November 2012
SFR-104

Capacity Report for Low-level Radioactive Waste

A Report to the 83rd Texas Legislature

Radioactive Materials Division

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

printed on
recycled paper

Capacity Report on Low-level Radioactive Waste

Prepared by
Radioactive Materials Division

SFR-104
November 2012

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Published and distributed
by the
Texas Commission on Environmental Quality
PO Box 13087
Austin TX 78711-3087

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Contents

Executive Summary 1
Definitions 7
References 9
List of Figures 9
List of Tables 9
1. Introduction 11
1.1 Background and Summary 11
1.2 Definition and Classes of Low Level Radioactive Waste 11
1.3 LLRW Volume and Radioactivity Projections 12
2. History of Low-Level Radioactive Waste Disposal in the United States 15
2.1 History of LLRW Disposal Outside Of Texas 15
2.2 History of LLRW Disposal in Texas 15
3. Commercial Radioactive Waste Generation in the United States 17
3.1 Low-Level Radioactive Waste Classification 17
3.1.1 LLRW Classes 17
3.1.2 Waste Stream Concept 18
3.1.3 Decay and Life of LLRW 19
3.2 Commercial Radioactive Waste Generation In Texas and Vermont 20
3.2.1 Technical Approach for LLRW Projections 20
3.2.2 Volume Predictions 21
3.2.3 Activity Predictions 27
3.3 Commercial Radioactive Waste Generation In Non-Party States 32
3.3.1 Non-Party State Volume Prediction 33
3.2 Non-Party State Activity Prediction 34
3.4 Volume Reduction 37
3.4.1 National Policy on Volume Reduction 37
3.4.2 Volume Reduction Techniques 37
3.4.3 Typical Volume Reduction Techniques and Factors in the Texas Compact 39
3.4.4 Costs and Benefits of Volume Reduction 39
4. Necessity of Containerized Waste 41
4.1 Stability of the MCCs 41
4.2 Shielding effects of the MCCs on Radiation Worker Dose 41

4.3 Role of Containerization in Environmental Protection and Water Infiltration 42
5. Projecting Capacity and Its Effect on Health and Safety of the Public 47
5.1 Public Health and Safety 47
5.1.1 Site Characteristics and its relationship to Capacity 48
5.2.2 Waste Inventory 49
6. Conclusion 51
Abbreviations, Initialisms, and Acronyms 53
Appendix A: Waste Stream Definitions 57
Appendix B: Volume Reduction Techniques 63

Executive Summary

In 2011, the Texas Legislature passed Senate Bill 1504 (82nd regular session), which charged the Texas Commission on Environmental Quality (TCEQ) with conducting "a study on the available volume and curie capacity of the compact waste disposal facility (CWF) for the disposal of party state compact waste and nonparty state compact waste." As codified in the Health and Safety Code, Chapter 401, Section 401.208, the TCEQ is required to consider and make recommendations on the following topics:

1) the future volume and curie capacity needs of party state and nonparty state generators and any additional reserve capacity necessary to meet those needs;
2) the calculation of radioactive decay related to the CWF and radiation dose assessments based on curie capacity;
3) the necessity of containerization of the waste;
4) the effects of the projected volume and radioactivity on the health and safety of the public; and
5) the costs and benefits of volume reduction and stabilized waste forms.

The TCEQ conducted a survey to obtain radioactivity projections for this report. The party state low-level radioactive waste (LLRW) generators were surveyed and the expected volume of waste over the life-span of the CWF was calculated. Of the hundreds of radioactive material licensees in the Texas Compact, approximately 200 were identified as potential LLRW generators and contacted. The remaining facilities were licensed for radioactive materials that generate waste but do not require LLRW disposal or disposal is prohibited by the license.

It is important to note that the CWF was licensed in 2009 for 15 years until 2024 and has the possibility for two additional 10-year renewal periods until 2044. Based on questionnaire responses, it was determined that approximately 0.73 million cubic feet and 0.08 million curies (Ci) of operational waste will be generated by 2024, and 1.15 million cubic feet and 0.14 million Ci of operational waste will be generated by 2044 by utility and non-utility generators within the Texas Compact.

Consideration was also given to the decommissioning volumes and activities for the Texas Compact nuclear utilities. The licenses of all five nuclear power electric generating units currently in operation will expire prior to 2033; therefore, capacity in the CWF must be reserved to account for the potential waste streams from the Texas Compact nuclear utilities. The combined decommissioning estimates for volume and radioactivity for the Texas Compact nuclear utilities are 1.7 million cubic feet and 0.67 million Ci, respectively.

In addition to the five existing units in the Texas Compact, two additional units are currently in the NRC licensing process and are anticipated by the applicant to be in operation after 2020. Texas law requires some reserve capacity within the CWF for Texas Compact generated LLRW. The operational volume and activity contribution

potential through 2024 is 136,000 cubic feet and 62,700 Ci. The operational volume and activity contribution potential through 2044 is 816,000 cubic feet and 376,000 Ci.

The predicted total decommissioning waste volume and activity for the future units is 1,556,587 cubic feet and 550,000 Ci, respectively. All capacity predictions provided by this study show the disposal needs of the Texas Compact with and without these two future units taken into account. The survey revealed the following information provided in Table 1.

Table 1: Future Capacity Needs of the Texas Compact

	Millions of cubic feet	Millions of Curies
Licensed Volume	2.31	3.89
Existing Facilities		
2024 Operating	0.73	0.08
2044 Operating	1.15	0.14
Decommissioning	1.70	0.67
Total (2044)	2.85	0.81
Possible New Facilities		
2024 Operating	0.136	0.0627
2044 Operating	0.816	0.376
Decommissioning	1.557	0.550
Total (2044)	2.373	0.926
Combined Total (2044)	5.223	1.736

Based on the operation and decommissioning estimates, the nuclear utilities generate in excess of 90 percent of the Texas Compact LLRW volume and more than 95 percent of the Texas Compact LLRW radioactive inventory. Texas Compact process and generation information regarding nuclear utilities were presumed to apply to nuclear utilities in nonparty states and suggests nuclear utilities in nonparty states will likely be

a majority of the LLRW that is currently in the United States, as opposed to academic, medical, or industrial sources.

Currently, there are eighty (80) nuclear power plant units in nonparty states that do not have viable disposal options. Table 2 shows the average annual generation rate of several waste streams and the total annual volume estimated to be generated by these nuclear utilities. The table separates out the two major types of reactors, Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR) because they operate differently and produce significantly different volumes of LLRW.

Table 2: US Industry Average Annual LLRW Generation Rate for Nuclear Utilities

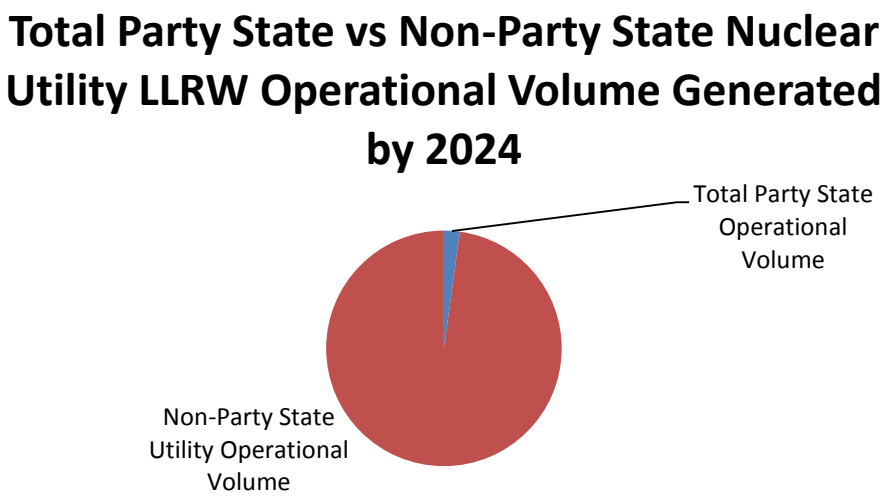
Number of Units	52 PWR	28 BWR	80 Total	
Combined Waste Streams	**Volume**			**Source**
Wet B/C (resins and filters)	5,720 ft3	1,680 ft3	7,400 ft3	EPRI RadBench™[1]
Wet A (resins and filters)	10,400 ft3	50,400 ft3	60,800 ft3	EPRI RadBench™
Dry Active Waste (DAW) (combined)	1,456,000 ft3	1,232,000 ft3	2,688,000 ft3	EPRI RadBench™
Activated Hardware	N/A	1372 ft3	1372 ft3	Texas Compact BWR questionnaire response[2]

Using these totals, by 2024 nuclear utilities in nonparty states are projected to produce a total of approximately 33.1 million cubic feet of operational LLRW. By 2044, nonparty state's nuclear utilities are projected to produce 88.2 million cubic feet of operational LLRW. This is approximately 14 times the capacity that the Texas Compact utilities will need for both operational and decommissioning volumes combined. Figure 1 illustrates the comparison of party state operatonal waste and non-party state operational waste for the 2024 predicted volumes.

1 EPRI RadBench Web enables member LLRW managers to compare, using an Internet browser, their liquid processing volume, waste characteristics, solid waste generation, waste disposition, and effluent performance with relevant sites throughout the industry.

2 Texas Compact BWR reported approximately 147 cubic feet of activated hardware generated every 3 years. This gives a theoretical average generation of 47 cubic feet per year. This calculation was made to estimate the volume of activated hardware could be produced by similar BWR-type reactors over a period of time, however, it should be noted that this waste stream is produced during outages and occurs periodically.

Figure 1: Comparison of Predicted Party State Operational Volumes to Non-Party State Nuclear Utility Operational Volume for 2024



In addition to survey results, six nonparty states provided their own LLRW studies. These studies showed highly variable volumes and activities generated each year, making it difficult to determine if these results can be extrapolated to be representative of the entire 36 states without viable disposal options. However, these reports did have several things in common. All six studies indicated that the majority of radioactive waste that is generated is Class A, and that the majority of this waste is generated by utilities. In addition, all stated that after the Barnwell, S.C. disposal site stopped accepting imported B and C LLRW in June 2008; Class B and C waste has been stored on site awaiting a disposal option.

Based on economic considerations and discussions with nonparty generators about a lack of other options, it can be assumed that nonparty states that get approval for importation will begin to dispose of their Class B and C waste at the Texas LLRW CWF. Due to the availability of other options, and for economic reasons, generators are likely to select disposal options other than the CWF for Class A waste unless there are regulatory or economic changes in Texas that make it economically sensible for generators to send Class A waste to Texas.

The volumes presented above are estimated prior to processing the waste. Processing of waste typically involves volume reduction techniques that can result in volume reduction factors of between 3 and 100, depending on the technique used. For dry active waste, super-compaction and incineration are typically chosen, and have volume reduction factors of 3-10 and 100, respectively. For process waste, such as utility resins and filters, conversion reforming is typically the technique of choice and volume reduction factors between 5 and 33 can be achieved. Conversion reforming is the processing of choice for wet waste for two reasons.

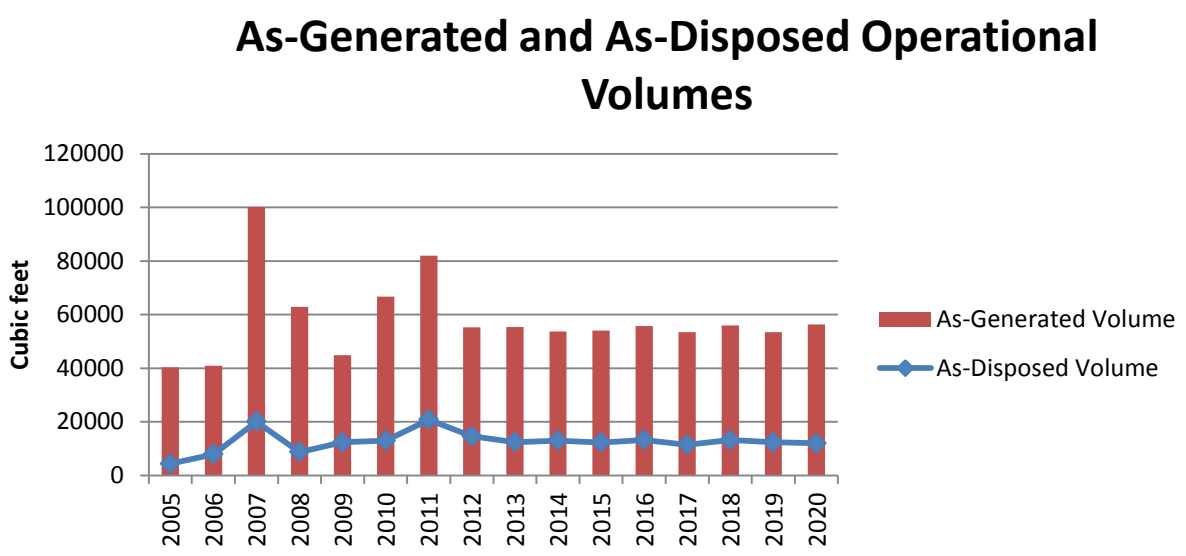
First, it can be very costly to ship unprocessed due to poor packing efficiencies and void spaces. Second, conversion reforming greatly reduces the water content of the wet waste, which, if not reduced, can lead to waste stability issues. However, this technique may concentrate the waste so as to produce a waste form which exceeds the acceptance

criteria of disposal facilities due to certain nuclide concentrations (i.e., could produce waste that is greater than Class C (GTCC) waste). Also of importance to note, is that neither of these predictions takes radioactive decay into account because it is very difficult to predict which radionuclides will be disposed of at what point in time.

It is apparent from the responses to the questionnaires that many generators in the Texas Compact continue to use volume reduction techniques due to the lack of LLRW disposal options in the past. The NRC identified volume reduction as a possible solution to the lack of disposal options beginning in 1981 with their Volume Reduction Policy Statement and generators have applied various volume reduction techniques since that time. The effect of implementing volume reduction techniques on the LLRW generated in the Texas Compact should increase the capacity of the CWF for taking non-party waste. However, the costs for disposal, transportation, and processing will factor into whether a generator of LLRW decides to use volume reduction techniques prior to disposal. Figure 2 illustrates generator responses regarding as-generated volumes verses as-disposed volumes.

In accordance with Section401.208(b)(3), this study also examines the necessity of containerization of LLRW. First, containerization helps maintain the structural stability of the site and the waste form, and can assure that the waste remains in the designated location and is required for some LLRW at Chapter 401 at Section401.218 relating to Disposal of Certain Waste. Second, containerization provides shielding for workers from radiation during operations. Shielding allows the CWF to accept higher activity LLRW while keeping the radiation dose incurred by the workers as low as reasonable achievable. Finally, containerization slows the movement of radionuclides into the environment.

Figure 2: As-Generated verses As-Disposed Volumes for the Texas Compact



In order to evaluate the effects of the volume and radioactivity of the LLRW to be disposed of in the CWF, the Texas LLRW license and applicable rules require a

Performance Assessment (PA) to be conducted. A PA for the CWF is a quantitative analysis used for demonstrating compliance with the following performance objectives:

- protection of the general population from releases of radioactivity;
- protection of individuals from inadvertent intrusion;
- protection of individuals during operations, and;
- stability of the disposal site after closure

Eighty-five (85) radionuclides were considered in evaluating the source term for the CWF. The PA evaluated short-term (i.e., 30 years) exposure for workers and long-term (i.e., 50,000 years) exposure for the public. As part of the long-term evaluation, the modeling accounted for decay of radionuclides over the 50,000 year period of analysis. Note that the decay of radionuclides was not considered for the short-term worker evaluation since radionuclides may be accepted for disposal at any time during the operational period.

