
LAW					
Waste Handling					
Analytical					
Chemical Receipt					
Balance of Plant					
Subtotal				**34.1**	**34.1**
TOTAL (m^3)	**34.1**				
TOTAL (m^3/MTHM)	**0.04**				

1. E – engineered containers

Table F.3.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From An 800 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	34.1	Undetermined	44.8
TOTAL (m^3)	**34.1**		**44.8**
TOTAL (m^3/MTHM)	**0.04**		**0.06**

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 ÷ 0.80 x 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.

Table F.4.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal		**195.5**	**9,695.2**	**5,089.0**	**14,979.7**
TOTAL (m^3)	**14,979.7**				
TOTAL (m^3/MTHM)	**149.8**				

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

Table F.4.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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[3,5]	14,754.9	7,378	18,445	1,476	3,690
Solidified low level waste disposal box	150	125	150	125	150
TOTAL (m^3)	**14,979.7**		**18,690.3**		**3,935.3**
TOTAL (m^3/MTHM)	**30.4**		**186.9**		**39.4**

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 ÷ 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 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1).

Table F.4.0-3
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

System	Container [1]	Annual Waste Volume (m^3)			
		Operational	Job Control	Maintenance	Subtotal
Fuel Receipt					
Shearing/Dissolving	A	10.2			10.2
	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 Solidification	E			0.5	0.5
	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					
Subtotal		**11.8**	**182.1**	**12.2**	**206.1**
TOTAL (m^3)	**206.1**				
TOTAL (m^3/MTHM)	**2.0**				

1. A – universal containers, E – engineered containers, G – GTCC disposal containers
2. Operational waste for Shearing and Dissolving is entirely comprised of metal waste (hulls and hardware). The volume shown is based on the average mass obtained from Table 4-2 of Reference 2 (i.e. 442.07 kg/MTHM). A compacted density of 4.35 g/cc is used to convert the mass to the unpackaged volume shown in Table F.4.0-3. This density is 60% of the average density of zirconium (6.5 g/cc) and stainless steel (8 g/cc).

Table F.4.0-4
Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume (m^3)
Universal container [2]	10.2	13	10.9
Engineered container [3]	10.8	Undetermined	13.5
GTCC waste disposal container [4]	185.1	145	246.5
TOTAL (m^3)	**206.1**		**270.9**
TOTAL (m^3/MTHM)	**2.0**		**2.7**

1. From Table F.4.0-3
2. Package Quantity for universal containers is calculated by dividing the average mass of the metal waste (i. e. 442.07 kg/MTHM) by 3,600 kg allowed per package. Packaged Volume is based on the average volume obtained from Table 4-2 of Reference 2 (i.e. 3.86 ft^3/MTHM).
3. 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 ÷ 0.80 = 13.5).
4. Package Quantity is determined by application of an 80% packing efficiency, i.e. 185.1 ÷ 0.80 ÷ 1.6 (internal volume from Appendix D, Table D.2.0-1) = 145. Packaged Volume is estimated by multiplying the Package Quantity by the Exterior Volume listed in Appendix D, Table D.2.0-1.

Table F.4.0-5
Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**4.4**	**4.4**
TOTAL (m^3)	**4.4**				
TOTAL (m^3/MTHM)	**0.04**				

1. D – drums, E – engineered containers

Table F.4.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	3.9	39	7.8
Engineered container	0.5	Undetermined	1.0
TOTAL (m^3)	**4.4**		**8.8**
TOTAL (m^3/MTHM)	**0.04**		**0.09**

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 ÷ 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%.

Table F.4.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

System	Container[1]	Annual Waste Volume (m^3)			
		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					
Subtotal				**4.3**	**4.3**
TOTAL (m^3)	**4.3**				
TOTAL (m^3/MTHM)	**0.04**				

1. E – engineered containers

Table F.4.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From A 100 MTHM/year Recycling Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	4.3	Undetermined	5.6
TOTAL (m^3)	**34.1**		**5.6**
TOTAL (m^3/MTHM)	**0.04**		**0.06**

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 ÷ 0.80 x 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
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 1, March 2010

Appendix G

Waste Estimates for the EAS Electrochemical Facility

G.1.0 Introduction

The Engineering Alternative 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.[1] 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
- Note that metal waste from electrochemical recycling is not regarded as GTCC waste as it is for the aqueous recycling processes. This is because the metal waste from electrochemical recycling is combined with the fission products making the metal waste high level waste.

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.

Table G.2.0-1
EAS Radioactive Waste Packages

Container	Description	Exterior Dimensions	Exterior Volume	Interior Volume	Weight	Usage
Drum			55 gallons ($0.2\ m^3$)	55 gallons ($0.2\ m^3$)		- mixed waste - bulk loaded into drum (not compacted)
Low level waste disposal box		6' long x 4' deep x 4' high	$2.5\ m^3$	$2.5\ m^3$		- 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	$1.2\ m^3$	$1.2\ m^3$		- solidified liquid low activity waste - solidified waste placed directly into container
High integrity containers			$0.25\ m^3$	$0.2\ m^3$		- low level waste requiring greater containment
GTCC disposal containers	- similar to Waste Isolation Pilot Plant (WIPP) standard waste boxes (SWB)		$1.7\ m^3$	$1.6\ m^3$		- 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 (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 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.

Table G.3.0-1
Summary Of EAS Annual Bulk (Unpackaged) Low Level Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal		**355.5**	**5,079.5**	**3,447.9**	**8,882.9**
TOTAL	**8,882.9**				
TOTAL (m^3/MTHM)	**29.6**				

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

Table G.3.0-2
Summary Of EAS Annual Packaged Low Level Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
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 [3]	8,445.0	4,223	10,557.5	845	2,112.5
Solidified low level waste disposal box	200	167	200	167	200
TOTAL (m^3)	**8,882.9**		**11,061.1**		**2,616.1**
TOTAL (m^3/MTHM)	**29.6**		**36.9**		**8.7**

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 ÷ 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. [shaded box]) indicate compacted waste.

Table G.3.0-3
Summary Of EAS Annual Bulk (Unpackaged) GTCC Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal		**9.4**	**564.0**	**125.3**	**698.7**
TOTAL	**698.7**				
TOTAL (m^3/MTHM)	**2.3**				

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

Table G.3.0-4
Summary Of EAS Annual Packaged GTCC Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	115.2	Undetermined	144.0
GTCC waste disposal container	583.5	456	775.2
TOTAL (m^3)	**699**		**919**
TOTAL (m^3/MTHM)	**2.3**		**3.1**

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.

Table G.3.0-5
Summary Of EAS Annual Bulk (Unpackaged) Mixed Low Level Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

System	Container [1]	Annual Waste Volume (m^3)			
		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
Subtotal				**14.6**	**14.6**
TOTAL	**14.6**				
TOTAL (m^3/MTHM)	**0.05**				

1. D – drums, E – engineered containers

Table G.3.0-6
Summary Of EAS Annual Packaged Mixed Low Level Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Drum	11.1	111	22.2
Engineered container	3.5	Undetermined	7.0
TOTAL (m^3)	**15**		**29**
TOTAL (m^3/MTHM)	**0.05**		**0.1**

1. From Table G.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 ÷ 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%.

Table G.3.0-7
Summary Of EAS Annual Bulk (Unpackaged) Mixed GTCC Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

System	Container [1]	Annual Waste Volume (m^3)			
		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					
Subtotal				**33.2**	**33.2**
TOTAL	**33.2**				
TOTAL (m^3/MTHM)	**0.11**				

1. E – engineered containers

Table G.3.0-8
Summary Of EAS Annual Packaged Mixed GTCC Solid Waste Volume Estimates From A 300 MTHM/year Recycling Facility Using The Electrochemical Process

Container	Bulk Waste Volume [1] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	33.2	Undetermined	43.6
TOTAL (m^3)	**33.2**		**43.6**
TOTAL (m^3/MTHM)	**0.11**		**0.15**

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 ÷ 0.80 x 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
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 1, March 2010

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:

Table H.1.0-1
LLW Disposal Sites

Site	From	Through
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

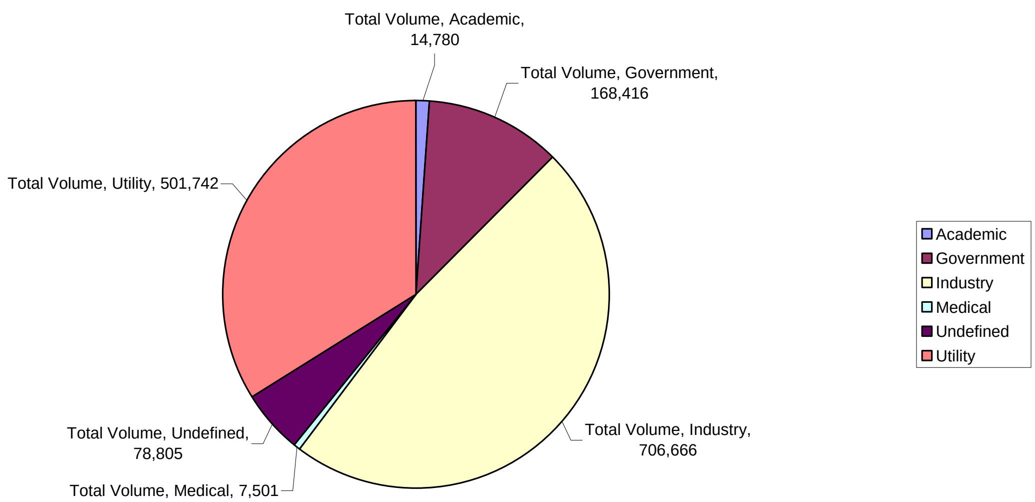
The volume and activity of LLW generated and disposed over the period from 1986 to 2008 are shown in Table H.2.0-1 and Figures H.2.0-1 through H.2.0-4. These results show that the largest amount of Class A LLW disposed, both in terms of volume and activity, is generated from nuclear utilities and industrial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