The results from the PA show that the dose from the waste inventory (with decay accounted for) is within acceptable limits. It can be further postulated that the doses from the capacity study acquired from Texas Compact generator questionnaires will also be within acceptable limits for the health and safety of the general population considering that the total activity predicted to be generated in only the Texas Compact by 2024 is less than what is currently allowed in the license. In addition, projections through the end of the CWF lifespan to 2044 indicate that it can accommodate Texas Compact waste.

Definitions

Activated Hardware – non-fuel reactor components that have been exposed to neutron radiation and made to be radioactive. Alternatively, irradiated hardware.

Anion – an atom or molecule with more electrons than protons. Anions have a net negative charge.

Bituminization – the process of mixing particles with asphalt (or bitumen) to reduce the risk of inadvertent inhalation of the particles.

Cation – an atom or molecule with more protons than electrons. Cations have a net positive charge.

Commingling – the act of mixing two or more sources of radioactive waste.

Containerization – the act of emplacing waste within a canister or a rectangular or cylindrical reinforced concrete container.

Crud – A colloquial term for corrosion and wear products (rust particles, etc.) that become radioactive (i.e., activated) when exposed to radiation.

Curie – a unit or measure of radioactivity from a certain element or radionuclide. One Curie equals the amount of radioactivity from one gram of Radium-226. Alternatively, one Curie equals 3.7×10^{10} Becquerel or undergoes 3.7×10^{10} disintegrations per second.

Diatomaceous earth – a naturally occurring sedimentary rock made up of fossilized algae, called diatoms.

Decommissioning – the act of removing from service any facilities that were used to store, process, or stage radioactive materials.

Decontamination – the act of removing radionuclides from equipment, structures, or other materials that have been in contact with radionuclides.

Dose - a measure of the energy deposited in a medium by ionizing radiation per unit mass.

Geomechanics – the study of the movement of soils and the subsurface.

Irradiate – the process of exposing materials to ionizing radiation. If the radiation is a neutron beam, the resulting material can become radioactive.

Irradiated Hardware or, alternatively, activated hardware.– non-fuel reactor components that have been exposed to neutron radiation.

Performance Assessment – an annual report required by the TCEQ Radioactive Material License and rules comprising a model or series of models used to quantitatively determine the amount of dose to a human being given a set of plausible scenarios due to the disposal of radioactive materials.

Permeability – a hydrologic characteristic of soils or other porous materials. The permeability is an indication of the ability of a liquid to move through the porous material.

Prediction interval – a statistical technique used to specify with a given confidence level a range of values for some *future* value from a set of past measurements.

Pyrolysis – the decomposition of organic material in the presence of superheated water or steam

Radionuclide – an element from the periodic table that is capable of spontaneously emitting its constitutive particles and thereby changing into another element. Such an element is termed radioactive and the emitted particle is called radiation.

Radon emanation – the process by which Radium decays into Radon, a radioactive gas. As a gas, Radon is transported into the environment quicker than other radionuclides. Thus, it appears as if it is emanating.

Rem – a unit of dose.

Slumping – a loss of structural integrity, usually in soils, due to excess water.

Transuranic – a term usually referring to radionuclides (or elements) with the number of protons greater than that of Uranium. These radionuclides are typically not found in nature.

References

List of Figures

Figure 1: Comparison of Predicted Party State Operational Volumes to Non-Party State Nuclear Utility Operational Volume for 2024 4

Figure 2: As-Generated verses As-Disposed Volumes for the Texas Compact 5

Figure 3.1: Decay of Initial Radioactivity of Common Radionuclides over Time by Half Life 20

Figure 3.2: Predicted Annual License Term Operational Volumes 26

Figure 3.3: Predicted Annual Site Life Span Operational Volumes..... 26

Figure 3.4: Predicted Texas Compact LLRW Volume Generation between 2012 and 2020 Distribution by Sector 27

Figure 3.5: Texas Compact Activity by Generator Sector 28

Figure 3.6: Texas Compact Activity Utility v Non-Utility 2012-2020 Predictions..... 28

Figure 3.7: Reported Texas Compact Utility Volume Variation 29

Figure 3.8: Reported Texas Compact Utility Activity Variation 30

Figure 3.9: Comparison of Predicted Party State Volumes to Nonparty State Utility Operational Volume for 2024 36

Figure 3.10: Nonparty Disposal Volume Between January 2000 and June 2008 [MIMS] 36

Figure 3.11: Nonparty Disposal Activity Between January 2000 and June 2008 [MIMS] 36

Figure 3.12: As-Generated Volumes Compared To As-Disposed Volumes for the Texas Compact 40

Figure 4.1 Cross Section of Cylindrical MCC from WCS LLRW License Application 43

Figure 4.2: Diagram of MCC Stacks from WCS LLRW License Application..... 44

Figure 4.3: Source Volume Unshielded and Shielded [MicroShield®]..... 45

Figure 5.1: A Schematic of the Various Pathways Analyzed in a Performance Assessment..... 48

List of Tables

Table 1.1: Future Capacity Needs of the Texas Compact.....13

Table 2: US Industry Average Annual LLRW Generation Rate for Nuclear Utilities 3

Table 3.1: Operational Waste Predictions 22

Table 3.2: Predicted Generated Operational Volumes by Sector 2012-2020..... 23

Table 3.3: Predicted Utility Decommissioning Volumes 24

Table 3.4: Predicted Future Units Operational and Decommissioning Volumes 24

Table 3.5: Total Volumes Projected in Texas Compact 25
Table 3.6: Activities Reported on Questionnaire by Generator Sector.....27
Table 3.7: Non-Utility Operation Waste Predictions 29
Table 3.8: Activity Prediction for Texas Compact Utilities.....31
Table 3.9: Decommissioning Activities for Current Utilities.....31
Table 3.10: Operation and Decommissioning of Future BWR units 31
Table 3.11: Total Activity Needs of the Texas Compact 2024 and 2044..... 32
Table 3.12: US Industry Average Annual Generation Rate (ft3/unit) 33
Table 3.13: Activity Concentration by Waste Stream for Utilities [EPRI]..... 34

1. Introduction

1.1 Background and Summary

In 2011, The Texas Legislature passed Senate Bill 1504, which charged the Texas Commission on Environmental Quality (TCEQ) with conducting "a study on the available volume and curie capacity of the compact waste disposal facility (CWF) for the disposal of party state compact waste and nonparty compact waste." Now codified in Chapter 401 at Section401.208, this study of capacity requires TCEQ to consider and make recommendations on the future volume and curie capacity needs of party state and nonparty state generators, a calculation of radioactive decay related to the CWF and radiation dose assessments based on curie capacity, an investigation of the necessity of containerization of waste, the effects of the projected volume and radioactivity on the health and safety of the public, and the costs and benefits of volume reduction for low-level radioactive waste (LLRW).

In conjunction with complying with the above statutory elements of the capacity study, this report also covers other topics incidental to capacity concerns. TCEQ offers a brief history of LLRW disposal in the United States and the Texas Compact; TCEQ identifies commercial LLRW and other radioactive wastes and materials that might be disposed of at a LLRW disposal facility. TCEQ describes LLRW generation and generator waste disposal activities in the Texas Compact and the rest of the United States. TCEQ projects total LLRW generation for the license period of 15 years and the site life span of 35 years.

1.2 Definition and Classes of Low Level Radioactive Waste

LLRW is defined in Texas Law with cross references to United States Nuclear Regulatory Commission (NRC) and other Texas state agency rules. LLRW is defined by what it is and by what it is not in Texas Health and Safety Code Section401.004:

It is:

- discarded or unwanted and is not exempt by board rule adopted under Texas Health and Safety Code Section401.106;
- waste, as that term is defined by Title 10, Code of Federal Regulations (10 CFR) Section61.2; and
- subject to concentration limits established under 10 CFR Section 61.55, or compatible rules established by the Texas Department of State Health Services (TDSHS) or TCEQ, as applicable.,.

It is not:

- high-level radioactive waste;
- spent nuclear fuel;
- by-product material;

- naturally occurring radioactive material (NORM) waste; or oil and gas NORM waste.

LLRW is classified for disposal as either Class A, Class B, or Class C waste according to a number of regulatory classification methods set forth in 10 CFR Section 61.55. Basically, Class A is the least radioactive, i.e. least hazardous, and Class C is the most radioactive, i.e. most hazardous. All classes of LLRW may contain either short-lived or long-lived radionuclides, or a combination of both. LLRW is generated in connection with normal activities that involve radioactive materials in locations such as:

- Nuclear power plants;
- Hospitals;
- Laboratories;
- Industries that manufacture and use radioactive materials;
- Institutions of higher learning; and
- State and local governments.

1.3 LLRW Volume and Radioactivity Projections

Radioactivity projections for this report were based on the results of a capacity survey conducted by the TCEQ. The Texas Compact LLRW generators were surveyed and the expected volume of waste over the life-span of the CWF was calculated. The CWF was licensed in 2009 for 15 years until 2024; however the total lifespan of the facility is 35 years, the original 15 year term plus two 10-year renewal periods. Of the hundreds of radioactive material licensees in the Texas Compact, approximately 200 were identified as potential LLRW generators. The remaining facilities that are licensed for radioactive materials in the party states were not identified as potential LLRW generators because they generate waste that either does not require LLRW disposal or is prohibited by the license.

Of the generators identified, five nuclear utility units generate in excess of 90 percent of the Texas Compact LLRW volume and more than 95 percent of the Texas Compact LLRW radioactive inventory. In addition to the five existing utility units, two additional units are currently in the United States Nuclear Regulatory Commission (NRC) licensing process and are anticipated to be in operation after 2020 within the Texas Compact. All capacity predictions provided by this study show the disposal needs of the Texas Compact with and without these future units taken into account.

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	Millions of cubic feet	Millions of Curies
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2044 Operating	0.816	0.376
Decommissioning	1.557	0.550
Total (2044)	2.373	0.926
Combined Total (2044)	5.223	1.736

The reported volumes are prior to any volume reduction as generator responses indicated that business decisions regarding waste processing are largely driven by economics and can change at any given time.

2. History of Low-Level Radioactive Waste Disposal in the United States

The history of Low-Level Radioactive Waste management in the United States is essential to understanding the matter of the CWF capacity in Texas. Prior to 1954, the U.S. Government controlled all atomic energy and activities and facilities. However, the Atomic Energy Act (AEA) of 1954 created a framework for civilian participation in the atomic field and the industrial use of radioactive materials by private industry to be regulated by the U.S. Atomic Energy Commission (AEC). Under the AEA framework, many private entities began using radioactive materials in industry, medicine, science, and research. Because of the now widespread use of radioactive materials, the AEA also authorized the AEC to enter into an agreement with any state or group of states to perform regulatory inspections or other regulatory functions on a cooperative basis, as the Commission deemed appropriate. The State of Texas entered such an agreement with the NRC (AEC's successor) in 1963.

To address the issue of the disposal of LLRW, Congress passed the LLRWPA (Public Law 96-573) (42 U.S.C. Sections 2021b-2021j). This statute creates a regional approach to LLRW disposal by providing that LLRW produced by non-DOE activities would be managed on a state or regional level. It encouraged the formation of regional compacts and in each compact one state would be designated as the host state of a disposal facility.

2.1 History of LLRW Disposal Outside Of Texas

The first commercial site for the disposal of LLRW opened in Beatty, Nevada, in 1962. Within the next 10 years, five more sites opened in Washington, Illinois, South Carolina, New York, and Kentucky. Between 1975 and 1979, three of the six commercial LLRW disposal sites in the U.S. closed. The site at Sheffield, Illinois, was closed when it was filled and the site operator withdrew an application for site expansion. Two other sites, located at West Valley, New York, and Maxey Flats, Kentucky, were closed because of operational and water management problems. The states of the three remaining sites, located in Beatty, Nevada; Richland, Washington; and Barnwell, South Carolina, grew concerned over the volumes of LLRW being sent for disposal. Over time, these states closed or restricted the use of the commercial LLRW facilities to generators within their respective compacts or jurisdictions. Prior to the CWF opening and the recent changes in law and rules regarding importation of nonparty LLRW, most facilities throughout the United States that generate LLRW had limited to no options for safe disposal of their LLRW.

2.2 History of LLRW Disposal in Texas

In 1981, the Texas Legislature created the Texas Low-Level Radioactive Waste Disposal Authority (TLLRWDA) to site, develop, operate, close, and decommission a Texas LLRW disposal facility. And in 1993, Texas, Vermont and Maine approved legislation for the formation of the Texas Compact. By 1998, the TLLRWDA had chosen a site along with a design of the facility to dispose of LLRW. The Texas

Natural Resource Conservation Commission (TNRCC) was given the authority to review the application, but denied the TLLRWDA the license to dispose of LLRW. By 2000, the TLLRWDA was disbanded. And in 2002, the Maine Legislature passed emergency legislation to repeal the enactment of the Texas Compact, due to the early closing and decommissioning of the state's only nuclear reactor, Maine Yankee. The Texas Compact is now composed of Texas and Vermont.

In 2003, the Texas Legislature passed H.B. 1567, which amended Texas Health and Safety Code provisions regarding the siting and operation of commercial LLRW disposal facilities for the Texas Compact and for federal facilities' waste. The legislation allowed for the creation of two privately run waste disposal facilities to be licensed by the TCEQ. One facility (later termed the Federal Waste Facility Disposal Facility or FWF) disposes of federal facility waste, as defined by the LLRWPA of 1980 and its 1985 amendments, subject to certain specified conditions. The other, adjacent facility (later termed the Compact Waste Disposal Facility or CWF) disposes of commercial low-level radioactive waste from Texas Compact generators.

After five years of technical review, the TCEQ Executive Director offered a draft license and the draft Environmental Analysis for public comment and opportunity for a public hearing. And on September 10, 2009, the TCEQ Executive Director issued a low-level radioactive waste disposal license to Waste Control Specialists LLC (WCS). Construction of the CWF was completed in 2012 and the TCEQ authorized the commencement of disposal operations at the CWF on April 25, 2012.

Texas Law in SB 1504(82nd Session, 2011), codified in the Texas Health & Safety Code in Chapter 401 at Section 401.207, allows for a system of importation of nonparty waste into the CWF. The Texas LLRW Disposal Compact Commission also promulgated rules regarding importation in both 2011 and 2012, which includes TCEQ certification through a written evaluation that the waste is authorized for disposal under the license. Section 401.207 also creates limits on the initial licensed capacity of the CWF.

3. Commercial Radioactive Waste Generation in the United States

3.1 Low-Level Radioactive Waste Classification

3.1.1 LLRW Classes

Low-level Radioactive Waste is comprised of three classes: A, B and C. Texas laws regarding radioactive waste are found in Texas Health & Safety Code (THSC) at Chapter 401, relating to Radioactive Materials and Other Sources of Radiation, Subtitle D. Nuclear and Radioactive Materials. Chapter 401 includes numerous cross references to NRC regulations at 10 CFR Part 61. Chapter 401 enabled rulemaking by TCEQ in Title 30, Texas Administrative Code Chapter 336. These authorities set forth various requirements and methods for radioactive waste classification and protective measures to protect human health and the environment.