Table H.2.0-1
Total Volume and Activity of Low Level Waste Disposed: 1986 - 2008

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

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^3): 1986-2008



Total Activity LLW Disposed (Ci): 1986-2008

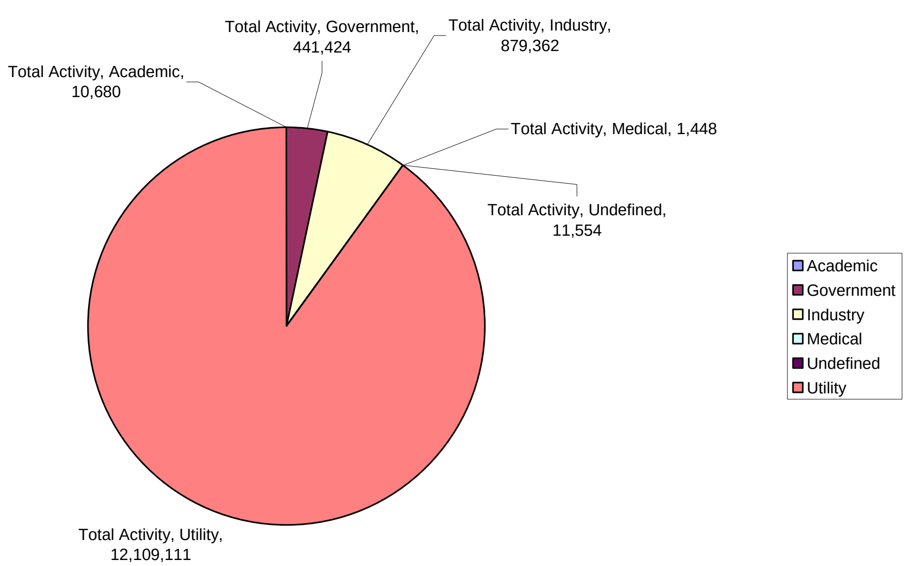
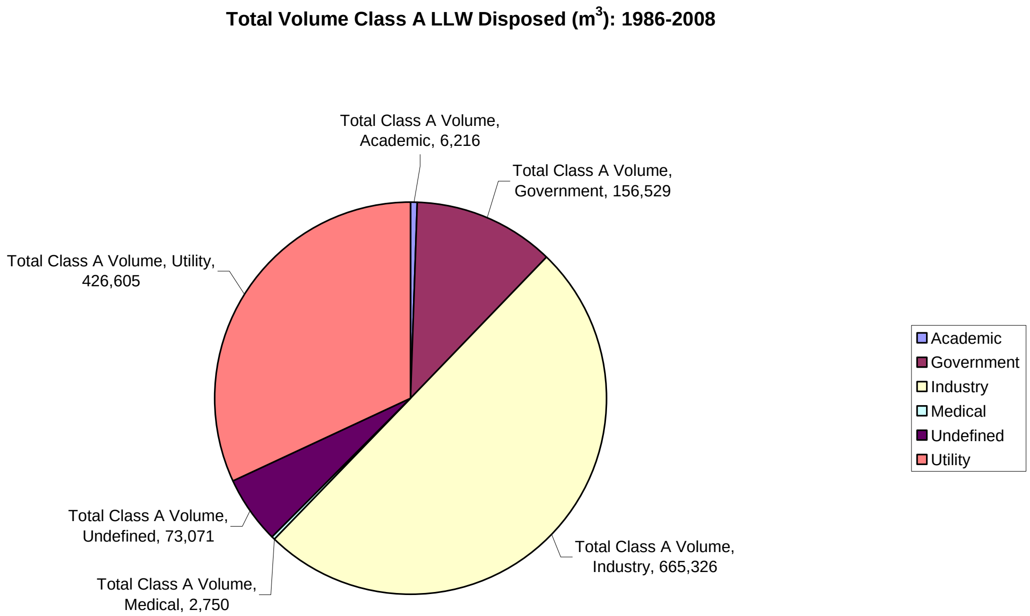


Figure H.2.0-1
Total LLW Volume and Activity Disposed



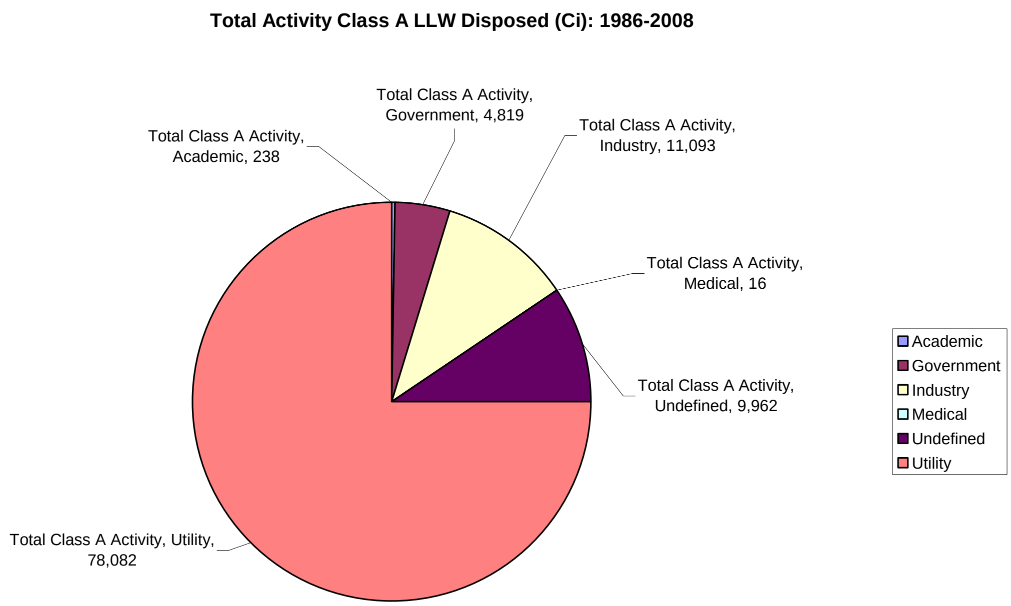
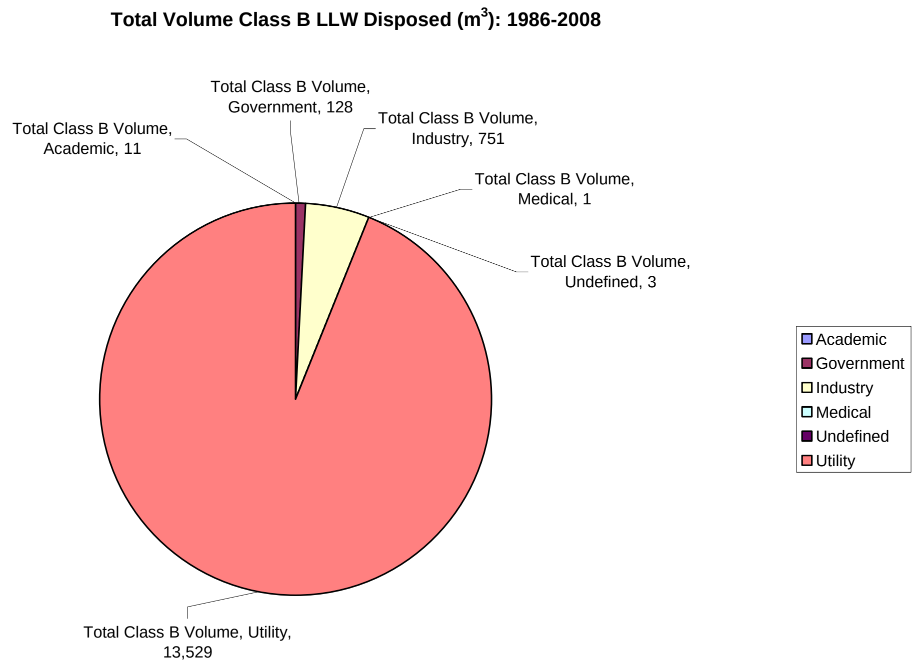


Figure H.2.0-2
Total Class A LLW Volume and Activity Disposed



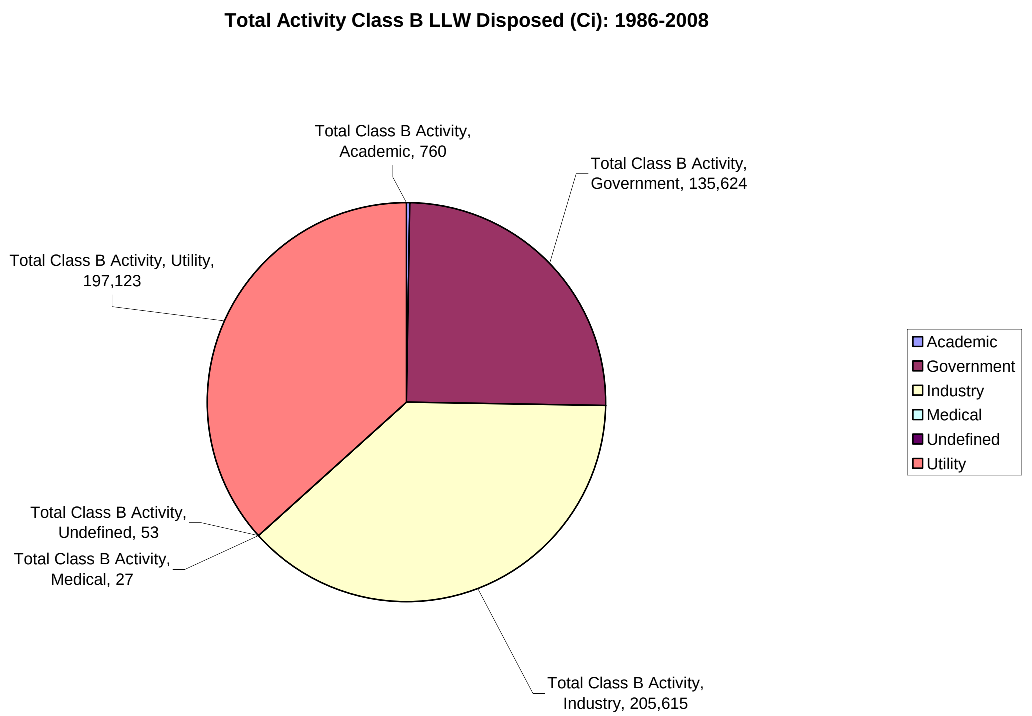
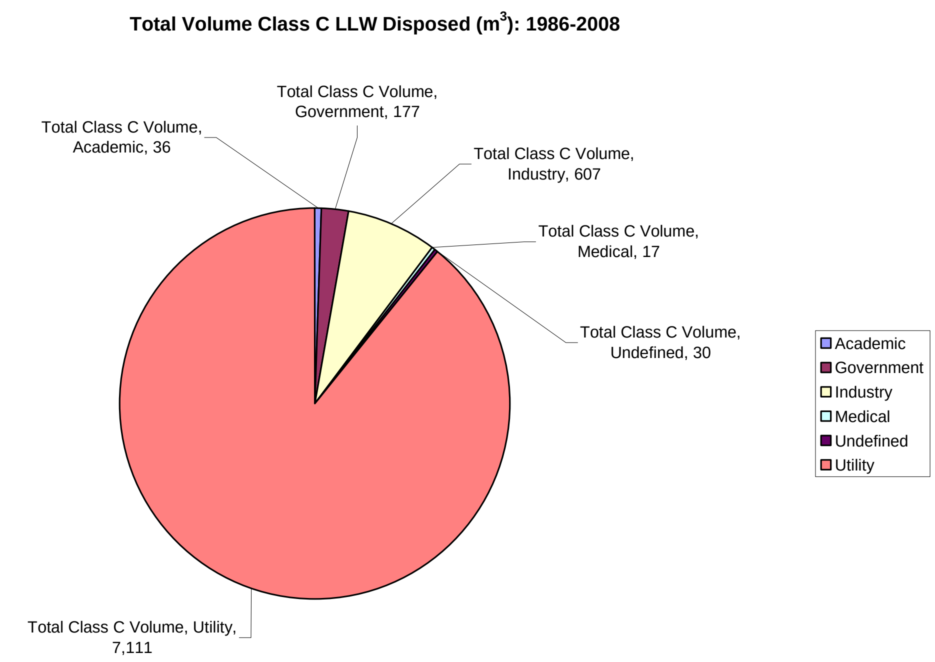