In accordance with NRC compatibility standards and in accordance with Texas laws, the TCEQ has adopted similar but not identical LLRW classification requirements and radionuclide concentration limits for each class. The NRC classification method for institutional control includes methods for how to stabilize the waste in various accident scenarios and safeguards to protect an inadvertent intruder. The TCEQ has adopted LLRW classification requirements that are equivalent to the NRC's with one exception. The NRC waste classification tables do not include radium-226 (226Ra). The Class C limit for 226Ra in 30 TAC Section 336.362, Appendix E is 100 nanocuries (nCi) per gram. The purpose of inclusion of a 226Ra concentration limit in the TCEQ waste classification tables was to provide an additional layer of safety for inadvertent intrusion, reduce radon emanation, and meet through performance objectives over the long-term.

In order to protect human health and the environment, TCEQ and NRC rules require the land owner or custodial agency to meet requirements called institutional controls. Institutional controls are designed to minimize human contact with the waste through periodic surveillance, physical barriers, and environmental monitoring for contaminant migration.

The various classes of radioactivity require increasing controls commensurate with their increasing radioactivity as required by TCEQ statutes, rules and the CWF license conditions. Class A is only required to meet the minimal institutional control requirements because it is of a lower concentration. Class B LLRW has a higher concentration of key radionuclides than that of Class A LLRW and its waste forms must meet more rigorous requirements to ensure stability after disposal. The physical form and characteristics of Class B LLRW must meet both the minimum and additional stability requirements intended to ensure that the waste does not degrade and affect the overall stability of the site through slumping, collapse, or other failure of the disposal unit, thereby leading to an increase in water infiltration. Further, Class B waste must be placed in a reinforced concrete canister or an equivalent alternative for disposal.

Class C LLRW has the highest concentration of key radionuclides acceptable for near-surface disposal and its waste forms not only must meet the more rigorous requirements to ensure stability, but also requires additional measures at the disposal facility, such as burial depth and engineered barriers, to protect against inadvertent intrusion. The physical form and characteristics of Class C LLRW must meet both the minimum and additional stability requirements. Like Class B waste, Class C LLRW must be placed in a reinforced concrete canister or an equivalent alternative for disposal.

LLRW that exceeds the radionuclide concentration limits specified for Class C waste is not generally acceptable for near-surface disposal. Such waste, usually referred to as "greater than Class C" (GTCC), is waste for which waste form and disposal methods must be different, and in general more stringent, than those required for Class C waste. Because disposal of this waste is not authorized for disposal in the license for the CWF, GTCC waste is not evaluated in this report.

3.1.2 Waste Stream Concept

Wastes can be generated as part of current operating procedures (operational LLRW) or as a result of decontamination and decommissioning activities (decommissioning LLRW).

Waste streams with similar characteristics generally can be managed in a similar manner. For the purposes of this report, LLRW generators were asked to supply radiological and volume information for specific waste streams as defined by the NRC. It is expected that wastes assigned to these waste streams are likely to exhibit similar physical and chemical characteristics regardless of the generator. While operating activities may differ from site to site, waste within a given waste stream generally exhibits similar characteristics.

The waste streams can be divided into three general categories: dry waste, process waste, and decommissioning waste. Dry and process waste is considered operational waste.

3.1.2.1Dry Waste Stream

The dry active waste category consists of six waste streams:

- Compactable trash (COTRASH)
- Non-compactable trash (NCTRASH)
- Non-fuel reactor components (NFRCOMP)
- Sealed Sources (SOURCES)
- High activity waste (HIGHACT)

3.1.2.2 Process (Wet) Waste Streams

Process wastes are those generated from industrial and commercial processes common to the various industries and institutions using radioactive material and producing LLRW. Under both federal and TCEQ disposal regulations and as required by the CWF license, any wastes from wet processes would have to be treated to remove free liquids before they could be accepted at a CWF.

The process (wet) waste category consists of eleven waste streams:

- Reactor water cleanup powder resins (RWCUPRS)
- Reactor water demineralization resins (RWDMRES)
- Secondary system resins (SSYSRES)
- Decontamination resins (DECONRS)
- Floor drain filter sludge (FLDRFSL)
- Fuel pool filter sludge (FPFILSL)
- Condensate filter sludge (CONDFSL)
- Process filters (PROCFIL)
- Low activity waste (LOWASTE)
- Biological waste (BIOWAST)
- Absorbed Liquids (ABSLIQD)

3.1.2.3 Decommissioning Waste

Decommissioning waste is generated when facilities have ceased operation involving radioactive materials and wish to be released to the public for other uses. These facilities must be decontaminated and decommissioned for this to occur. As an example, when a nuclear power facility is permanently shut down, any waste that cannot be decontaminated must be disposed of as decommissioning waste. This waste stream is called Decommissioning Waste (D&D).

Detailed descriptions of these waste streams can be found in Appendix A.

3.1.3 Decay and Life of LLRW

A radionuclide's half-life is the amount of time it takes for its radioactivity to decrease by one half. As shown in Figure 3-1, the extent to which the total amount of radioactivity of a given LLRW declines over time depends upon the half-lives of the radionuclides contained in the waste. Radioactive constituents that could potentially be released from LLRW after disposal at a facility must not produce doses exceeding the regulatory limit of 25 millirems per year, therefore, longer-lived radionuclides are required to be evaluated in a site-specific performance assessment (PA) to determine the maximum amount of activity that can be received in order to keep the peak dose below the regulatory limit. This concept will be discussed further in Section 5.

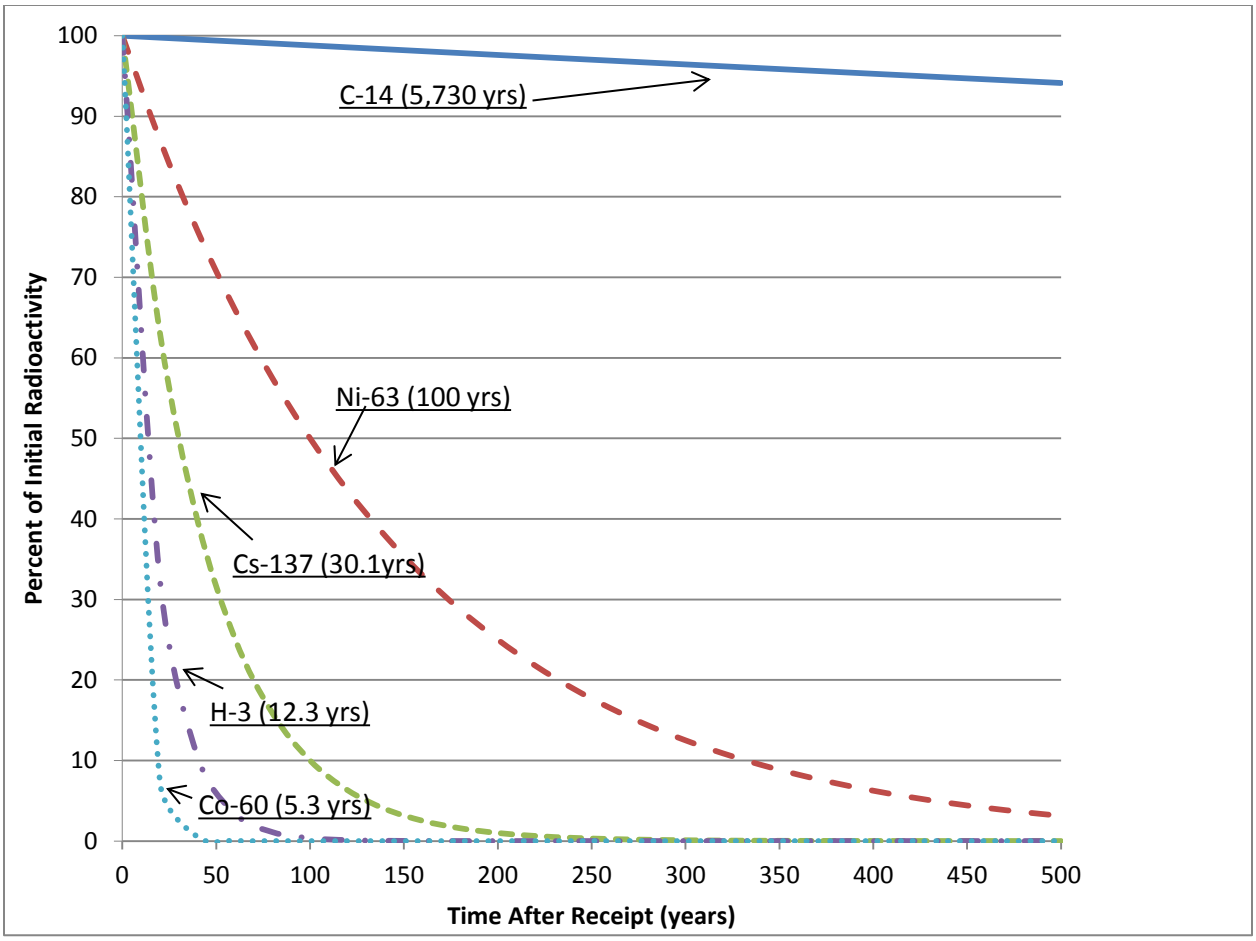


Figure 3.1: Decay of Initial Radioactivity of Common Radionuclides over Time by Half Life

3.2 Commercial Radioactive Waste Generation In Texas and Vermont

3.2.1 Technical Approach for LLRW Projections

TCEQ worked with the Texas Department of State Health Services (TDSHS) and the Vermont Department of Health to determine the potential universe of Texas Compact generators. The TDSHS provided a list of 175 potential waste generators, including academic, medical institutions and industrial companies. The Vermont Department of Health provided a list of 25 potential waste generators. Starting in February 2012, detailed questionnaires were provided to the 200 potential Texas and Vermont generators requesting information on historical and future LLRW generation, treatment, shipment, and disposal. In addition, seven Veterans Health Administration hospitals in the Texas Compact were identified and contacted, as well as the military bases located in the Texas Compact. Since many waste streams are unique to nuclear power stations (e.g., reactor components, ion-exchange resins) two questionnaires were developed: one for nuclear utilities and one for non-utilities.

However, other than differences in the waste streams identified, both questionnaires requested the following information:

- Historically as-generated volumes and radioactivity for the years of 2005 through 2011 (by waste stream).
- Projected as-generated volumes and radioactivity expected to require disposal between 2012 and 2020 (by waste stream).
- Processing performed on each waste stream, including volume reduction estimates.
- Historical and projected as-disposed volumes of LLRW shipped directly to a disposal facility (by waste stream).
- Historical and projected as-disposed volumes of LLRW shipped to a waste broker before disposal (by waste stream).
- Types of containers used to ship LLRW for disposal (by waste stream).
- Radioactivity by radioisotopes for the year 2005 and the year 2011, or the average radioactivity by isotope per year for 2005-2011 and projected average radioactivity by isotope per year for 2012-2020 (by waste stream and waste class).
- Recent and planned changes to facility processes if they influence LLRW generation.
- Current volume of LLRW in storage and anticipated LLRW volume in storage in January 2013.
- Facility decommissioning policies and plans.

Although most were not LLRW generators, it was possible to successfully identify the generators that will most likely contribute the most volume and radioactivity. If questionnaire responses required additional follow-up, generators were contacted by telephone and email to clarify their responses and gain additional insights into their LLRW generation projections.

The response rate from potential generators within the entire Texas Compact was greater than seventy percent; one hundred and fourty-six (146) responded, with sixty seven (67) reporting LLRW generation, out of two hundred and seven (207) letters mailed. The current questionaire responses revealed that not all generators produce low level radioactive waste requiring disposal within the CWF or produce waste that is prohibited from being disposed in the CWF.

3.2.2 Volume Predictions

To calculate the license and site term predicted volumes and activity of LLRW, four main sections were logged: generated waste volumes and activities, disposed waste volumes either directly or by broker / processor, current volume in storage, and radionuclide identification. Predictions through 2024, the expiration year for License Number R04100, and 2044, the life span of the disposal facility, were made based on respondent information. The equation used to predict volumes and activities into the year 2024 and 2044 is as follows:

$$Prediction\ Interval = \bar{X} \pm T_{\left(\frac{\frac{\alpha}{L}}{2},(n-1)\right)} S\sqrt{1+\frac{1}{n}}$$

where $\bar{X}$ is the sample average. In this case the respondent predicted waste volumes and activities from year 2012-2020 were used to determine the sample average. The term:

$$T_{\left(\frac{\alpha}{\frac{t}{2}},(n-1)\right)}$$

acts as a critical value for the T distribution given a certain level of confidence (1-α), (n) is the number of samples, (t) is the number of years that are being projected to in the future and (S) is standard deviation of the waste volumes and activities. The level of confidence used was 95%. The result is an interval where future volumes and activities should fall between the upper and lower bound numbers with the chosen level of confidence.

All of the licenses for the nuclear utilities within the Texas Compact are set to expire well before 2044; the last of the five licenses expires in 2033 and it was assumed that each utility will operate until their license expires and then they will commence decommissioning. This means that each nuclear utility will discontinue operational LLRW generation at different points in time after 2024. Therefore, to calculate the projected operational volume expected to be generated by 2044, the prediction interval was performed on each nuclear utility separately and then the total expected operational LLRW volume for each nuclear utility was combined with the predicted non-utility operational total. None of the non-utility respondents reported planned decommissioning before 2044.

Total reported volumes of LLRW are in the table below.

Table 3.1: Operational Waste Predictions

	Volume [cubic feet] [3]			
Total anticipated in storage by January 2013	19,500			
Total predicted to be generated between 2013-2020	471,000			
Total generated by 2020	491,000			
2024 Prediction				
Average annual volume generation	59,000			
Lower Bound of annual volume generation	53,400			
Upper Bound of annual volume generation	64,500			
Total operational volume range predicted	704,600 to 749,000			
2044 Prediction	Utility 1	Utility 2	Utility 3	Non-Utility
License Expiration Date	2032	2027/2028	2030/2033	
Lower Bound of annual volume generation	12,106	20,511	13,874	2,387
Upper Bound of annual volume generation	23,192	21,034	14,466	10,332
Total operational volume range predicted	984,163 to 1,318,605			

Figures 3.2 and 3.3 illustrate the results of the statistical prediction analysis. The data between 2012 and 2020 represent the data obtained from the questionnaires, while the data after 2020 depicts the upper and lower bounds calculated from the prediction interval equation. Compact non-utility waste

3 Based from 2012-2020 questionnaire data and have been rounded to the nearest one hundredth

volumes average approximately 6,000 cubic feet through the year 2020, while average utility waste volume is approximately 52,600 cubic feet. The nuclear utility waste volume is a substantial portion, suggesting that the utility waste may very well be the driving factor in the future volume projections. The vast majority of waste volume is considered Class A, followed by Class B and Class C.

Within the individual generator categories, the following table shows the volume in cubic feet predicted by the respondents to be generated between 2012 and 2020:

Table 3.2: Predicted Generated Operational Volumes by Sector 2012-2020

Sector	Predicted Volume [cubic feet]
Academic	4,542
Industry	5,823
Medical	44,950
Utility	473,324
Total	528,639

Figure 3.4 graphically depicts low level radioactive waste generated volumes by sectors. This figure illustrates that the nuclear utilities make up approximately ninty percent (90%) of the predicted operational waste in the Texas Compact.

Decommissioning waste volume projections were provided by all party state utility generators who responded and were included in the site life span volume and activity predictions. For the units that are currently in operation, an estimated 1.67 million cubic feet of decommissioning waste was predicted. Four (4) of the five (5) units in operation are Pressurized Water Reactors (PWR), while the fifth is a Boiling Water Reactor (BWR). Typically, BWRs produce a larger volume of low level radioactive waste upon decommissioning because steam is produced directly within the reactor pressure vessel itself.

The steam is then capable of spreading radioactive activation and fission products throughout the system including piping, turbine housing, steam condenser units, pumps, and anywhere else water can accumulate. Conversely, PWRs typically produce less waste because of the separate steam generation loop; this allows contaminated water within the core loop to remain separate from the overall system.

Generated steam should be free of contamination, thus reducing low level radioactive waste production. The volume reported by the conventional party state PWRs take into account volume reduction through processing and survey and release with respect to the volume of waste disposed of in a licensed facility.

However, two of the PWRs in the Texas Compact have a unique design which produces an additional volume of decommissioning waste that some other power plants do not have. The volume reported by this non-conventional utility is pre-volume reduction. The reported estimated decommissioning volumes are displayed in the table below.

Table 3.3: Predicted Utility Decommissioning Volumes

Unit	Predicted Volume [cubic feet]
BWR	348,220
Two conventional PWRs	233,984
Two unconventional PWRs	1,092,116
Total	1,674,320

Source: Responses to Questionnaires

There are currently two future nuclear power units in the licensing process with the NRC. These units are BWR-type reactors, and will therefore produce a higher volume of waste at decommissioning than the conventional PWR-type. These units are not anticipated to have completed construction activities and be producing waste prior to 2020. An assumption used in the calculation of the future unit's waste was that if these units begin operation in 2020, there is little chance that they will be decommissioned by 2024. Therefore, decommissioning of future units was only accounted for in the 35-year site life-span. Data submitted by this utility is summarized in the table below.

Table 3.4: Predicted Future Units Operational and Decommissioning Volumes

	Volume [cubic feet]
Predicted annual operational waste	34,000
Predicted total decommissioning waste[4]	1,556,587
Predicted additional waste 2021-2024[5]	136,000
Predicted additional waste 2021-2044[6]	2,370,043

The total expected volume of Texas Compact LLRW that will require space in the Compact Waste Disposal Facility by 2024 and 2044 is displayed in the table below.

4 Assumes no volume reduction
5 Four years operational waste
6 Twenty-four years operational waste plus decommissioning

Table 3.5: Total Volumes Projected in Texas Compact

	Millions of cubic feet
Licensed Volume	2.31
Existing Facilities	
2024 Operating	0.73
2044 Operating	1.15
Decommissioning	1.70
Total (2044)	2.85
Possible New Facilities	
2024 Operating	0.136
2044 Operating	0.816
Decommissioning	1.557
Total (2044)	2.373
Combined Total (2044)	5.223

All predicted volumes reported, with the exception of the conventional PWR units, are pre-volume reduction. Currently, Radioactive Material License R04100 authorizes 2.3 million cubic feet of LLRW for disposal in the 15-year term.

Figure 3.2: Predicted Annual License Term Operational Volumes

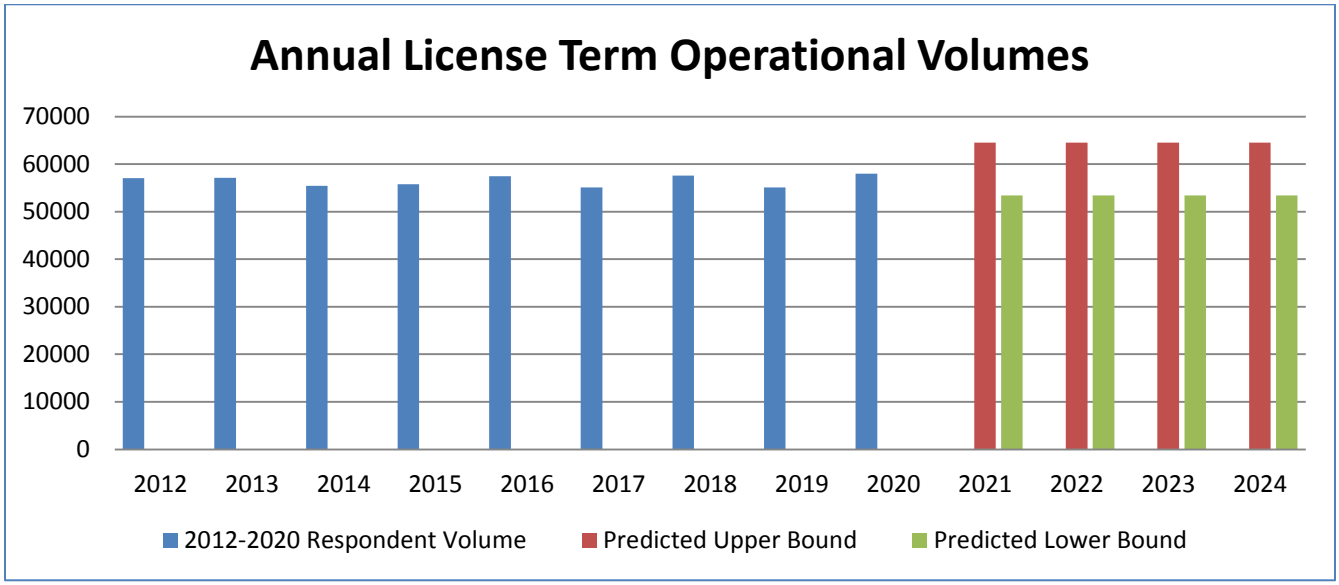


Figure 3.3: Predicted Annual Site Life Span Operational Volumes

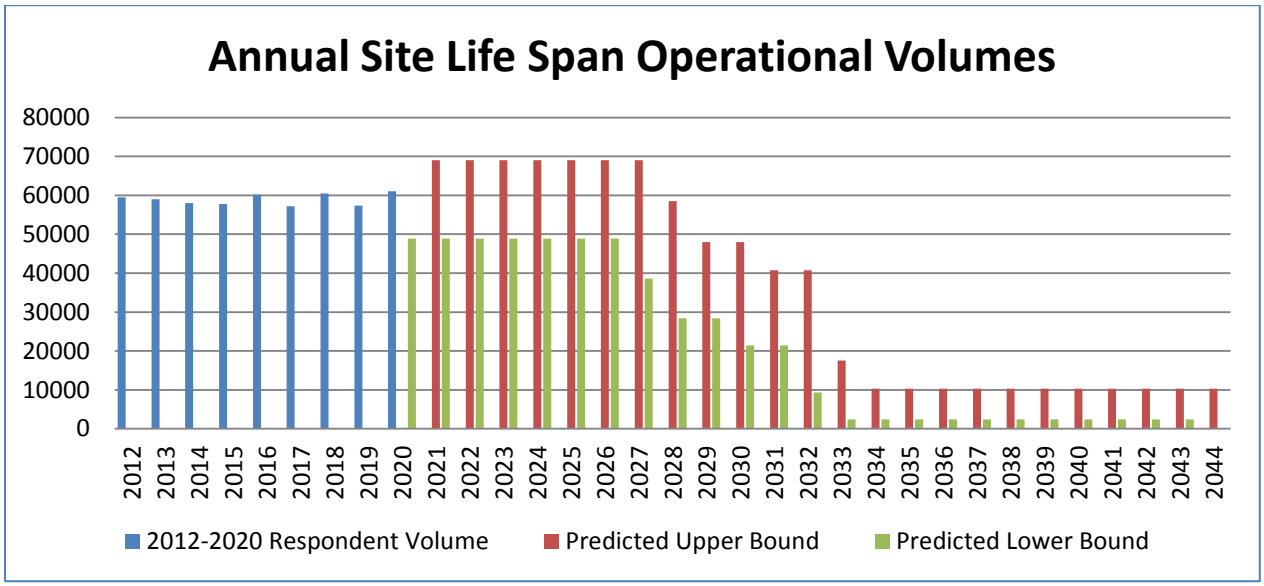
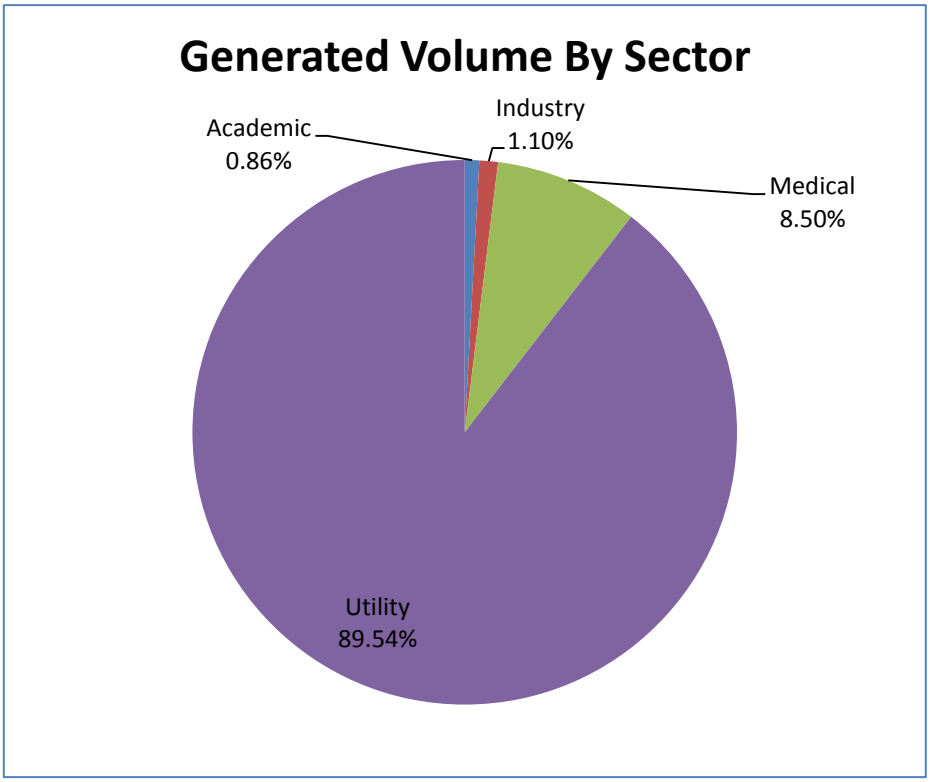


Figure 3.4: Predicted Texas Compact LLRW Volume Generation between 2012 and 2020 Distribution by Sector



3.2.3 Activity Predictions

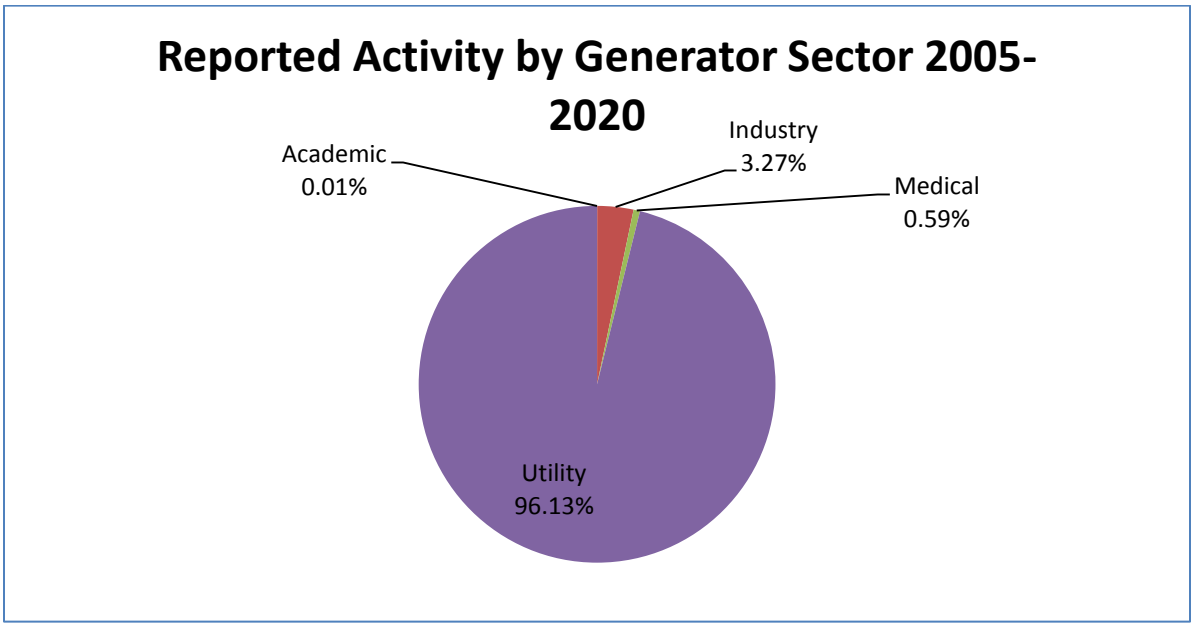
The TCEQ LLRW disposal license limits the amount of radioactivity that may be disposed of at the site to 3,890,000 Ci. As established in the discussion above, the majority of radioactivity produced within the Texas Compact originates with the utility generators. LLRW activity varies from each generator type, with academic producing the least and utilities producing the most. The activity resulting from operation and decommissioning of utility plants varies greatly from year to year.

Radioactivity predictions for 2024 and 2044 were made in a similar manner as those for the waste volumes. The following table shows the activites, by sector based on questionnaire responses, for the years 2005-2020. This data is shown in figure 3.5.

Table 3.6: Activities Reported on Questionnaire by Generator Sector

Sector Activity Generation 2005-2020	Activity [Ci]
Academic	11
Industry	3,266
Medical	586
Utility	95,882
Total	99,745

Figure 3.5: Texas Compact Activity by Generator Sector



Between 2012 and 2020, it is predicted that Texas compact non-utilities will generate 3,300 Ci of LLRW and the utilities will generate 56,762 Ci of operational LLRW, totaling approximately 60,062 Ci. The breakdown for predicted activities is shown in figure 3.6.

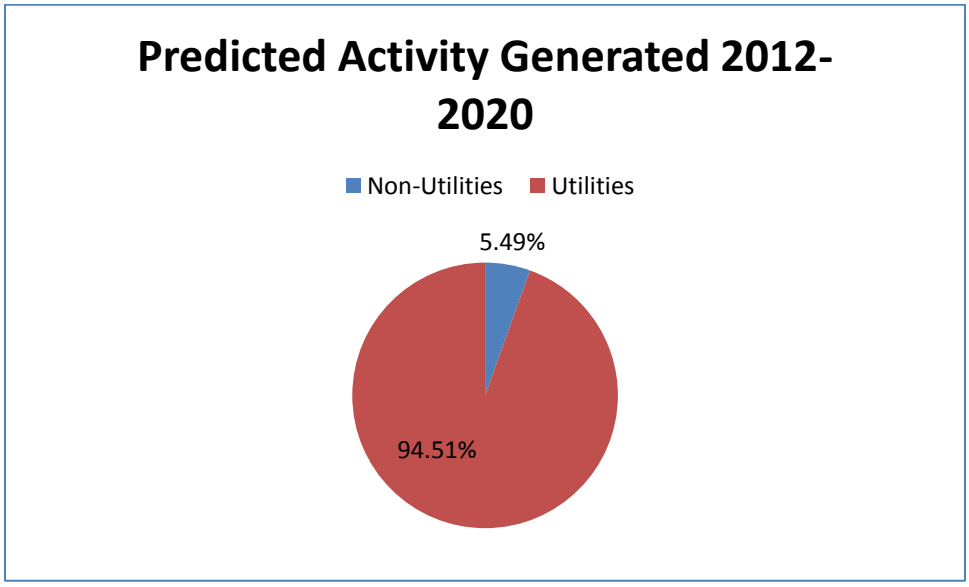


Figure 3.6: Texas Compact Activity Utility v Non-Utility 2012-2020 Predictions

The same prediction interval equation used for the volume prediction was applied to the responses for years 2012-2020 to project the activity generation for

2024 and 2044. The upper and lower bounds of the predicted activity generation for the non-utilities in the Texas Compact are shown in the table below.