Figure H.2.0-3
Total Class B LLW Volume and Activity Disposed



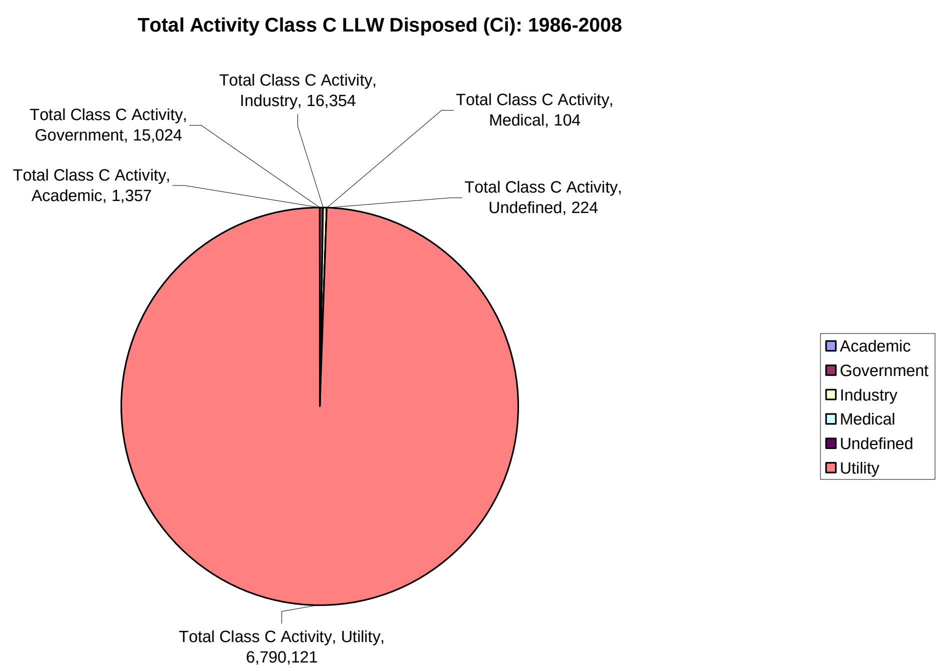


Figure H.2.0-4
Total Class C LLW Volume and Activity Disposed

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^3/year. The volume of utility generated Class B waste disposed is trending downward, from approximately 50,000 ft^3/year in 1986 to approximately 10,000 ft^3/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.

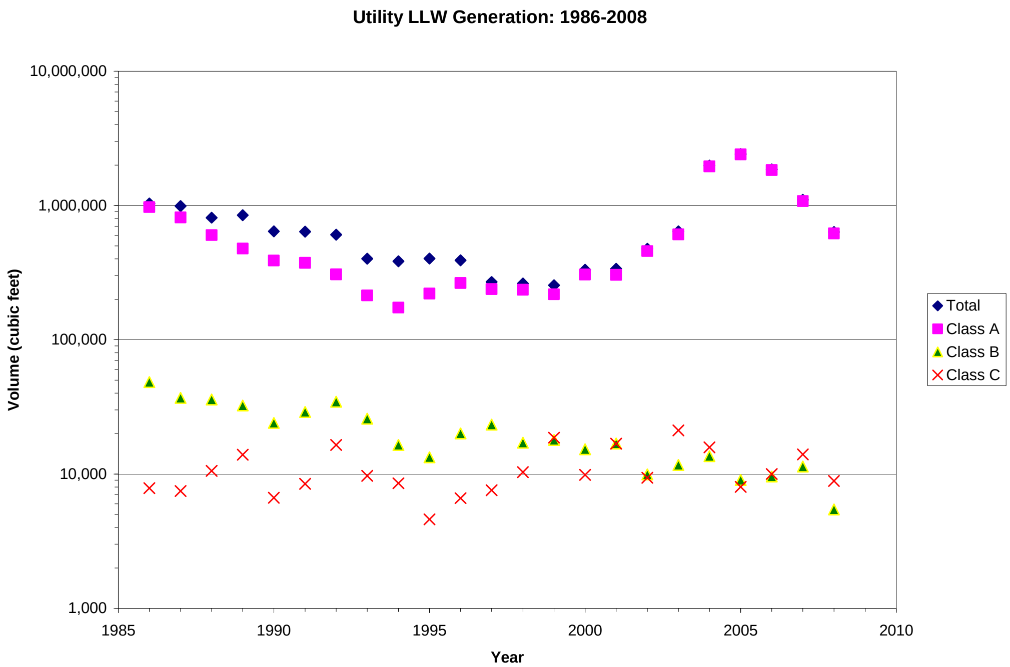


Figure H.2.1-1
Utility Generated Low Level Waste Disposed: 1986 - 2008

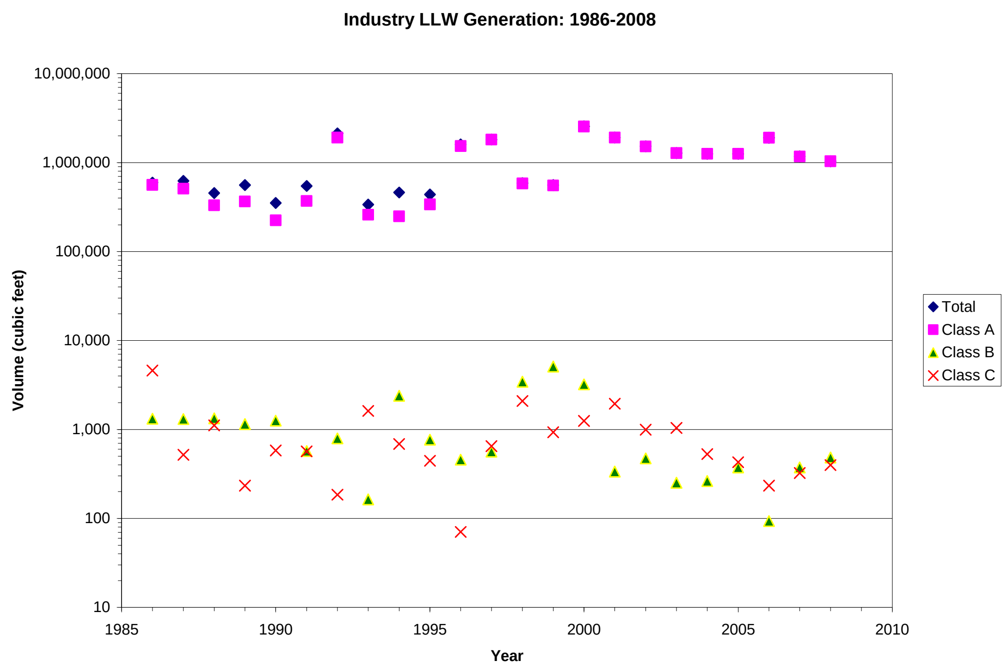
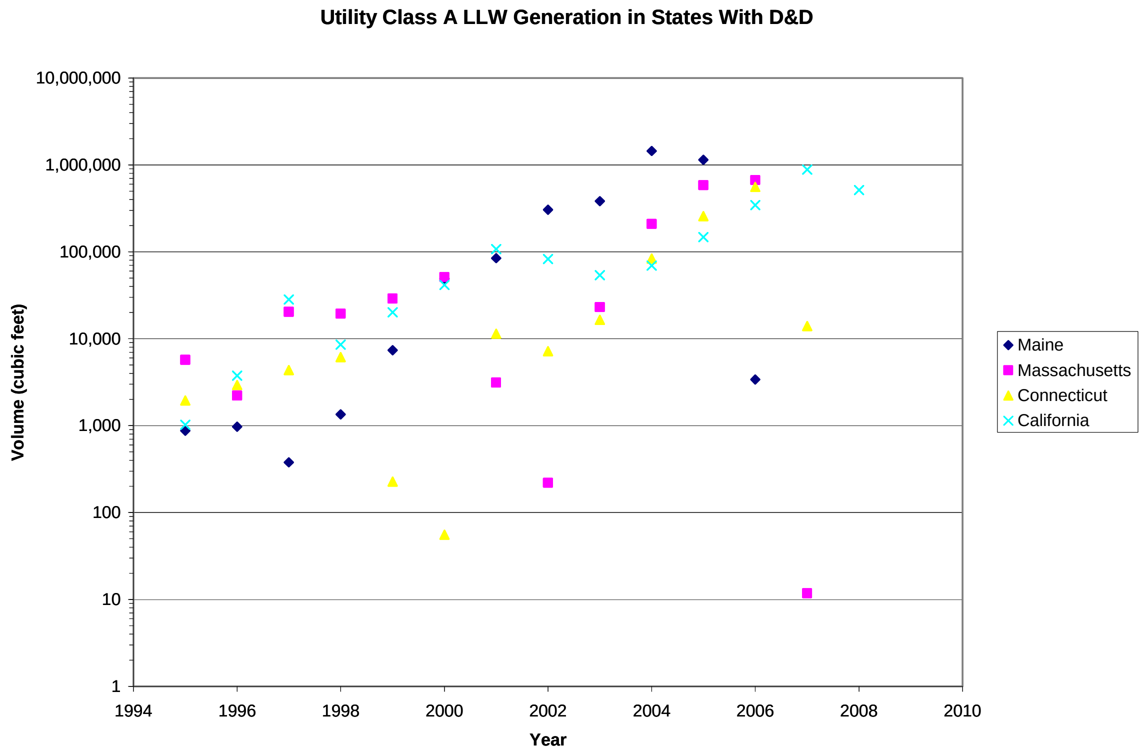


Figure H.2.1-2
Industry Generated Low Level Waste Disposed: 1986 - 2008



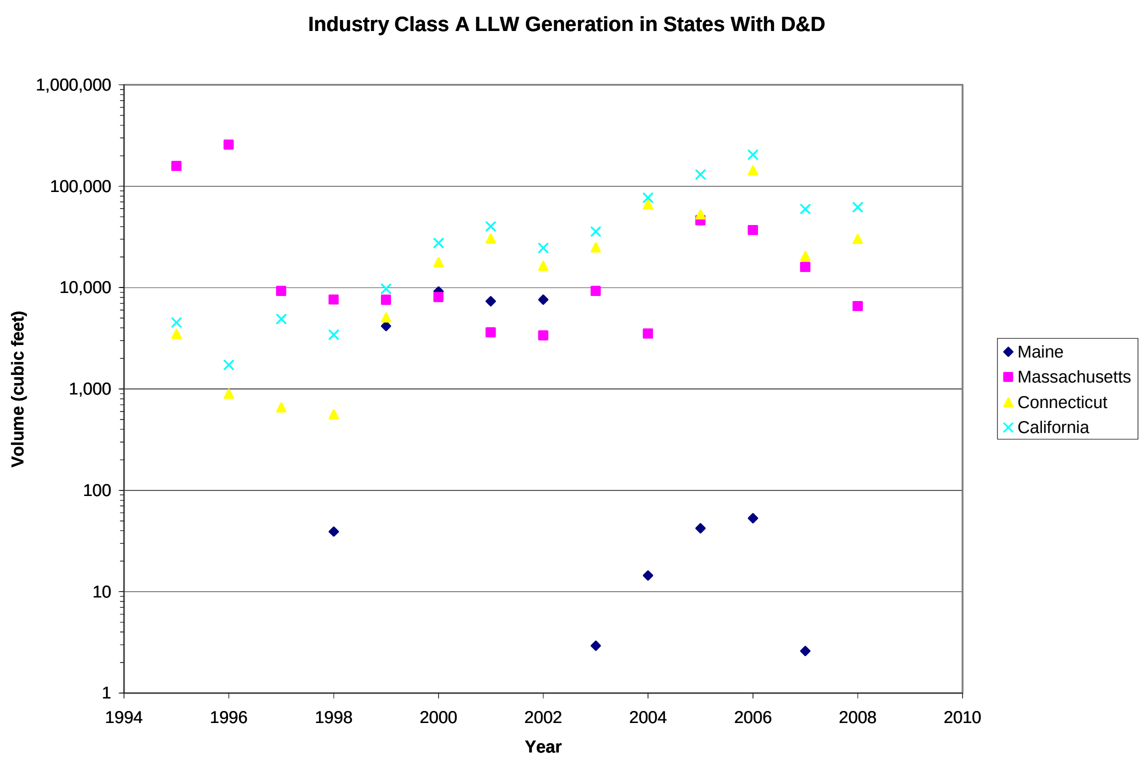


Figure H.2.1-3
Utility and Industry Generated Class A Low Level Waste Disposed in States with Active D&D

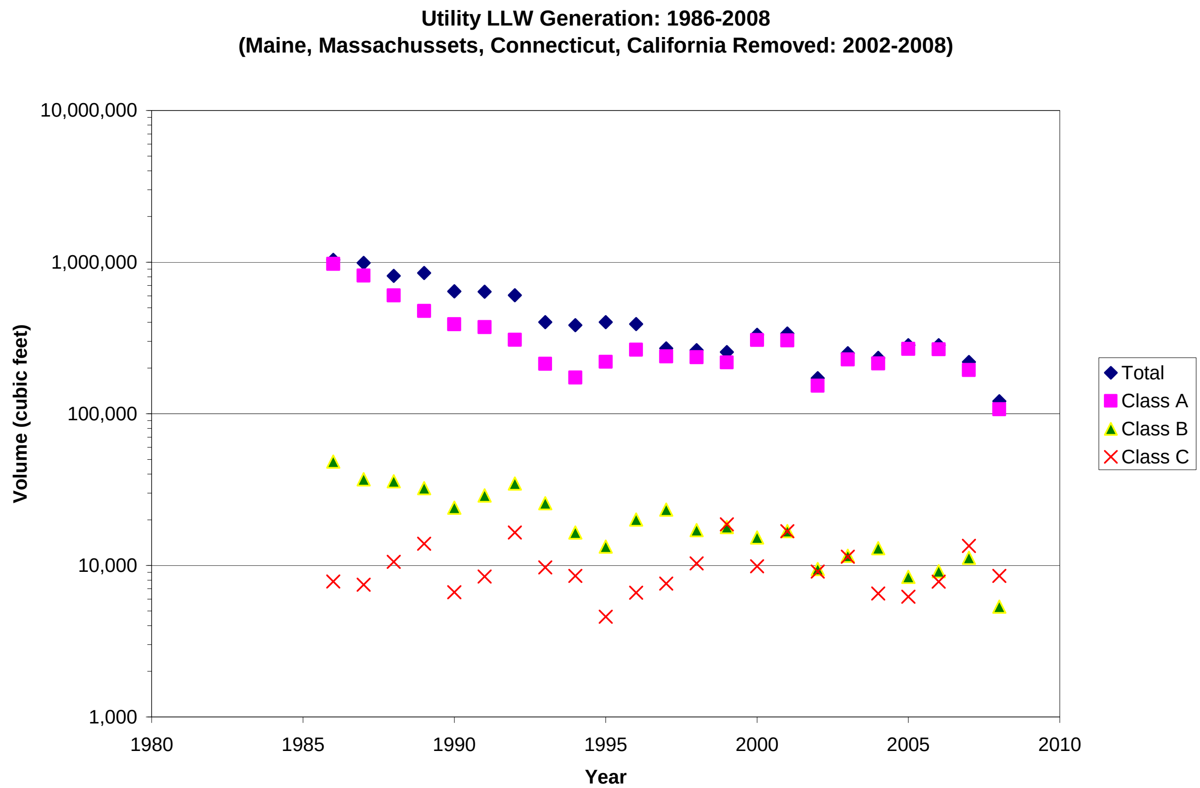


Figure H.2.1-4
Utility Generated Low Level Waste Disposed, Adjusted for Plant Decommissioning: 1986 - 2008

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.

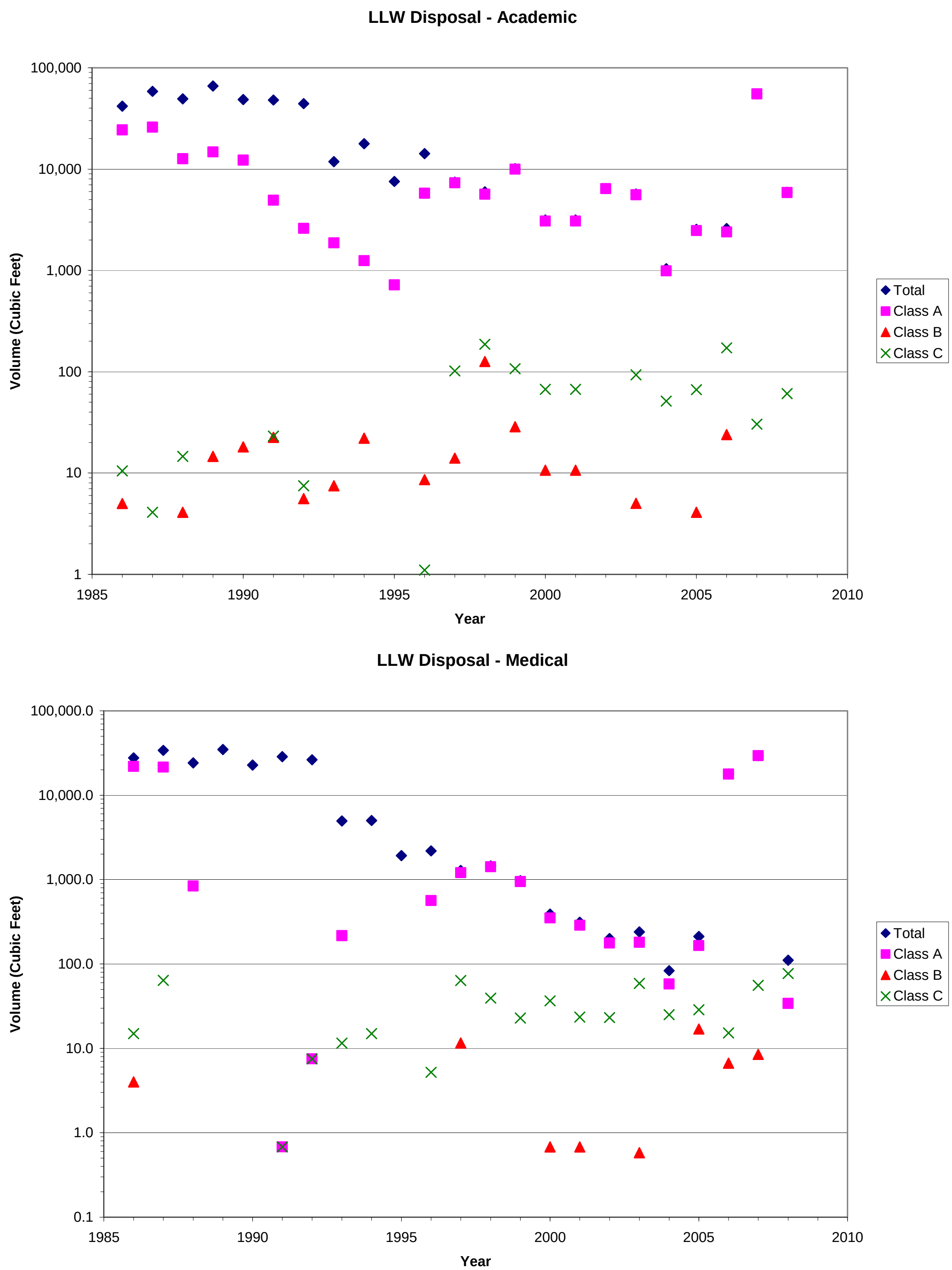


Figure H.2.2-1
Academic and Medical Generated Low Level Waste Disposed: 1986 - 2008.