Table 3.7: Non-Utility Operation Waste Predictions

	Activity [Ci] [7]
Average annual activity generation	364
2024 Prediction Interval	328 - 400
2044 Prediction Interval	314 - 413

The Texas Compact utilities predicted radioactivity generation with more variability than for the non-utilities. The variability in the utility predictions is due to the cyclical nature of utility waste generation because of outages. Outages typically occur every few years, and in the case of the BWR in the Texas Compact, high activity irradiated hardware that is not typically generated, will be generated during these outages, or down times. This effect was not considered in the volume statistical prediction interval because the additional volume from these outages is not as significant as the additional radioactivity. Figures 3.7 and 3.8 depict the predicted volume and activity generation for 2012 to 2020 from Texas Compact utility generators.

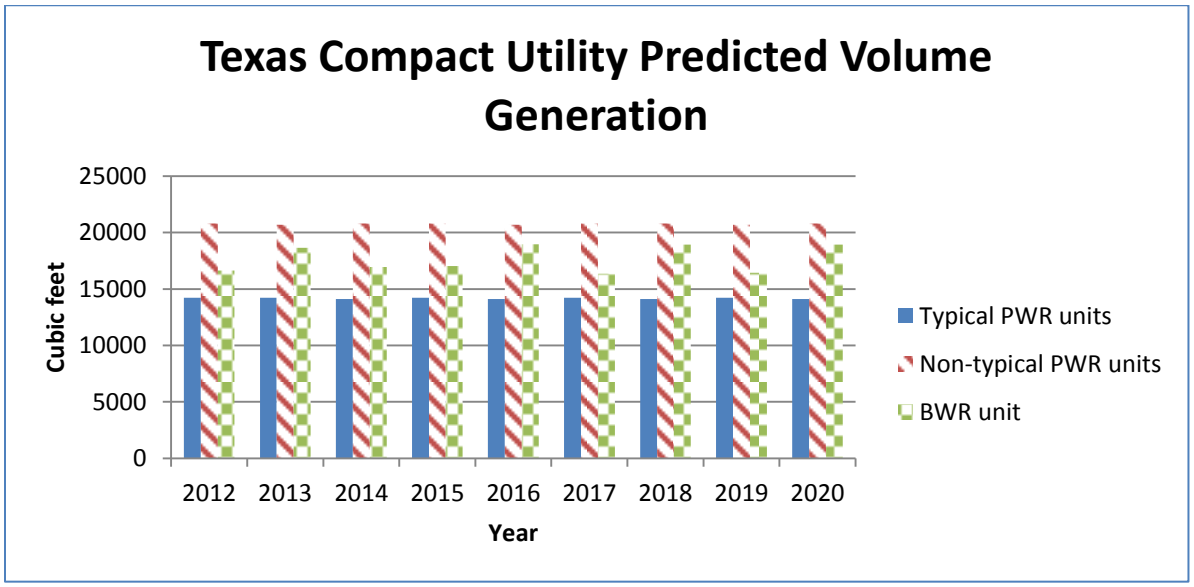


Figure 3.7: Reported Texas Compact Utility Volume Variation

7 Based on 2012-2020 questionnaire data and have been rounded to the nearest one hundredth

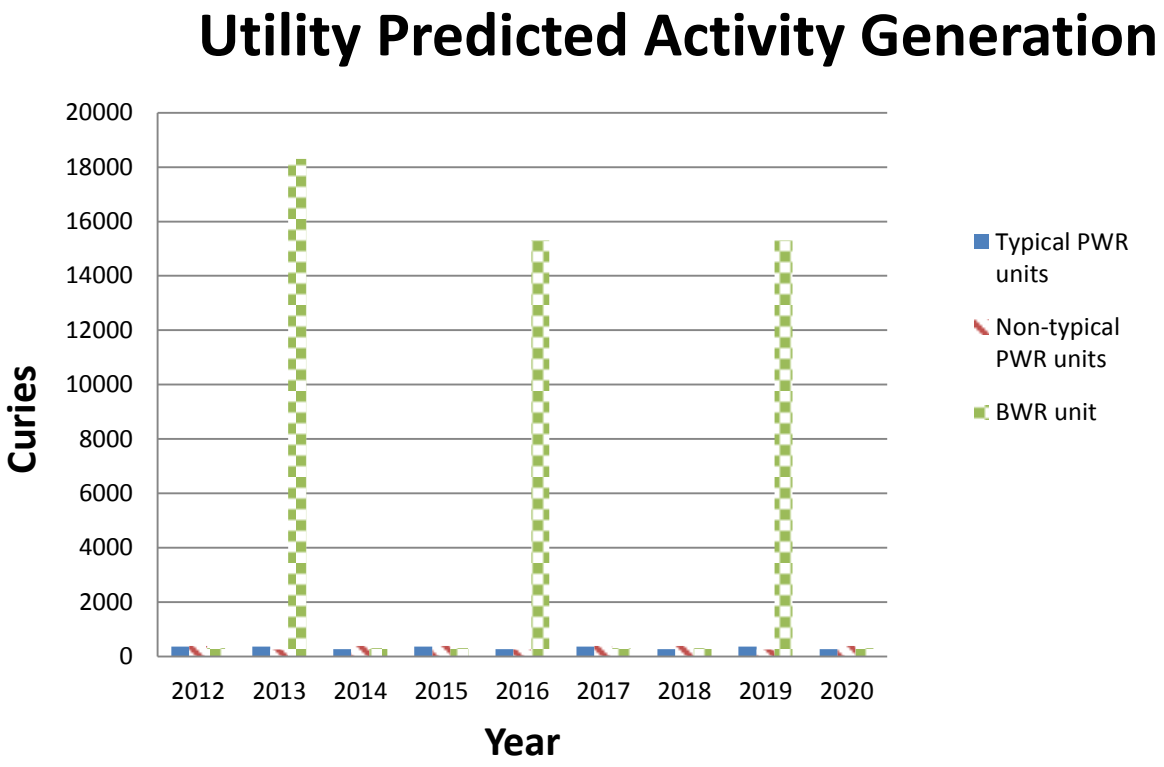


Figure 3.8: Reported Texas Compact Utility Activity Variation

The response from questionnaire data submitted by the BWR utility shows that an outage occurs every third year, with an average of 16,000 additional Ci being generated. Therefore, the statistical prediction interval was calculated using all of the waste streams except irradiated hardware, and then the average activity of irradiated hardware was added back in three year increments.

The average activity, excluding irradiated hardware, was 1,337 Ci, with an upper annual bound of 1,643 Ci and a lower annual bound of 1,031 Ci for 2024. The four years between 2020 and 2024 calculated with the prediction interval were summed with the amount of operational radioactivity predicted to be generated between 2012 and 2020. As the BWR utility will likely have an outage, and thus generate irradiated hardware, between the years 2020 and 2024, the average activity of irradiated hardware for one year was also included. This calculation gives a projected total operational radioactivity in the CWF of 0.078 to 0.082 million Ci. For 2044, as it was assumed that each utility will operate until their current license expires and then decommission, the bounds and totals were calculated separately for each utility, and then summed. The total operational radioactivity generated by 2044 was calculated to be between 0.135 and 0.148 million Ci if four years of outages are included (2022, 2025, 2028, 2031 – the BWR unit license expires in 2032). Neither of the predictions takes radioactive decay into account because it is very difficult to predict which radionuclides will be disposed of at what point in time. These calculations are summarized in the table below.

Table 3.8: Activity Prediction for Texas Compact Utilities

2024	**Activity [Ci]**			
Annual average, excluding irradiated hardware	1,337			
Lower bound 2024	1,031			
Upper bound 2024	1,643			
One outage (2022)	16,000			
Total activity range needing space 2024	0.078 to 0.082 million			
2044	Utility 1	Utility 2	Utility 3	Non-Utility
License Expiration Date	2032	2027/2028	2030/2033	
Lower bound 2044	285	62	75	314
Upper bound 2044	331	627	568	413
Four outages (2022, 2025, 2028, 2031)	64,000			
otal activity range needing space 2044	0.135 to 0.148 million			

Predicted decommissioning radioactivity for the current utilities were also provided and displayed in the table below.

Table 3.9: Decommissioning Activities for Current Utilities

	Activity [Ci]
Single existing BWR	144,216
Two conventional PWRs	253,603
Two unconventional PWRs	270,428
Total	668,247

For the two future BWR's that are in the licensing process, the estimated total operational radioactivity will be approximately 48,200 Ci for 35 years of operation, with an additional 500,000 Ci of irradiated hardware and an estimated 550,000 Ci of decommissioning waste. Using the same assumption that was used in calculating the estimated volumes to include future nuclear power plant units, four years of operational waste can be added to the 2024 totals, and 24 years of operational waste and all of the decommissioning waste should be included in the 2044 totals. This calculation is summarized in the table below.

Table 3.10: Operation and Decommissioning of Future BWR units

	Activity [Ci]
Activity of 35 years of operation	48,200
Annual activity of operation	1377
Total activity of irradiated hardware	500,000
Annual activity of irradiated hardware	14,285
Total decommissioning activity	550,000
Four years of operation (2021 – 2024)	62,648
Twenty-four years of operation and decommissioning (2021 – 2044)	925,888

The table below depicts the total activity needs of the Texas Compact.

Table 3.11: Total Activity Needs of the Texas Compact 2024 and 2044

	Millions of Curies
Licensed Volume	3.89
Existing Facilities	
2024 Operating	0.08
2044 Operating	0.14
Decommissioning	0.67
Total (2044)	0.81
Possible New Facilities	
2024 Operating	0.0627
2044 Operating	0.376
Decommissioning	0.550
Total (2044)	0.926
Combined Total (2044)	1.736

3.3 Commercial Radioactive Waste Generation In Non-Party States

There are currently eighty (80) nuclear power plant units that are in non-party states that do not have viable disposal options. Based on the examination of Texas Compact utilities, it can be presumed that nuclear utilities in non-party states contribute a large majority of the LLRW that is currently in the United States, as opposed to academic, medical, or industrial sources.

To support this presumption, TCEQ gathered limited information from the NRC, the Electric Power Research Institute (EPRI) and the Manifest Information Management System (MIMS). In addition, the regulatory agency for each of the thirty-six (36) states that do not have disposal options were contacted requesting a mailing list of potential non-utility LLRW generators from their state. Fourteen states provided potential generator lists and six provided LLRW studies performed by their own states. Approximately 560 questionnaires were sent to the potential nonparty non-utility generators and only about 50 were returned. Therefore, it was determined that the questionnaire responses received were not representative of the actual volumes and activity produced by non-utility generators in non-party states.

Due to the low response rate to the questionnaire and the discovery that in the MIMS database, LLRW brokers and processors have waste attributed to them as if they were the generator possibly making the state-of-origin designation within the system inaccurate, the following data was primarily drawn from the information received from EPRI. Since the Texas Compact nuclear utilities make up greater than 90% of both the volume and activity produced in the Texas Compact states, it was assumed that operational LLRW generated by utilities in non-party states would similarly make up a large fraction of the total LLRW generated.

3.3.1 Non-Party State Volume Prediction

United States average annual generation rates in cubic feet per unit are shown in the following table 3.1:

Table 3.12: US Industry Average Annual Generation Rate (ft3/unit)

Number of Units	52 PWR	28 BWR	80 Total	
Combined Waste Streams	**Volume**			**Source**
Wet B/C (resins and filters)	5,720 ft3	1,680 ft3	7,400 ft3	EPRI RadBench™[8]
Wet A (resins and filters)	10,400 ft3	50,400 ft3	60,800 ft3	EPRI RadBench™
Dry Active Waste (DAW) (combined)	1,456,000 ft3	1,232,000 ft3	2,688,000 ft3	EPRI RadBench™
Activated Hardware	N/A	1,372 ft3	1,372 ft3	Texas Compact BWR questionnaire response[9]

In the non-party states considered, there are eighty (80) nuclear power plant units, fifty-two (52) of which are PWRs and twenty-eight (28) of which are BWRs. Using the values in the above table, it can be predicted that the non-party utilities generate a total of 7,400 cubic feet per year of Wet B/C resins and filters, 60,800 cubic feet per year of Wet A resins and filters, 2,688,000 cubic feet per year of dry active waste (DAW) and approximately 1,400 cubic feet of activated hardware. Using these totals, by 2024 utilities in the considered nonparty states will produce a total of approximately 33,100,000 cubic feet of operational LLRW and by 2044, these utilities will produce 88.2 million cubic feet of operational LLRW. This is approximately 14 times the capacity needs of the Texas Compact for both operational and decommissioning volumes combined. Figure 3.9 displays the comparison of party state waste and non-party state waste for the 2024 predicted volumes.

8 EPRI RadBench Web enables member LLW managers to compare, using an Internet browser, their liquid processing volume, waste characteristics, solid waste generation, waste disposition, and effluent performance with relevant sites throughout the industry.

9 Texas Compact BWR reported approximately 147 cubic feet of activated hardware generated every 3 years. This gives a theoretical average generation of 47 cubic feet per year. This calculation was made to estimate the volume of activated hardware could be produced by similar BWR-type reactors over a period of time, however, it should be noted that this waste stream is produced during outages and occurs periodically.

The LLRW studies received as part of the questionniare response from six of the contacted states showed highly variable volumes and activities generated each year, making it difficult to determine if these results can be extrapolated to be representative of the entire 36 states without disposal options. These reports have several things in common. First, all six stated that the majority of radioactive waste that is generated is Class A. Second, all state that after Barnwell's closure in June 2008, Class B and C has been stored on site awaiting a future disposal option. Currently, EnergySolutions in Clive, UT only accepts Class A waste. Based on economic considerations and discussions with nonparty generators, it can be assumed that nonparty states will continue to dispose of Class A waste at the Clive, UT facility, and will begin to dispose of their Class B and Class C waste at the CWF, unless there are regulatory changes that make it economically feasible to send Class A waste to Texas.

Third, for most states, there was a spike in LLRW disposal in 2007 and 2008 due to Barnwell's closure to non-Atlantic compact states. Reported annual disposal volumes per state from these studies range anywhere between 600 cubic feet to 800,000 cubic feet. Fourth, all of the submitted reports substantiate the assumption that utility operational waste makes up a large majority of the volume and activity of LLRW generated in each state and that states without utilities generate significantly less LLRW than states with utilities.

3.2 Non-Party State Activity Prediction

Also taken from the data provided by EPRI is the following table regarding activity per cubic foot for the different utility waste streams.