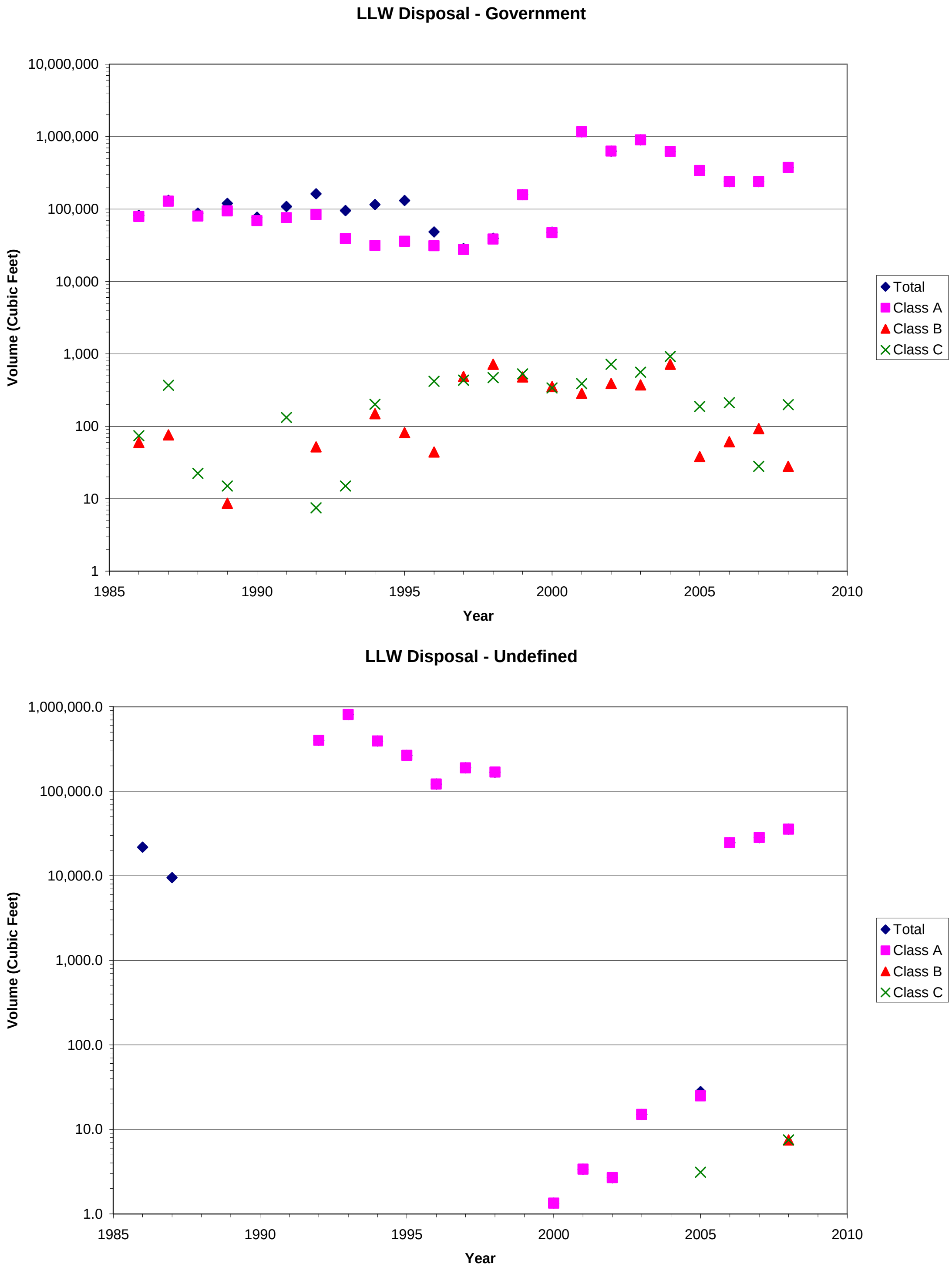


Figure H.2.2-2
Government and Undefined Generated Low Level Waste Disposed: 1986 - 2008.

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^3/year
Class B: 0.2 m^3/year
Class C: 2 m^3/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^3/year
Class B: 0.1 m^3/year
Class C: 1 m^3/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^3/year
Class B: 7 m^3/year
Class C: 11 m^3/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^3/year
Class B: 0.1 m^3/year
Class C: 0.1 m^3/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.

Table H.3.0-1
Estimated LLW Disposal Rates for Utility and Industry Generators

Waste Class	Utility (w/o D&D)	Industry	Total Nuclear	
Class A	7,000 m^3/year	45,000 m^3/year	52,000 m^3/year	66 m^3/TW-hr
Class B	320 m^3/year	20 m^3/year	340 m^3/year	0.4 m^3/TW-hr
Class C	280 m^3/year	20 m^3/year	300 m^3/year	0.4 m^3/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^3/year
Class B: 5 m^3/year
Class C: 50 m^3/year

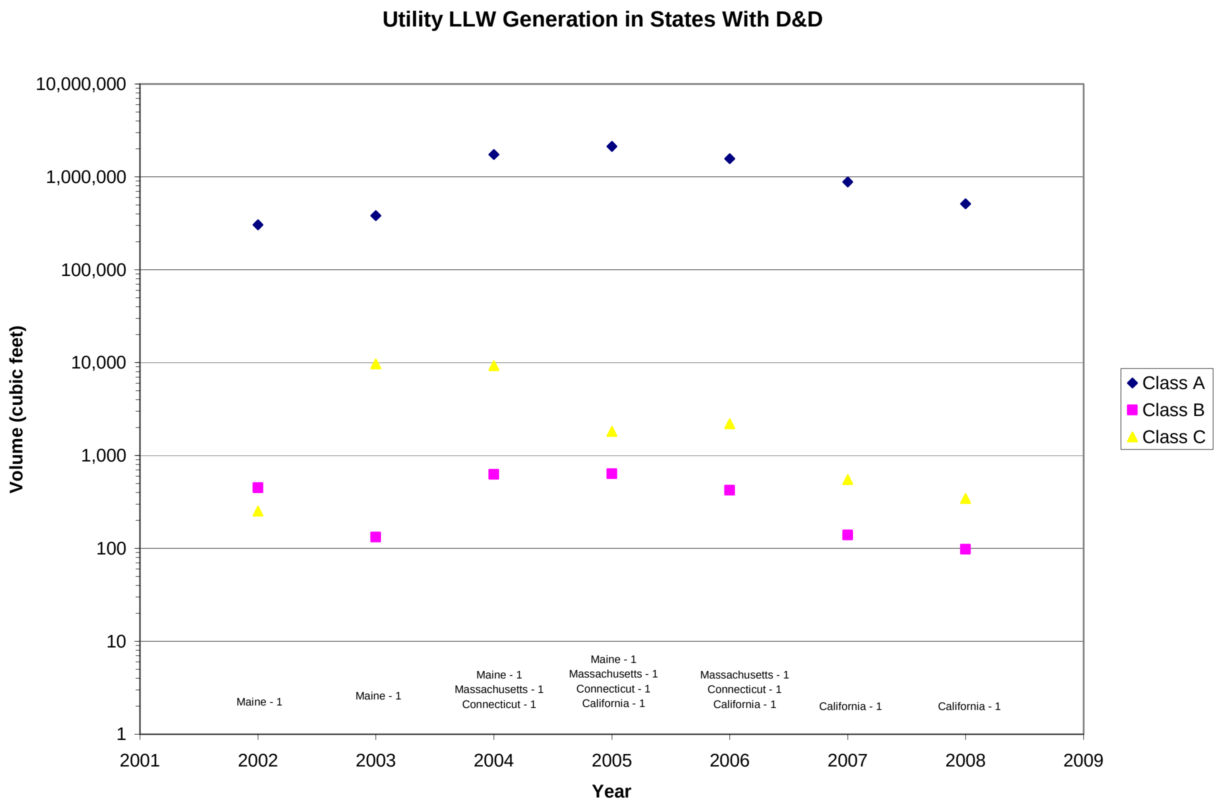


Figure H.3.0-1
Utility Generated Low Level Waste Disposed, States with Active D&D: 2002 - 2008.

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Appendix I

Waste Estimates for Recycling Sodium Fast Reactor Used Fuel by the Aqueous Co-extraction Process

I.1.0 Introduction

Aqueous recycling of used fuel from sodium fast reactors (SFR) by the co-extraction process is expected to be essentially the same as aqueous recycling of light water reactor (LWR) used fuel. Only the minor differences listed below that have the potential to affect low level waste (LLW) generation have been identified.

1. Metal waste from hulls and hardware will be increased due to the different configuration of SFR fuel. This difference will impact the greater than Class C (GTCC) waste generated by the Disassembly and Shearing operations. Waste volumes for other waste types are not expected to be affected.
2. Sodium fast reactor fuel is expected to have a smaller quantity of heavy metal per assembly than LWR fuel. This difference will impact the quantity of fuel casks received which in turn will impact the volume of waste generated from Fuel Receipt operations.

I.2.0 Assumptions

1. Residual sodium coolant is removed from the exterior of the used fuel at the reactor site. No sodium is present on the exterior of the fuel when received at the recycling plant.
2. Oxide fuel is not sodium bonded and is suitable for recycling in an aqueous plant.
3. Metal fuel is sodium bonded and is not suitable for recycling in an aqueous plant.
4. Although SFR fuel hardware is physically different from LWR fuel hardware, this physical difference will not affect process functions to disassemble and shear the fuel. Plant designs may need to provide additional operations to remove certain hardware components such as the fuel shroud; however, these additional processes should not require significantly more space, equipment, process time or personnel such that waste generation would be impacted.
5. On average, LWR fuel contains approximately three times the quantity of heavy metal per fuel assembly than SFR fuel. Accordingly, SFR fuel requires three times the number of shipments than LWR fuel for a given amount of heavy metal shipped.
6. The fuel storage pool for SFR used fuel in the Fuel Receipt area does not require enlargement to accommodate the greater number of used fuel assemblies to be received and processed; however, the available lag storage capacity in terms of heavy metal stored in the pool will be reduced by a factor of three. This assumes that the same quantity of used fuel assemblies (SFR versus LWR) can be accommodated.

I.3.0 Waste Estimate Adjustments

The waste estimates previously made for recycling LWR used fuel by the co-extraction process provide the basis for the waste estimates for recycling SFR fuel by the co-extraction process (Reference 1). The previous estimates for the co-extraction process are based on the following sources:

- An 800 MTHM/year plant based on AREVA data
- An 800 MTHM/year plant based on data from the Engineering Alternative Studies
- A 100 MTHM/year plant based on data from the Engineering Alternative Studies

The AREVA data does not provide sufficient detail to make specific adjustments for the differences described in Section I.1.0. The data from the Engineering Alternative Studies (EAS) does provide sufficient detail to make the adjustments described in Section I.1.0. Applicable adjustments based on the EAS data are derived in the sections that follow.

I.3.1 Metal Waste

Metal waste volume estimates are provided in Reference 2 for the NUEX recycling process. The metal waste volume for the co-extraction recycling process is not calculated in Reference 2; however, the volume would be the same as for the NUEX process and linear with plant capacity. Metal waste volumes per metric ton of heavy metal (MTHM) recycled are given in Table I.3.1-1. Metal waste from aqueous recycling is considered to be GTCC waste.

Table I.3.1-1
Metal Waste From Recycling Sodium Fast Reactor Fuel Using the Co-Extraction Process

Fuel Parameters		Metal Waste		
Fuel Burn-Up (GWD/MTHM)	Conversion Ratio	Mass (kg/MTHM)	Volume (m^3/MTHM)	Containers Per MTHM [1]
131	0.75	2,890	0.71	0.8
166	0.5	3,960	0.98	1.1

1. Containers are 2 feet diameter and 10 feet tall. Each container is limited to 3,600 kg of metal waste.

Table I.3.1-2 shows a comparison of the metal waste volume estimates associated with recycling SFR used fuel to that of LWR used fuel. Also shown is the incremental amount of metal waste associated with recycling SFR used fuel relative to LWR used fuel.

Table I.3.1-2
Incremental Metal Waste From Recycling Sodium Fast Reactor Fuel Using the Co-Extraction Process

Fuel Burn-Up (GWD/MTHM)	Plant Capacity (MTHM/year)	Waste Volume		
		Previous LWR Basis (m^3) [1]	SFR Basis (m^3) [2]	Delta (m^3)
131	800	87.5	568.0	480.5
	100	10.9	71.0	60.1
166	800	87.5	784.0	696.5
	100	10.9	98.0	87.1

1. From Table E.3.0-4 (800 MTHM/year) and E.4.0-4 (100 MTHM/year).
2. Values from Table I.3.1-1 multiplied by the appropriate Plant Capacity.

I.3.2 Fuel Receipt Waste

Waste streams from Fuel Receipt operations impacted by the recycling of SFR used fuel are:

- unusable multi-purpose canisters (MPC)
- machining chips from multi-purpose canisters
- fuel cask and canister decontamination wipes
- fuel cask and canister decontamination filters

All of these waste streams are solid LLW. The waste associated with unusable MPCs (MPCs themselves and the machining chips) could be eliminated if SFR used fuel is not packaged into MPCs to begin with. These waste streams are included here for consistency with the previous EAS waste basis and for conservatism. Elimination of this waste stream would avoid the generation of approximately 0.2 m^3 of LLW per year per MTHM recycled. The co-extraction waste estimates are based on the assumption that the amount of SFR used fuel to be received is approximately three times that of the LWR used fuel assumed in the previous estimates.

Tables I.3.2-1 through I.3.2-4 show the waste previously estimated for the recycling of LWR used fuel by the co-extraction process and the new estimates for recycling SFR used fuel.

Table I.3.2-1
Incremental Unpackaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In An 800 MTHM/year Facility Using The Co-Extraction Process

Plant Capacity (MTHM/year)	Waste Stream	Container [1]	Unpackaged Waste Volume: Previous LWR Basis (m^3)	Unpackaged Waste Volume: SFR Basis (m^3) [2]	Unpackaged Waste Volume: Delta (m^3)
800	Unusable MPCs	E	48.0	144.0	96.0
	Machining chips	L	0.3	0.9	0.6
	Decontamination wipes	L	144.0	432.0	288.0
	Decontamination filters	H	9.0	27.0	18.0
		TOTAL (m^3)	**201.3**	**603.9**	**402.6**
		TOTAL (m^3/MTHM)	**0.25**	**0.75**	**0.5**

1. E - engineered containers, H - high integrity containers, L - low level waste disposal box
2. The values listed for the SFR Basis are 3 times the values listed for the Previous LWR Basis.

Table I.3.2-2
Incremental Packaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In An 800 MTHM/year Facility Using The Co-Extraction Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	96.0	Undetermined	120.0	Undetermined	120.0
High integrity container	18.0	113	28.25	113	28.25
Low level waste disposal box [3,5]	288.6	145	362.5	29	72.5
TOTAL (m^3)	**402.6**		**510.8**		**220.8**
TOTAL (m^3/MTHM)	**0.5**		**0.6**		**0.3**

1. Incremental (i.e. "Delta") from Table I.3.2-1
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 (96.0 ÷ 0.80 = 120.0). 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. 288.6 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1) = 145.

Table I.3.2-3
Incremental Unpackaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In A 100 MTHM/year Facility Using The Co-Extraction Process

Plant Capacity (MTHM/year)	Waste Stream	Container 1	Waste Volume		
			Previous LWR Basis (m^3)	SFR Basis (m^3)	Delta (m^3)
100 (see Note 2)	Unusable MPCs	E	6.0	18.0	12.0
	Machining chips	L	0.04	0.12	0.08
	Decontamination wipes	L	18	54.0	36.0
	Decontamination filters	H	1.1	3.3	2.3
	TOTAL (m^3)		25.14	75.42	50.38
	TOTAL (m^3/MTHM)		0.25	0.75	0.5

1. E - engineered containers, H - high integrity containers, L - low level waste disposal box
2. The previous waste volumes for the 100 MTHM/year capacity facility were derived by adjustment based on capacity (i.e. 1/8 of the 800 MTHM/year values)

Table I.3.2-4
Incremental Packaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In A 100 MTHM/year Facility Using The Co-Extraction Process

Container	Bulk Waste Volume 1 (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume 2 (m^3)	Package Quantity	Packaged Volume 2 (m^3)
Engineered container	12.0	Undetermined	15.0	Undetermined	15.0
High integrity container	2.3	15	3.8	15	3.8
Low level waste disposal box 3,5	36.08	18	45.0	4	10.0
TOTAL (m^3)	**50.4**		**63.8**		**28.8**
TOTAL (m^3/MTHM)	**0.5**		**0.6**		**0.3**

1. Incremental (i.e. "Delta") from Table I.3.2-3
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 (12.0 ÷ 0.80 = 15.0). 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. 36.08 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1) = 18.

I.4.0 Waste Estimate Summary

Table I.4.0-1 summarizes the waste estimates for recycling of SFR used fuel by the co-extraction process. These estimates are based on the relevant estimates provided for LWR recycling by co-extraction as shown in Section 2.2.1 of the report and adjusted by the incremental values determined in Section I.3.0

Table I.4.0-1
Summary of Annual Waste Volume Estimates For Recycling Sodium Fast Reactor Fuel Using The Co-Extraction Process

Estimate Reference [1]	Estimate Basis (MTHM/yr)	Fuel Burn-Up (GWD/MTHM)	Volume	Low Level Waste Class A	Low Level Waste Class B	Low Level Waste Class C	Low Level Waste Total	GTCC Waste CH-TRU	GTCC Waste RH-TRU + GTCC	GTCC Waste Total	Mixed LLW	Mixed GTCC
AREVA [2]	800	131	m^3/year				1,448.8			628.5		
			m^3/MTHM				1.8			0.8		
		166	m^3/year				1,448.8			844.5		
			m^3/MTHM				1.8			1.1		
EAS Co-Extraction	800	131	m^3/year				7,699.8			827.5	28.6	44.8
			m^3/MTHM				9.6			1.0	0.04	0.06
		166	m^3/year				7,699.8			1,043.5	28.6	44.8
			m^3/MTHM				9.6			1.3	0.04	0.06
	100	131	m^3/year				3,912.8			221.1	8.4	5.6
			m^3/MTHM				39.1			2.2	0.08	0.06
		166	m^3/year				3,912.8			248.1	8.4	5.6
			m^3/MTHM				39.1			2.5	0.08	0.06

1. AREVA - Appendix A
   EAS Co-Extraction - Appendix E
2. The waste volumes estimated by AREVA are increased by the same comparable amounts as the waste volumes derived for the EAS estimates in Section J.3.0.
3. Shaded areas (i.e.) indicate values not changed due to recycling of SFR used fuel relative to LWR used fuel. Compare the changed values to the values for LWR used fuel in Table 2.2-1.

I.5.0 References

1. FCRD-USED-2010-000033, *Low Level Waste Disposition - Quantity and Inventory*, Revision 0, June 2010
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 2, September 2010

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Appendix J

Waste Estimates for Recycling Sodium Fast Reactor Used Fuel by the Aqueous NUEX Process

J.1.0 Introduction

Aqueous recycling of used fuel from sodium fast reactors (SFR) is expected to be essentially the same as aqueous recycling of light water reactor (LWR) used fuel. Only the minor differences listed below that have the potential to affect low level waste (LLW) generation have been identified.

1. Metal waste from hulls and hardware will be increased due to the different configuration of SFR fuel. This difference will impact the greater than Class C (GTCC) waste generated by the Disassembly and Shearing operations. Waste volumes for other waste types are not expected to be affected.
2. Sodium fast reactor fuel is expected to have a smaller quantity of heavy metal per assembly than LWR fuel. This difference will impact the quantity of fuel casks received which in turn will impact the volume of waste generated from Fuel Receipt operations.

J.2.0 Assumptions

The assumptions listed in Appendix I, Section I.2.0 for recycling SFR used fuel by the co-extraction process are relevant to the recycling of SFR used fuel by the NUEX process.

J.3.0 Waste Estimate Adjustments

The waste estimates previously made for recycling LWR used fuel by the NUEX process provide the basis for the waste estimates for recycling SFR fuel by the NUEX process (Reference 1). The previous estimates for the NUEX process are based on the following sources:

- A 1,500 MTHM/year plant based on Energy*Solutions* data
- An 800 MTHM/year plant based on data from the Engineering Alternative Studies
- A 100 MTHM/year plant based on data from the Engineering Alternative Studies

The Energy*Solutions* data does not provide sufficient detail to make specific adjustments for the differences described in Section J.1.0. The data from the Engineering Alternative Studies (EAS) does provide sufficient detail to make the adjustments described in Section J.1.0. Applicable adjustments based on the EAS data are derived in the sections that follow. The EAS adjustments with correction for plant capacity are assumed to be applicable to the EnergySolutions data for the purpose of estimating waste associated with recycling SFR used fuel.

J.3.1 Metal Waste

Normalized metal waste volume estimates are provided in Reference 2 for the NUEX recycling process. These are the same values shown in Table I.3.1-1 in Appendix I for the co-extraction process and are repeated here as Table J.3.1-1.