Table 3.13: Activity Concentration by Waste Stream for Utilities [EPRI]

Combined Waste Streams	Ci/ft3
Wet B/C (resins and filters)	1.48
Wet A (resins and filters)	0.15
DAW (combined)	0.00024
Activated Hardware	73.99

Using the volumes stated above and activity per cubic foot in Table 3.2, it appears that for the fifty-two (52) PWRs and the twenty-eight (28) BWRs in the thirty-six (36) nonparty states that do not have a disposal option, annual radioactivity of the LLRW generated will be approximately 10,952 Ci of Wet B/C resins and filters, 9,120 Ci of Wet A resins and filters, 645 Ci of all classes of Dry Active Waste, and 103,586 Ci of irradiated hardware. These utilities will generate a total radioactivity of 1.5 million Ci of operational LLRW by 2024, and a total radioactivity of 4 million Ci of operational LLRW by 2044. These values do not reflect reactor decommissioning.

Based on the nonparty nuclear reactors alone, it is evident that there is more waste in the 36 nonparty states without a current class B and C waste disposal option than within the Texas Compact. In addition, it is clear that the Texas LLRW disposal facility should expect to receive import petitions from non-compact states for mostly Class B and C waste. According to MIMS, in the 36 nonparty states considered, 99.2% of the LLRW volume disposed of between 2000 and Barnwell's closure was class A, 0.39% of the volume was class B, and 0.38% of the volume was class C. Conversely, in the same time period, 1.2% of the total activity disposed was was class A, 6.7% of the radioactivity diposed of was class B, and 92.1% of the radioactivity was class C LLRW[10]. This is depicted by figures 3.10 and 3.11.

10 Numbers have been rounded to the hundredth of a percentage and may not add up to 100.00%

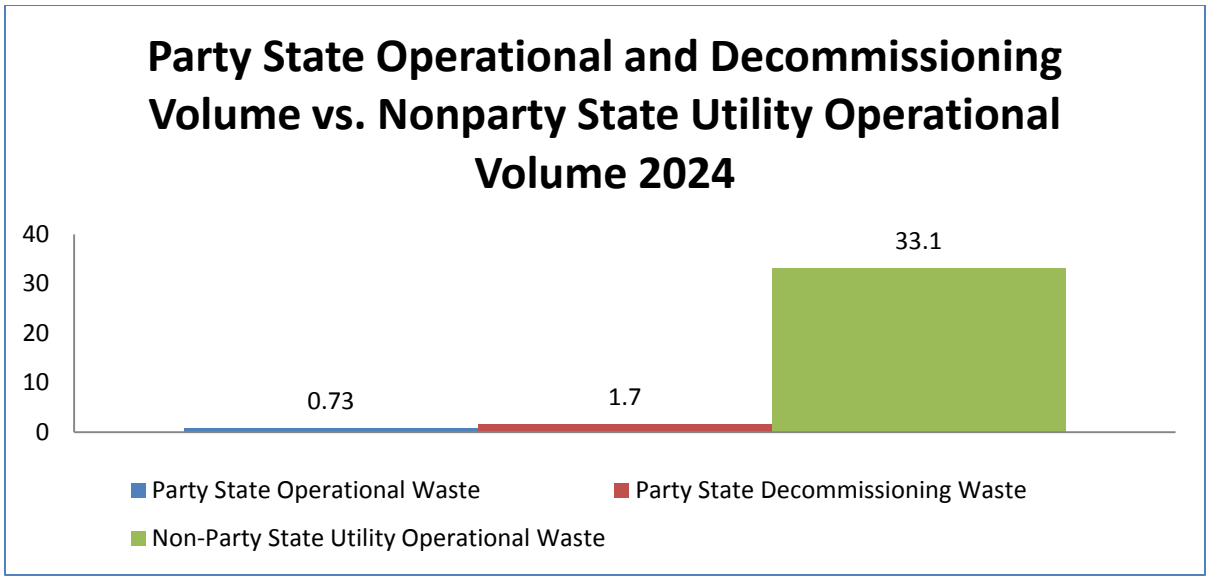


Figure 3.9: Comparison of Predicted Party State Volumes to Nonparty State Utility Operational Volume for 2024

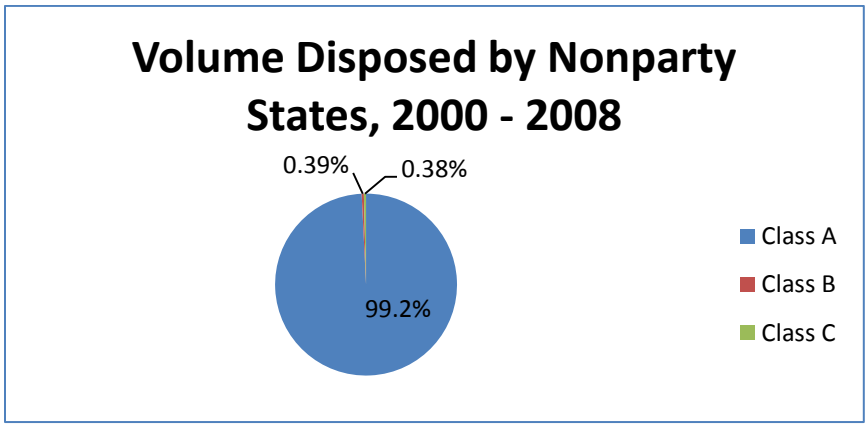


Figure 3.10: Nonparty Disposal Volume Between January 2000 And June 2008. [MIMS]

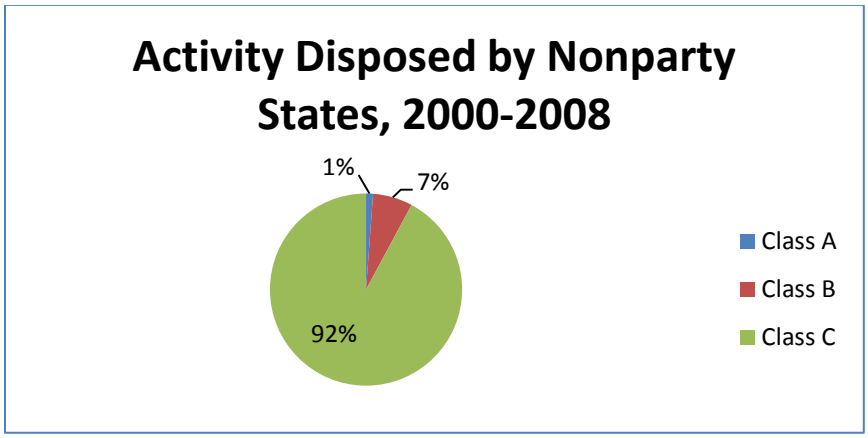


Figure 3.11: Nonparty Disposal Activity Between January 2000 And June 2008 [MIMS]

3.4 Volume Reduction

The predicted volumes presented in section 3.2.1, in general, do not take volume reduction into account. Utility respondents utilize volume reduction more frequently than non-utility respondents. By comparing the reported as-generated volumes to the reported as-disposed volumes, it is a fair conclusion that volume reduction techniques are an industry standard for utilities.

3.4.1 National Policy on Volume Reduction

In 1981, the NRC published a Policy Statement regarding the volume reduction of LLRW[11]. The Policy Statement addressed:

- The need for a volume reduction policy; and
- The need for waste generators to minimize the quantity of waste produced.

For 30 years, the Policy Statement has conveyed the NRC's expectations that generators of LLRW should reduce the volume of waste shipped for disposal at licensed commercial waste disposal facilities. The NRC stated that such action would:

1) Extend the operational lifetimes of the existing commercial low-level disposal sites;
2) Alleviate concern for adequate storage capacity if there are delays in establishing additional regional sites; and
3) Reduce the number of waste shipments.

While policy statements from the NRC are not regulations per se, they have impacted industry standards. This policy statement in particular clarifies that there are a variety of options for management of LLRW that are secure and protect public health and safety.

3.4.2 Volume Reduction Techniques

Current Volume Reduction Techniques are varied. In the thirty years since the 1981 NRC Policy Statement, volume reduction techniques have changed in several ways. Additional details on each of these volume reduction techniques can be found in Appendix B.

1) **Compaction**:

Compaction involves compressing the waste to reduce its volume. Compaction is a relatively inexpensive and widely available option, which is used by many low-level radioactive waste generators[12]. Compactors can range from low-force compaction systems (~5 tons or more) to presses with a compaction force over 1000 tons, referred to as supercompactors. Volume reduction factors are typically between 3 and 10, depending on the waste material being treated.

6) Incineration

11 46 FR 51100(October 16, 1981)

12 RER-40 How Is Low-Level Radioactive Waste Treated Prior to Disposal? Fentiman, A., Jorat, M., Meredith, J. of The Ohio State University. http://ohioline.osu.edu/rer-fact/rer_40.html

Incineration is a volume reduction option for combustible radioactive wastes. Following the segregation of combustible waste from non-combustible constituents, the waste is incinerated in a specially engineered kiln up to around 1000°C. Volume reduction factors up to 100 can be achieved in incineration, depending on the density of the waste[13].

7) Vitrification

Vitrification is a process during which low-level radioactive waste is mixed with glass-making material and heated, which makes glass "beads" or disks. One advantage of vitrified waste is that the radioactive material is bound up in the glass and is not easily released, even if water comes in contact with the waste after it is placed in a disposal facility[14].

8) Steam Reforming

Steam reforming is a thermal treatment technology classified as “pyrolysis,” which differs significantly from an open-flame incineration/combustion process. When used for reduction of nonmetal filter cartridges in a tank conversion reformer, this process is referred to as “conversion reforming.” Steam reforming uses temperatures elevated just enough to release the organic gases and water vapor from the waste without it combusting. The resultant waste residue appears as a dry granular media which can be disposed in liners or high integrity containers. A benefit of this type of processing is that it greatly reduces the water content of the wet waste, which, if not reduced, can lead to stability issues in the future. The volume reduction efficiency of the as-generated waste is between 5:1 and 33:1. However, the potential remains for concentrating the waste so as to produce a waste form which exceeds the acceptance criteria of disposal facilities due to certain nuclide concentrations (i.e., could produce waste that is greater than Class C (GTCC) waste.) Typically, this limitation is mitigated by blending high and low activity wastes from the same waste classification prior to steam reforming to ensure a disposable end product.

Steam reforming is the preferred method for volume reduction of high activity wet waste, which can be very costly to ship unprocessed due to poor packing efficiencies and void spaces. Per 30 TAC Section 336.362(b)(2)(C), void spaces within the waste and between the waste and its package must be reduced to the extent practicable. Filter waste contains substantial amount of void space within the center of the filter cartridge, and within the waste collection container. Therefore, in addition to the reduction in disposed waste volume, conversion reforming of the mechanically rigid, high void space, fixed geometry filter cartridge into a reformed residue also provides a reduction in void spaces within the waste container.[15]

13 Treatment and Conditioning of Nuclear Wastes. World Nuclear Association. http://www.world-nuclear.org/info/inf04ap1.html

14 RER-50 What Is Being Done to Reduce the Volume of Low-Level Radioactive Waste? Fentiman, A., Karam, P., Meyers, R. The Ohio State University. http://ohioline.osu.edu/rer-fact/rer_50.html

15 Advanced Volume Reduction and Waste Segregation Strategies for Low-Level Waste Disposal, EPRI Report 1003436 (November 2003)

3.4.3 Typical Volume Reduction Techniques and Factors in the Texas Compact

Much of the generated LLRW undergoes some form of processing before disposal. Processing methods include incineration, compaction, solidification and dewatering depending on the waste form. As a result, waste generation volumes differ from disposal volumes. Figure 3.12 below illustrates this difference. Each bar represents the yearly generated volumes for utility and non-utility generators, while the line represents disposed volumes as reported in response to the TCEQ questionnaire. Disposal projections for 2005-2020 average around 12,815 cubic feet of waste per year based on respondent information. Based on the comparison of the reported as-generated volumes and the reported as-disposed volumes, it appears that overall, there is a volume reduction factor of approximately 4.5. However, this factor can vary greatly between different waste streams.[16]

Texas Compact utilities use several volume reduction techniques for dry active waste: sorting and segregation, incineration, and supercompaction. For process waste, Texas Compact utilities use thermal treatment/pyrolization. Many Texas Compact non-utility generators reported the use of volume reduction techniques such as incineration typically for dry and wet waste streams and compaction for predominantly dry waste streams.

3.4.4 Costs and Benefits of Volume Reduction

When deciding whether to use volume reduction techniques, a generator must consider the price per cubic foot for disposal at the disposal facility, price of transportation and the price for the processing when deciding whether to use volume reduction techniques.

Volume reduction provides two benefits. First, it allows for more waste to be placed in the disposal facility. Second, steam reforming of wet waste streams greatly reduces the water content of the waste, which will improve the stability of the waste.

However, reducing waste volumes does have the potential to result in a change in waste classification due to changing or over-concentrating the radioactivity of the waste. Further, blending waste to a lower classification cannot be used to prevent this inadvertent over concentration because dilution is prohibited in current TCEQ rules at 30 TAC Chapter 336.

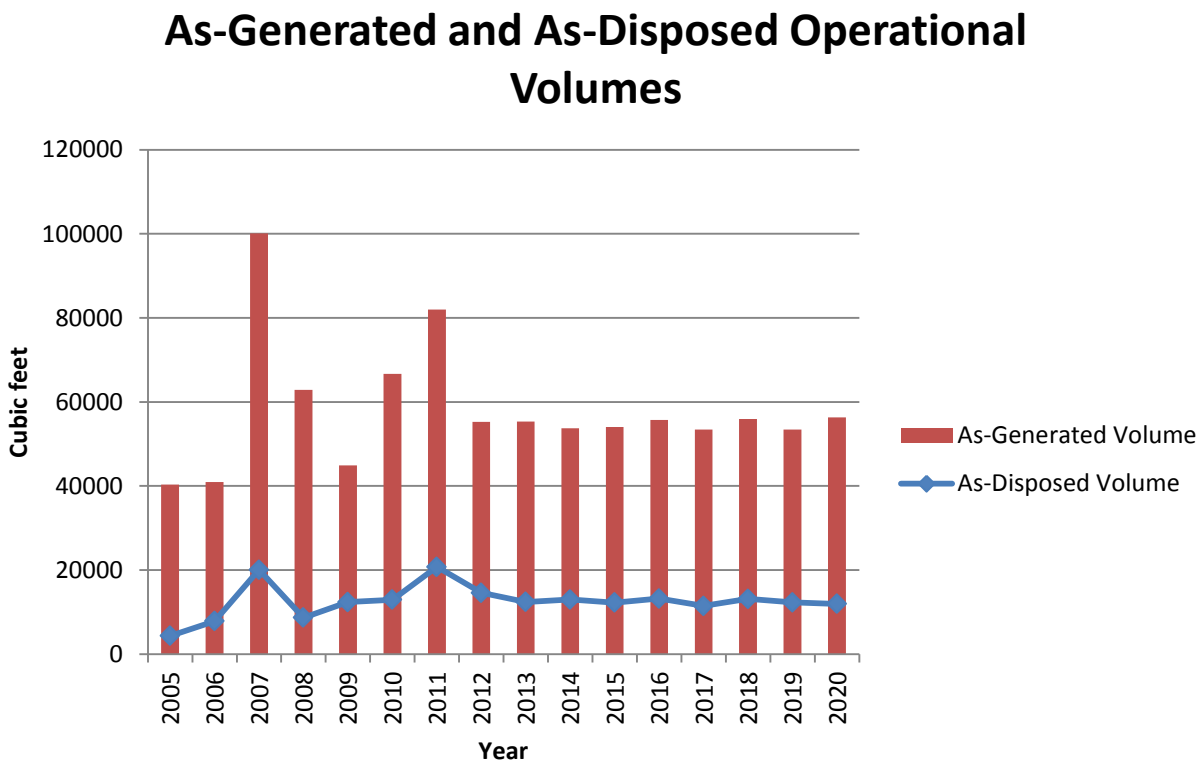
Another consideration when deciding whether or not to volume reduce is commingling party state waste with non-party state waste. Commingling is defined as any process that combines radioactive substances from two or more generators resulting from the commercial processing of radioactive substances. Per 30 TAC Section 336.745, a licensee may not dispose of low-level radioactive waste that contains party state compact waste that has been commingled at a commercial processing facility with waste from other sources unless the

16 It should be noted that questionnaire responses from generators regarding as-disposed volumes varied in their completeness.

commingling was incidental to the processing of the waste and processing has not altered the waste class, and follows TCEQ comingling guidelines.

It is apparent from the questionnaires that many generators in the Texas Compact use volume reduction techniques today due to the lack of LLRW disposal options in the past. However, volume reduction activities may decline in the future as generators and processors weigh the potential risk of concentrating LLRW volumes into a form that exceeds waste acceptance criteria and the prohibition on dilution per 30 TAC Section 336.229. In addition, the costs for disposal, transportation, and processing will play a huge factor in whether a generator of LLRW decides to use volume reduction techniques prior to disposal.

Figure 3.12: As-Generated Volumes Compared To As-Disposed Volumes for the Texas Compact



4. Necessity of Containerized Waste

Containerization is currently a statutory requirement and includes specifications for Class B and C waste, and optional rulemaking for certain types of Class A waste at Section 401.218. The principal containerization apparatus used for disposal of LLRW is the Modular Concrete Canister (MCC). The function of the MCC is threefold. First, the canisters help maintain the structural stability of the site. Second, the canisters provide shielding for workers from radiation during operations. Finally, the canisters slow the movement of radionuclides into the environment. The grouting of the waste within the MCC is also significant as will be discussed below.

4.1 Stability of the MCCs

Stability is essential to meeting various NRC and Texas requirements for LLRW disposal. MCCs are designed to have individual structural integrity and to contribute to maintaining the structural integrity of the waste repository. The canisters can either be cylindrical or rectangular in shape and are designed to resist various load combinations, and changes or disturbances of course, arrangement, or motion, including seismic (or lateral) motions.

These canisters are designed in a manner that enables the placement of one directly on top of another. Thus, the bottom of one canister constitutes the lid of the canister beneath it. The canisters were designed to contain reinforcing steel. This reinforcing steel has strength of 60,000 pounds per square inch, which will enable the canisters to withstand the anticipated loads under tension. For compression loading, the concrete mix utilized strength of 5,000 pounds per square inch. Under this design, calculations show that the canisters should be able to ensure the waste remains containerized for at least 300 years and the site is stable. See Figures 4.1 and 4.2 for diagrams of cylindrical MCCs.

4.2 Shielding effects of the MCCs on Radiation Worker Dose

Safety is an important legal and regulatory consideration in determining the necessity of containers as containers serve as shielding to protect workers. An essential component of a radiation safety program is shielding the radiation worker from the radiation source. The MCCs provide such shielding from the emplaced LLRW and therefore greatly reduce worker dose. To demonstrate the effect of shielding, a waste container with similar dimensions and material to a high integrity liner was modeled in MicroShield® v6.02 in three configurations: unshielded, ungrouted in an MCC and grouted in an MCC. MicroShield® is a is a comprehensive gamma ray shielding and dose assessment computer program that is widely used for designing shields, estimating source strength from radiation measurements, minimizing exposure to people, and teaching shielding principles.

The ungrouted MCC scenario model showed a decrease in dose by a factor of nearly 30 of the unshielded scenario, and the grouted MCC scenario model showed a decrease in dose by a factor of nearly 4,650 compared to the unshielded scenario. As evidenced by the MicroShield® simulation, the use of the MCC makes a large impact on keeping

radiation worker dose as low as reasonable achievable (ALARA). Figure 4.3 illustrates the unshielded and shielded waste container used in the MicroShield® model.

If the waste in this scenario were left unshielded, a worker would receive the regulatory dose (5 rem/year) in approximately 46 seconds. In the scenario with the waste placed in the MCC without grout, the worker could work for 22 minutes before receiving the regulatory dose. Finally, with the waste fully grouted in the MCC, a worker could work for approximately 60 hours in that radiation field before receiving the regulatory dose. Therefore, it is not just the container, but also the use of grout in the container which greatly reduces occupational worker dose.

4.3 Role of Containerization in Environmental Protection and Water Infiltration

Containers, such as the currently used MCCs, are also used to provide an extra layer of protection to prevent water from encroaching into the contained waste. This low permeability can decrease the flow of water into and out of the MCCs. Since the speed of the flow of water is the primary means of restricting the movement of radionuclides into the environment, reducing the flow of water can be advantageous. However, it is important to note that the low permeability of concrete is not an ultimate barrier in preventing the mixing of water and waste. For instance, cracks in the concrete and the degradation of concrete over time may allow water to enter the MCCs and mix with the waste. It is important to note that throughout the operational life of the facility, water is managed through a series of pumps, trenches, and wells subject to periodic testing to catch a release of radionuclides at the earliest stage. Nevertheless, concrete containerization remains an important factor in the protection of the environment from the release of radionuclides.

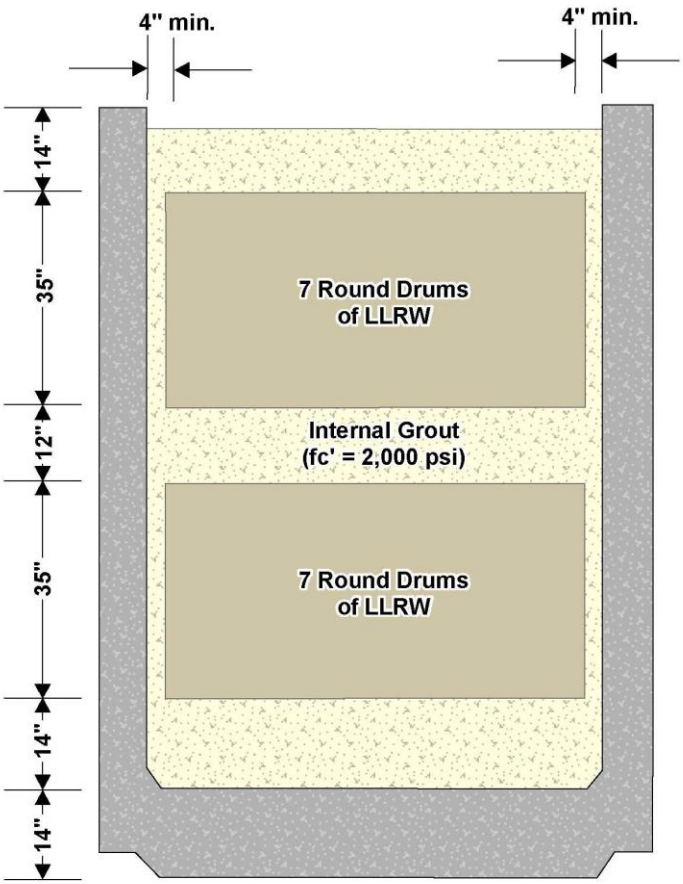


Figure 4.1 Cross Section of Cylindrical MCC from WCS LLRW License Application

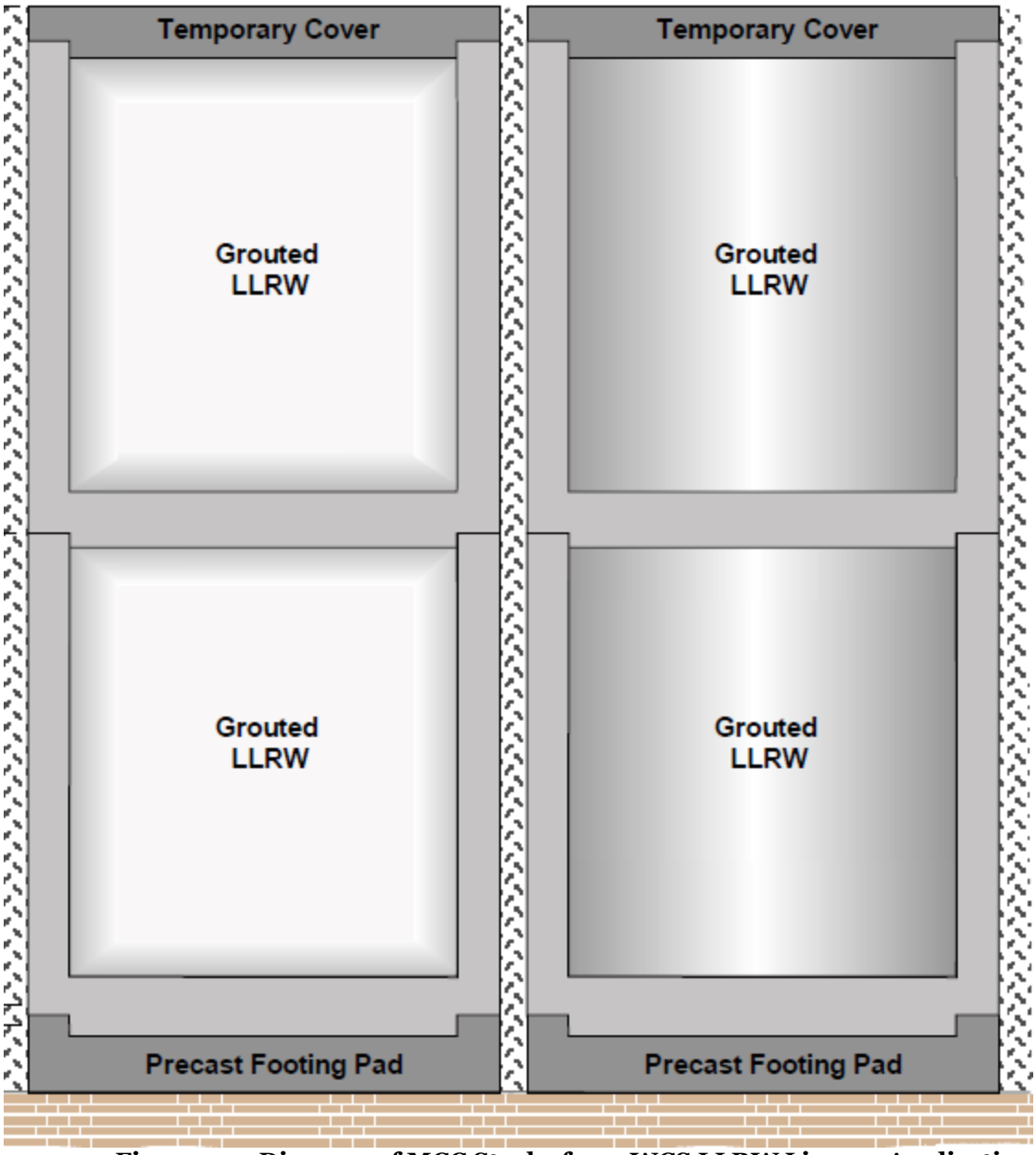


Figure 4.2: Diagram of MCC Stacks from WCS LLRW License Application

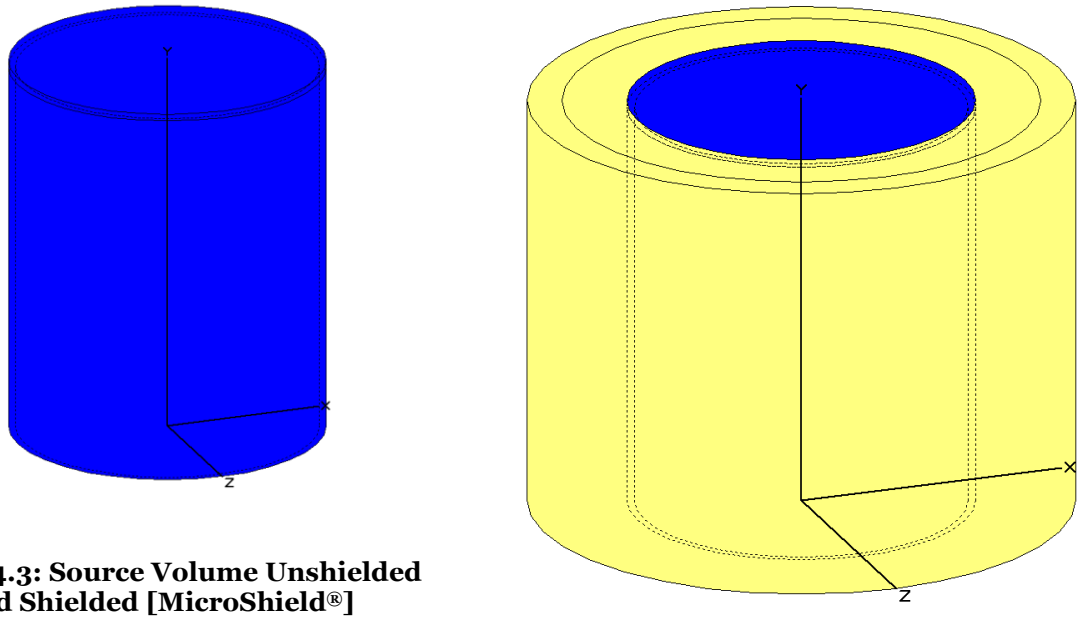


Figure 4.3: Source Volume Unshielded and Shielded [MicroShield®]

5. Projecting Capacity and Its Effect on Health and Safety of the Public

5.1 Public Health and Safety

In order to evaluate the effects of the projected volume and radioactivity of the waste among other performance objectives, TCEQ requires an annual Performance Assessment. A Performance Assessment (PA) for a LLRW disposal facility is a quantitative analysis used for demonstrating compliance with performance objectives. The concept of a PA stems from the NRC requirements regarding Performance Objectives in NRC regulations. In order to preserve its status as an Agreement State with the federal government, the State of Texas is required to maintain compatibility with the performance objectives, and TCEQ established the PA as a technological and environmental regulatory method. These performance objectives include protection of the general population from releases of radioactivity, protection of individuals from inadvertent intrusion, protection of individuals during operations, and stability of the disposal site after closure.

The performance objectives are analyzed with two separate models. A short term analysis is used to evaluate the protection of individuals during operations. A long term analysis is required for meeting the remaining objectives. This partitioning of the objectives into the two analyses ensures that the appropriate measures are taken into account for the various effects associated with the time-dependent nature of the waste.

In meeting the performance objectives the following information is required:

- Site characterization;
- Development of conceptual model(s);
- Defining scenarios and pathways;
- Selection of appropriate mathematical model(s) and code(s);
- Sensitivity and uncertainty analyses; and
- A detailed comprehensive radionuclide inventory.

As part of demonstrating that performance objectives can be met, site-specific data related to area and site characteristics are provided and include ecology, geology, seismology, soils, topography, surface hydrology, hydrogeology, air quality, natural background radiation, meteorology, climatology, and demographics. The data used for demonstrating compliance must be representative of current conditions and sufficient for modeling future conditions. Data collected must be obtained from site-specific environmental monitoring in all sample media (water, soil and air) and from characterization investigations. Monitoring data must be collected, analyzed, and reported following the appropriate quality assurance/quality control (QA/QC) and chain of custody protocols for the given analytical method. In the absence of site-specific data, literature values may be used if they can be demonstrated to be conservative and representative of site conditions.