Table J.3.1-1
Metal Waste From Recycling Sodium Fast Reactor Fuel Using the NUEX Process

Fuel Parameters		Metal Waste		
Fuel Burn-Up (GWD/MTHM)	Conversion Ratio	Mass (kg/MTHM)	Volume (m^3/MTHM)	Containers Per MTHM [1]
131	0.75	2,890	0.71	0.8
166	0.5	3,960	0.98	1.1

1. Containers are 2 feet diameter and 10 feet tall. Each container is limited to 3,600 kg of metal waste.

The incremental waste volumes determined in Appendix I for the co-extraction process at 100 MTHM/year and 800 MTHM/year are directly applicable to the EAS NUEX estimates at these plant capacities. Table J.3.1-2 shows a comparison of the metal waste volume estimates associated with recycling SFR used fuel to that of LWR used fuel. Also shown is the incremental amount of metal waste associated with recycling SFR used fuel relative to LWR used fuel. The incremental waste volumes relevant to the Energy*Solutions* data require adjustment for plant capacity (1,500 MTHM/year versus 800 MTHM/year) and are also shown in Table J.3.1-2.

Table J.3.1-2
Incremental Metal Waste From Recycling Sodium Fast Reactor Fuel Using the NUEX Process

Fuel Burn-Up (GWD/MTHM)	Plant Capacity (MTHM/year)	Waste Volume		
		Previous LWR Basis (m^3) [1]	SFR Basis (m^3) [2]	Delta (m^3)
131	1,500	164.1	1,065.0	900.9
	800	87.5	568.0	480.5
	100	10.9	71.0	60.1
166	1,500	164.1	1,470.0	1,305.9
	800	87.5	784.0	696.5
	100	10.9	98.0	87.1

1. The Previous LWR Basis for the 800 MTHM/year and 100 MTHM/year plant capacities are obtained from Table F.3.0-4 (800 MTHM/year) and F.4.0-4 (100 MTHM/year). The Energy*Solutions* data in Appendix B provides the Previous LWR Basis for the 1,500 MTHM/year plant capacity; however, the Energy*Solutions* data is insufficient to provide the specific metal waste volume. The volume shown is calculated by prorating the metal waste volume for the 800 MTHM/year EAS case (1,500/800 x 87.5 m^3/year = 164.1 m^3/year).
2. Values from Table J.3.1-1 multiplied by the appropriate Plant Capacity.

J.3.2 Fuel Receipt Waste

Waste streams from Fuel Receipt operations impacted by the recycling of SFR used fuel are:

- unusable multi-purpose canisters (MPC)
- machining chips from multi-purpose canisters
- fuel cask and canister decontamination wipes
- fuel cask and canister decontamination filters

All of these waste streams are solid LLW. The waste associated with unusable MPCs (MPCs themselves and the machining chips) could be eliminated if SFR used fuel is not packaged into MPCs to begin with. These waste streams are included here for consistency with the previous EAS waste basis and for conservatism. Elimination of this waste stream would avoid the generation of approximately 0.2 m^3 of LLW per year per MTHM recycled. The NUEX waste estimates are based on the assumption that the amount of SFR used fuel to be received is approximately three times that of the LWR used fuel assumed in the previous estimates.

Tables I.3.2-1 through I.3.2-4 in Appendix I show the incremental waste previously estimated for the recycling of SFR used fuel by the co-extraction process at 100 MTHM/year and 800 MTHM/year. The values calculated for the co-extraction process are applicable to the NUEX process at these plant capacities. Table J.3.2-1 provides the incremental unpackaged waste for a 1,500 MTHM/year plant. Table J.3.2-2 provides the incremental packaged waste for a 1.500 MTHM/year plant.

Table J.3.2-1
Incremental Unpackaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In A 1.500 MTHM/year Facility Using The NUEX Process

Plant Capacity (MTHM/year)	Waste Stream	Container [1]	Unpackaged Waste Volume		
			Previous LWR Basis (m^3) [2]	SFR Basis (m^3) [3]	Delta (m^3)
1,500	Unusable MPCs	E	90.0	270.0	180.0
	Machining chips	L	0.6	1.8	1.2
	Decontamination wipes	L	270.0	810.0	540.0
	Decontamination filters	H	16.9	50.7	33.8
	TOTAL (m^3)		**377.5**	**1132.5**	**755.0**
	TOTAL (m^3/MTHM)		**0.25**	**0.75**	**0.5**

1. E - engineered containers, H - high integrity containers, L - low level waste disposal box
2. The Energy*Solutions* data in Appendix B provides the Previous LWR Basis for the 1,500 MTHM/year plant capacity; however, the Energy*Solutions* data is insufficient to provide the specific waste volumes indicated in the table (i.e. "Unusable MPCs", "Machining chips", etc.). The volume shown is calculated by prorating the waste volumes for the 800 MTHM/year EAS case (e.g. 1,500/800 x 48.0 m^3/year = 90.0 m^3/year). The EAS adjustments with correction for plant capacity are assumed to be applicable to the EnergySolutions data for the purpose of estimating waste associated with recycling SFR used fuel.
3. The values listed for the SFR Basis are 3 times the values listed for the Previous LWR Basis.

Table J.3.2-2
Incremental Packaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In A 1,500 MTHM/year Facility Using The NUEX Process

Container	Bulk Waste Volume [1] (m^3)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m^3)	Package Quantity	Packaged Volume [2] (m^3)
Engineered container	180	Undetermined	225.0	Undetermined	225.0
High integrity container	33.8	212	53.0	212	53.0
Low level waste disposal box [3,5]	541.2	271	677.5	54	135.0
TOTAL (m^3)	**755.0**		**955.5**		**413.0**
TOTAL (m^3/MTHM)	**0.5**		**0.6**		**0.3**

1. Incremental (i.e. “Delta”) from Table J.3.2-1
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 (180.0 ÷ 0.80 = 225.0). 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. 541.2 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1) = 271.

J.4.0 Waste Estimate Summary

Table J.4.0-1 summarizes the waste estimates for recycling of SFR used fuel by the NUEX process. These estimates are based on the relevant estimates provided for LWR recycling by NUEX as shown in Section 2.2.1 of the report and adjusted by the incremental values determined in Section K.3.0

Table J.4.0-1
Summary of Annual Waste Volume Estimates For Recycling Sodium Fast Reactor Fuel Using The Co-Extraction Process

Estimate Reference [1]	Estimate Basis (MTHM/yr)	Fuel Burn-Up (GWD/MTHM)	Volume	Low Level Waste – Class A	Low Level Waste – Class B	Low Level Waste – Class C	Low Level Waste – Total	GTCC Waste – CH-TRU	GTCC Waste – RH-TRU + GTCC	GTCC Waste – Total	Mixed LLW	Mixed GTCC
Energy *Solutions* [2,3]	1,500	131	m^3/year	12,960.0		166.0	13,126.0	130	1,271.9	1,401.9		
			m^3/MTHM	8.6		0.1	8.8	0.09	0.85	0.93		
		166	m^3/year	12,960.0		166.0	13,126.0	130	1,676.9	1,806.9		
			m^3/MTHM	8.6		0.1	8.8	0.09	1.12	1.20		
EAS NUEX	800	131	m^3/year				7,810.8			1,044.5	29.8	44.8
			m^3/MTHM				9.8			1.31	0.04	0.06
		166	m^3/year				7,810.8			1,260.5	29.8	44.8
			m^3/MTHM				9.8			1.58	0.04	0.06
	100	131	m^3/year				3,963.8			331.1	8.8	5.6
			m^3/MTHM				39.6			3.31	0.09	0.06
		166	m^3/year				3,963.8			358.1	8.8	5.6
			m^3/MTHM				39.6			3.58	0.09	0.06

1. Energy*Solutions* - Appendix B
   EAS NUEX - Appendix F
2. All of the increased LLW volume is assumed to be Class A waste except for that contained in high integrity containers which is assumed to be Class C waste.
3. All of the increased GTCC waste is assumed to be remote handled waste (RH TRU + GTCC).
4. Shaded areas (i.e.) indicate values not changed due to recycling of SFR used fuel relative to LWR used fuel. Compare the changed values to the values for LWR used fuel in Table 2.2-1.

J.5.0 References

1. FCRD-USED-2010-000033, *Low Level Waste Disposition - Quantity and Inventory*, Revision 0, June 2010
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 2, September 2010

Appendix K

Waste Estimates for Recycling Sodium Fast Reactor Used Fuel by the Aqueous UREX+1a Process

K.1.0 Introduction

Aqueous recycling of used fuel from sodium fast reactors (SFR) is expected to be essentially the same as aqueous recycling of light water reactor (LWR) used fuel. Only the minor differences listed below that have the potential to affect low level waste (LLW) generation have been identified.

1. Metal waste from hulls and hardware will be increased due to the different configuration of SFR fuel. This difference will impact the greater than Class C (GTCC) waste generated by the Disassembly and Shearing operations. Waste volumes for other waste types are not expected to be affected.
2. Sodium fast reactor fuel is expected to have a smaller quantity of heavy metal per assembly than LWR fuel. This difference will impact the quantity of fuel casks received which in turn will impact the volume of waste generated from Fuel Receipt operations.

K.2.0 Assumptions

The assumptions listed in Appendix I, Section I.2.0 for recycling SFR used fuel by the co-extraction process are relevant to the recycling of SFR used fuel by the UREX+1a process.

K.3.0 Waste Estimate Adjustments

The waste estimates previously made for recycling LWR used fuel by the UREX+1a process provide the basis for the waste estimates for recycling SFR fuel by the UREX+1a process (Reference 1). The previous estimates for the UREX+1a process are based on the following sources:

- An 800 MTHM/year plant based on data from the Engineering Alternative Studies
- A 100 MTHM/year plant based on data from the Engineering Alternative Studies

The data from the Engineering Alternative Studies (EAS) provides sufficient detail to make the adjustments described in Section K.1.0. Applicable adjustments based on the EAS data are derived in the sections that follow.

K.3.1 Metal Waste

Metal waste volume estimates are provided in Reference 2 for the NUEX recycling process. The metal waste volume for the UREX+1a recycling process is not specifically calculated in Reference 2; however, the incremental volume increase (i.e. Delta) calculated for the NUEX process in Appendix J, Section J.3.1, is applicable to the UREX+1a process. The previous UREX+1a estimate of metal waste based on LWR used fuel assumes some of the metal waste is diverted to the technetium waste form and is, therefore, less than the amounts shown in Appendix I and J for the co-extraction and NUEX processes respectively. Metal waste from aqueous recycling is considered to be GTCC waste.

Table K.3.1-1 shows a comparison of the metal waste volume estimates associated with recycling SFR used fuel to that of LWR used fuel using the UREX+1a process. Also shown is the incremental amount of metal waste associated with recycling SFR used fuel relative to LWR used fuel (same as calculated in Appendix J, Section J.3.1.

Table K.3.1-1
Incremental Metal Waste From Recycling Sodium Fast Reactor Fuel Using the UREX+1a Process

Fuel Burn-Up (GWD/MTHM)	Plant Capacity (MTHM/year)	Waste Volume		
		Previous LWR Basis (m^3) [1]	Delta (m^3) [2]	SFR Basis (m^3) [3]
131	800	85.2	480.5	565.7
	100	10.6	60.1	70.7
166	800	85.2	696.5	781.7
	100	10.6	87.1	97.7

1. From Table D.3.0-4 (800 MTHM/year) and D.4.0-4 (100 MTHM/year).
2. Values from Table J.3.1-2.
3. SFR Basis = Previous LWR Basis + Delta

K.3.2 Fuel Receipt Waste

Waste streams from Fuel Receipt operations impacted by the recycling of SFR used fuel are:
- unusable multi-purpose canisters (MPC)
- machining chips from multi-purpose canisters
- fuel cask and canister decontamination wipes
- fuel cask and canister decontamination filters

All of these waste streams are solid LLW. The waste associated with unusable MPCs (MPCs themselves and the machining chips) could be eliminated if SFR used fuel is not packaged into MPCs to begin with. These waste streams are included here for consistency with the previous EAS waste basis and for conservatism. Elimination of this waste stream would avoid the generation of approximately 0.2 m^3 of LLW per year per MTHM recycled. The UREX+1a waste estimates are based on the assumption that the amount of SFR used fuel to be received is approximately three times that of the LWR used fuel assumed in the previous estimates.

Tables I.3.2-1 through I.3.2-4 in Appendix I show the incremental waste previously estimated for the recycling of SFR used fuel by the co-extraction process at 100 MTHM/year and 800 MTHM/year. The values calculated for the co-extraction process are applicable to the UREX+1a process at these plant capacities.

K.4.0 Waste Estimate Summary

Table K.4.0-1 summarizes the waste estimates for recycling of SFR used fuel by the UREX+1a process. These estimates are based on the relevant estimates provided for LWR recycling by the UREX+1a process as shown in Section 2.2.1 of the report and adjusted by the incremental values determined in Section K.3.0

Table K.4.0-1
Summary of Annual Waste Volume Estimates For Recycling Sodium Fast Reactor Fuel Using The UREX+1a Process

Estimate Reference [1]	Estimate Basis (MTHM/yr)	Fuel Burn-Up (GWD/MTHM)	Volume	Low Level Waste				GTCC Waste			Mixed LLW	Mixed GTCC
				Class			Total	CH-TRU	RH-TRU + GTCC	Total		
				A	B	C						
EAS UREX+1a	800	131	m^3/year				8,021.8			1,730.5	32	76.9
			m^3/MTHM				10.0			2.2	0.04	0.1
		166	m^3/year				8,021.8			1,947.5	32	76.9
			m^3/MTHM				10.0			2.4	0.04	0.1
	100	131	m^3/year				4,054.8			768.1	9.6	9.7
			m^3/MTHM				40.5			7.7	0.1	0.1
		166	m^3/year				4,054.8			795.1	9.6	9.7
			m^3/MTHM				40.5			8.0	0.1	0.1

1. EAS UREX+1a - Appendix D
2. Shaded areas (i.e.) indicate values not changed due to recycling of SFR used fuel relative to LWR used fuel. Compare the changed values to the values for LWR used fuel in Table 2.2-1.

K.5.0 References

1. FCRD-USED-2010-000033, *Low Level Waste Disposition - Quantity and Inventory*, Revision 0, June 2010
2. FCRD-USED-2010-000031, *Fuel Cycle Potential Waste Inventory for Disposition*, Revision 2, September 2010

Appendix L

Waste Estimates for Recycling Sodium Fast Reactor Used Fuel by the Electrochemical Process

L.1.0 Introduction

Electrochemical recycling of used fuel from sodium fast reactors (SFR) is expected to be essentially the same as electrochemical recycling of light water reactor (LWR) used fuel. Only the minor difference listed below that has the potential to affect low level waste (LLW) generation has been identified.

1. Sodium fast reactor fuel is expected to have a smaller quantity of heavy metal per assembly than LWR fuel. This difference will impact the quantity of fuel casks received which in turn will impact the volume of waste generated from Fuel Receipt operations.

Metal waste from hulls and hardware will be increased due to the different configuration of SFR fuel; however, this increase will be reflected in the volume of high level waste since all the metal waste from electrochemical recycling is combined with the fission product waste stream. The increased metal waste volume has no impact on LLW (Class A/B/C or GTCC) volumes.

L.2.0 Assumptions

1. Residual sodium coolant is removed from the exterior of the used fuel at the reactor site. No sodium is present on the exterior of the fuel when received at the recycling plant.
2. Oxide and metal fuel are both suitable for recycling in an electrochemical plant.
3. Metal fuel is sodium bonded. The sodium contained in the fuel adds a negligible amount to the salt waste (e.g. glass bonded zeolite) and is ignored.
4. Although SFR fuel hardware is physically different from LWR fuel hardware, this physical difference will not affect process functions to disassemble and shear the fuel. Plant designs may need to provide additional operations to remove certain hardware components such as the fuel shroud; however, these additional processes should not require significantly more space, equipment, process time or personnel such that waste generation would be impacted.
5. On average, LWR fuel contains approximately three times the quantity of heavy metal per fuel assembly than SFR fuel. Accordingly, SFR fuel requires three times the number of shipments than LWR fuel for a given amount of heavy metal shipped.
6. The fuel storage pool for SFR used fuel in the Fuel Receipt area does not require enlargement to accommodate the greater number of used fuel assemblies to be received and processed; however, the available lag storage capacity in terms of heavy metal stored in the pool will be reduced by a factor of three. This assumes that the same quantity of used fuel assemblies (SFR versus LWR) can be accommodated.

L.3.0 Waste Estimate Adjustments

The waste estimates previously made for recycling LWR used fuel by the electrochemical process provide the basis for the waste estimates for recycling SFR fuel by the electrochemical process (Reference 1). The previous estimates for the co-extraction process are based on the following source:

- A 300 MTHM/year plant based on data from the Engineering Alternative Studies

The data from the Engineering Alternative Studies (EAS) provides sufficient detail to make the adjustments described in Section L.1.0. Applicable adjustments based on the EAS data are derived in the sections that follow.

L.3.1 Fuel Receipt Waste

Waste streams from Fuel Receipt operations impacted by the recycling of SFR used fuel are:

- unusable multi-purpose canisters (MPC)
- machining chips from multi-purpose canisters
- fuel cask and canister decontamination wipes
- fuel cask and canister decontamination filters

All of these waste streams are solid LLW. The waste associated with unusable MPCs (MPCs themselves and the machining chips) could be eliminated if SFR used fuel is not packaged into MPCs to begin with. These waste streams are included here for consistency with the previous EAS waste basis and for conservatism. Elimination of this waste stream would avoid the generation of approximately 0.2 m^3 of LLW per year per MTHM recycled. The electrochemical waste estimates are based on the assumption that the amount of SFR used fuel to be received is approximately three times that of the LWR used fuel assumed in the previous estimates.

Tables L.3.1-1 and L.3.1-2 show the waste previously estimated for the recycling of LWR used fuel by the electrochemical process and the new estimates for recycling SFR used fuel.

Table L.3.1-1
Incremental Unpackaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In A 300 MTHM/year Facility Using The Electrochemical Process

Plant Capacity (MTHM/year)	Waste Stream	Container [1]	Unpackaged Waste Volume: Previous LWR Basis (m^3)	Unpackaged Waste Volume: SFR Basis (m^3) [2]	Unpackaged Waste Volume: Delta (m^3)
300	Unusable MPCs	E	23.4	70.2	46.8
	Machining chips	L	0.1	0.3	0.2
	Decontamination wipes	L	56.0	168.0	112.0
	Decontamination filters	H	3.5	10.5	7.0
	TOTAL (m^3)		**83.0**	**249.0**	**166.0**
	TOTAL (m^3/MTHM)		**0.28**	**0.83**	**0.6**

1. E - engineered containers, H - high integrity containers, L - low level waste disposal box
2. The values listed for the SFR Basis are 3 times the values listed for the Previous LWR Basis.

Table L.3.2-2
Incremental Packaged Waste From Fuel Receipt Operations Associated With Recycling Sodium Fast Reactor Fuel In A 300 MTHM/year Facility Using The Electrochemical Process

Container	Bulk Waste Volume [1] (m³)	Packaging Scenario Without Compaction		Packaging Scenario With Compaction	
		Package Quantity	Packaged Volume [2] (m³)	Package Quantity	Packaged Volume [2] (m³)
Engineered container	46.8	Undetermined	58.5	Undetermined	58.5
High integrity container	7.0	44	11.0	44	11.0
Low level waste disposal box [3,5]	112.2	57	142.5	12	30
TOTAL (m³)	**166.0**		**212**		**99.5**
TOTAL (m³/MTHM)	**0.6**		**0.7**		**0.3**

1. Incremental (i.e. "Delta") from Table L.3.2-1
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 (96.0 ÷ 0.80 = 120.0). 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. 112.2 ÷ 0.80 ÷ 2.5 (internal volume from Appendix D, Table D.2.0-1) = 57.

L.4.0 Waste Estimate Summary

Table L.4.0-1 summarizes the waste estimates for recycling of SFR used fuel by the electrochemical process. These estimates are based on the relevant estimates provided for LWR recycling by the electrochemical process as shown in Section 2.3 of the report and adjusted by the incremental values determined in Section L.3.0

Table L.4.0-1
Summary of Annual Waste Volume Estimates For Electrochemical Recycling Of Sodium Fast Reactor Used Fuel

Data Reference	Estimate Basis (MTHM/yr)	Volume	Low Level Waste				GTCC Waste			Mixed LLW	Mixed GTCC
			Class								
			A	B	C	Total	CH-TRU	RH-TRU + GTCC	Total		
EAS Electrochemical	300	m³/year				2,715.6			919	29	43.6
		m³/MTHM				9.1			3.1	0.1	0.15

L.5.0 References

1. FCRD-USED-2010-000033, *Low Level Waste Disposition - Quantity and Inventory*, Revision 0, June 2010