The groundwater pathway scenarios are given greater consideration due to the significance of this pathway as the main contributor of dose to an individual. Figure 5.1 is a conceptual site model showing the various radionuclide transport pathways in the environment and potential exposure pathways.

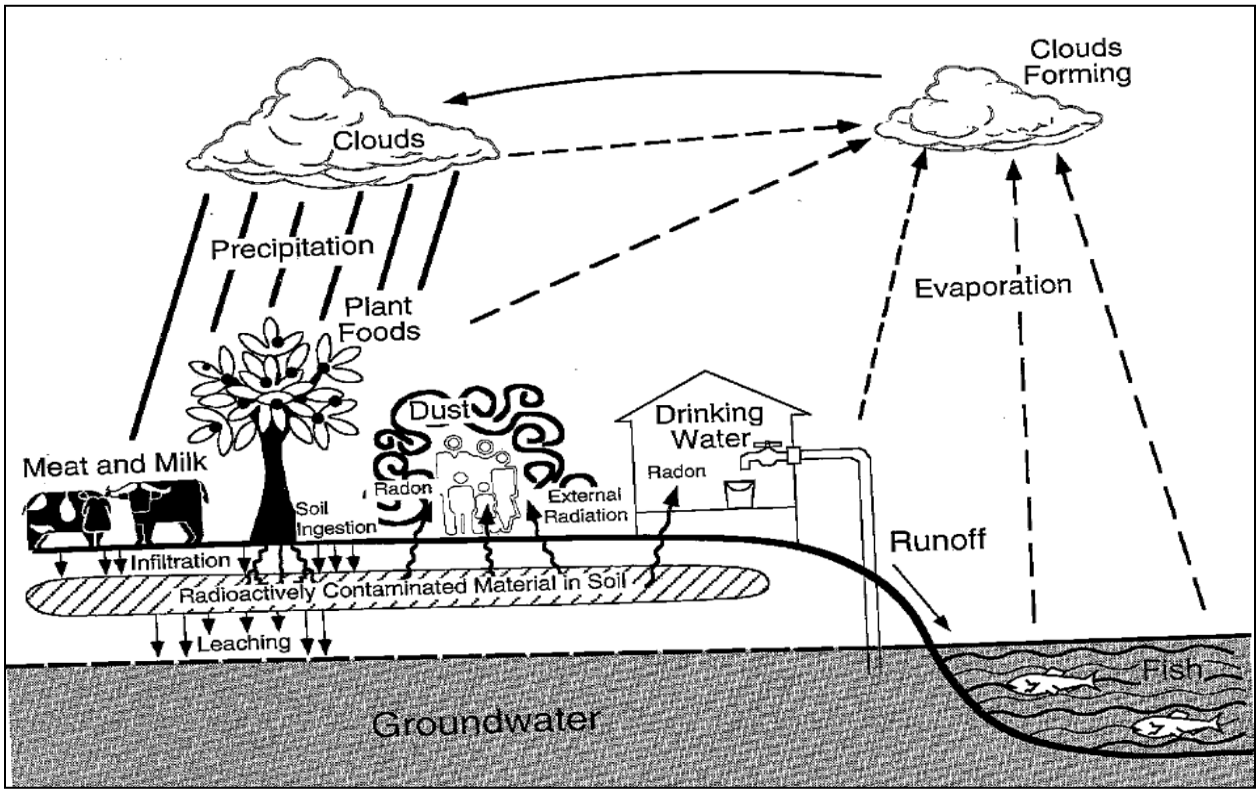


Figure 5.1: A Schematic of the Various Pathways Analyzed in a Performance Assessment [Source: US DOE "Manual for Implementing Residual Radioactive Materials Guidelines Using RESRAD, Version 5.0." (1993) pp 5 Figure 1.1]

In addition to meeting NRC compatibility requirements, the PA should be a useful tool for both TCEQ and the Compact Commission to make determinations on how capacity may impact the performance of the landfill, the need for expansion or limits on the type, volume and concentration of waste and other environmental impacts.

5.1.1 Site Characteristics and its relationship to Capacity

Certain changes or information regarding the above site characteristics could impact capacity by relating to decision-making on expansion or limitations on type of waste, concentrations and volume. An assessment of site characteristics is essential in evaluating both dose and the resulting health effects. Dose calculations rely on site characteristics, such as meteorology, geology, hydrology data, and also waste inventory information. It is within the specific site characteristics that the transport of radionuclides to the general environment is evaluated. Both transports by air and by water were considered in the PA, and both contribute to the potential health effects or dose.

5.2.2 Waste Inventory

Keeping an accurate waste inventory, bearing in mind the role of decay and declining or increasing radioactivity will be vital in making capacity decisions. The radionuclide source term (or inventory) is characterized by the composition and magnitude of total radioactive material received over the facility life, including chemical and physical properties of the radioactive material.

A typical LLRW inventory would consist of approximately 85 radionuclides. Of those 85 radionuclides roughly 62 (73%) would decay to insignificant levels after 500 years, the time at which engineered barriers are expected to fail. The remaining 23 radionuclides (27%) are the primary concern for evaluating long-term effects to public health and safety, with particular attention to the more environmentally mobile radionuclides.

Eighty-five (85) radionuclides were considered in evaluating the source term for the Texas LLRW disposal facility. As part of that evaluation, the modeling accounted for decay of radionuclides over the 50,000 year period of analysis. Note that the decay of radionuclides was not considered for short term (i.e. 30 yrs) analyses when evaluating potential worker doses. This is due to the fact that the radionuclides may be accepted for disposal at any time during the operational period. The does could be underestimated if a large shipment is disposed toward the end of the operational life, but was considered disposed during the beginning of the operational life. Thus, the full inventory amount, and not the decayed amount, was utilized for short term analyses. Worker dose evaluations for external exposure and during accident scenarios were considered short term analyses and resulted in no adverse health and safety effects.

Note that because a PA is a time intensive process and because radionuclide breakdown data projections between 2012 and 2020 were not requested from potential generators, the radionuclide inventory from the August 2000 study was utilized in the long term analysis, rather than the curie capacity from this study. However, because the capacities from both studies are similar, the dose effects using the inventory from the August 2000 study can be used as a proxy for the dose effects using the curie capacity from this current study. The results from the PA shows that the dose from the August 2000 inventory (with decay accounted for) are within acceptable limits. It can be further postulated that the doses from the capacity study data acquired from Texas Compact generator questionnaires will also be within acceptable limits for the health and safety of the general population considering that the total activity predicted to be generated in only the Texas Compact by 2024 is less than what is currently licensed.

6. Conclusion

As required by Chapter 401, the Texas Legislature requested TCEQ conduct a study on the volume and curie capacity of the CWF for the disposal of party state compact waste and nonparty compact waste. Based on the generators' responses to questionnaires and other information, TCEQ has projected that the LLRW generators in the Texas Compact are likely to generate 0.73 million cubic feet and 0.08 million curies of operational waste by the 2024. As required by statute, TCEQ considered the available information and made the following recommendations:

When considering the future volume and curie capacity needs, consideration should be given to the impact of high volumes of Class B and C waste, mostly from nuclear utilities. The information gathered suggests that nuclear utilities generate most of the LLRW eligible for disposal at the CWF in the near future. Some of the reason for a large projection could be related to the historical lack of disposal options for this type of waste prior to the Texas site's authorization.

On the subject of calculations of radioactive decay and radiation dose assessments, the projected volume and activity of the site is comparable to what was evaluated in the CWF's licensing activities, which include ongoing performance assessments. Based on the current information, it can be postulated that doses from the capacity study data will also be within acceptable limits for the health and safety of the general population.

On the topic of the necessity of the containerization of waste, TCEQ recommends that prior to consideration of any alternatives to containerization, the alternative would need to be fully reviewed and studied for compliance with applicable environmental laws and radiation safety standards.

Further, the health and safety effects of the licensed volume and activity were evaluated and are acceptable. It is important to note that this consideration is also required as part of the annual performance assessments, already required by TCEQ, which accounts for radioactive decay over a maximum period of 50,000 years among other considerations.

Lastly, regarding the costs and benefits of volume reduction and stabilized waste forms, TCEQ advises that the above projection of volume did not incorporate the impact of LLRW processing as it is highly variable. Currently, the choice to process LLRW prior to delivery to the CWF is up to the individual generator. It is TCEQ's understanding from generator input that the choice to utilize volume reduction and other processing techniques are primarily economically driven. Another variable is that NRC is in the process of reevaluating certain classifications based on processing. TCEQ recommends that volume reduction considerations include the benefits of stabilization of certain waste forms, federal policy and rule changes, conservation of current capacity, and other beneficial environmental impacts in addition to prevailing economic concerns.

Abbreviations, Initialisms, and Acronyms

ABSLIQD – Absorbed Liquids

ADAMS – NRC Agencywide Documents Access and Management System

AEA – Atomic Energy Act

AEC – Atomic Energy Commission

ALARA – As Low as Reasonably Achievable

BIOWAST – Biological Waste

BWR – Boiling Water Reactor

Ci - Curies

CFR – Code of Federal Regulations

CONDFSL – Condensate Filter Sludge

COTRASH – Compactable Trash

CWF – Compact Waste Disposal Facility

DAW – Dry Active Waste

DECONRS – Decontamination Resins

D&D – Decommissioning Waste

DNA – Deoxyribonucleic Acid

DOE – Department of Energy

EPRI – Electric Power Research Institute

FLDRFSL – Floor Drain Filter Sludge

FPFILSL – Fuel Pool Filter Sludge

FR – Federal Register

FWF – Federal Waste Disposal Facility

GTCC – Great than Class C

HB – House Bill

HIGHACT – High Activity Waste

LLRW – Low-Level Radioactive Waste

LLRWPA – Low-Level Radioactive Waste Policy Act of 1980

LLRWPAA – Low-Level Radioactive Waste Policy Amendments Act of 1986

LOWASTE – Low Activity Waste

MCC – Modular Concrete Canister

MIMS – Manifest Information Management System

nCi - Nanocuries

NCTRASH – Non-Compactable Trash

NFRCOMP – Non-Fuel Reactor Components (Irradiated Hardware / Activated Hardware)

NORM – Naturally Occurring Radioactive Material

NRC – Nuclear Regulatory Commission

OAG – Ogallala, Antlers and Gatuña Acquifer

PA – Performance Assessment

PROCFIL – Process Filters

PWR – Pressurized Water Reactor

RWCUPRS – Reactor Water Cleanup Powder Resins

RWDMRES – Reactor Waste Demineralization Resins

SB – Senate Bill

SECY – Nuclear Regulatory Commission Paper

SOURCES – Sealed Sources

SSYSRES – Secondary System Resins

TAC – Texas Administrative Code

TCEQ – Texas Commission on Environmental Quality

TDSHS – Texas Department of State Health Services

TLLRWDA – Texas Low-Level Radioactive Waste Disposal Authority

TNRCC – Texas Natural Resource Conservation Commission

VR – Volume Reduction

WCS – Waste Control Specialists, LLC

Appendix A: Waste Stream Definitions

Dry Active Waste (DAW) Streams

The dry active waste category consists of six waste streams:

- Compactable trash (COTRASH)
- Non-compactable trash (NCTRASH)
- Non-fuel reactor components (NFRCOMP)
- Sealed Sources (SOURCES)
- High activity waste (HIGHACT)

Compactable and non-compactable trash are highly diverse waste streams and may include materials ranging from paper towels to contaminated metal components. Generally, compactable trash contains combustible material (e.g., paper, cloth, and plastic), whereas non-compactable trash contains metallic components and discarded equipment. Some trash also contains cellulose materials, which is subject to chemical attack by acids and oxidizers, and to degradation by bacterial action. Nuclear utilities frequently ship compactable and non-compactable trash in the same container, and frequently small pieces of metal are packaged with relatively innocuous materials. This practice is not as common among non-utility generators. These practices make independent characterization of these waste streams difficult. To help account for the non-homogeneity in waste packages generators and processors are required to minimize void spaces to the maximum extent practicable.

Compactable Trash (COTRASH):

Compactable trash includes:

- Decontamination waste (rags, mops, personal protection clothing)
- Miscellaneous paper, plastic and cloth (swipes, plastic bags and sheeting, packaging)

Non-compactable Trash (NCTRASH):

Non-compactable trash includes:

- Concrete rubble and high density concrete block
- Contaminated soil
- Filters (filter cartridges, high-efficiency particulate air (HEPA) filters, respirator cartridges)
- Contaminated tools and equipment
- Glass and ceramics
- Miscellaneous metal (aerosol cans, conduit, crushed 55-gallon drums, pipes and valves)
- Spent fuel racks
- Miscellaneous wood (pallets, demolition lumber).

The density of as-generated waste is difficult to estimate due to its highly variable nature and because waste is often compacted before shipment for disposal.

Non-fuel reactor components (NFRCOMP)

Non-fuel reactor components periodically are discarded from nuclear power plants. These components consist of fuel channels (not including the fuel itself), control rods, control rod channels, shim rods, in-core instrumentation, and flux wires. They are usually manufactured with corrosion-resistant alloys, which may contain boron, cadmium, or hafnium as neutron absorbers. Additionally, many of the components may be exposed to primary reactor coolant and all are exposed to the in-core neutron flux, and are thus sometimes called irradiated hardware. The physical and chemical characteristics of non-fuel reactor components resemble those of activated stainless steel and boron steel. The density of the material generally ranges from 375 to 560 pounds per cubic foot.

Sealed Sources (SOURCES)

Sealed sources contain radioactive materials which are encapsulated to prevent leakage of the radioactive material. Low-activity sealed sources are used as calibration and reference standards for many types of radiation detectors, and are used in some gas chromatographs. High-activity sealed sources are used in neutron generators as both generators and targets, and are also used for sterilization in medical and industrial irradiators. This waste stream includes industrial sealed irradiation sources, as well as sealed calibration sources from institutions.

High activity waste (HIGHACT)

High activity wastes are a broad category of wastes generated by non-utility sources. The waste may contain activated metals and equipment produced by accelerators and research reactors. The waste stream includes accelerator targets used for research and isotope production. Activated metals generally exist in the form of pipes and plates that often have high-specific activities. Non-utility generators usually produce it from impact and tensile strength tests. Activated metals generally have the properties of the metals, e.g., stainless steel, of which they are composed. This waste generally has an average density of approximately 500 pounds per cubic foot. Accelerator targets used in accelerators generally are made of heavy-metal elements like uranium or lead. Tungsten also is used because it can withstand the high temperatures of accelerator beam impingement.

Process (Wet) Waste Streams

Process wastes are those generated from specific processes. Under both federal and TCEQ disposal regulations, any wastes from wet processes would have to be treated to remove free liquids before they could be accepted at a CWF.

The process (wet) waste category consists of eleven waste streams:

- Reactor water cleanup powder resins (RWCUPRS)
- Reactor water demineralization resins (RWDMRES)
- Secondary system resins (SSYSRES)

- Decontamination resins (DECONRS)
- Floor drain filter sludge (FLDRFSL)
- Fuel pool filter sludge (FPFILSL)
- Condensate filter sludge (CONDFSL)
- Process filters (PROCFIL)
- Low activity waste (LOWASTE)
- Biological waste (BIOWAST)
- Absorbed Liquids (ABSLIQD)

Reactor water cleanup powder resins (RWCUPRS), reactor water demineralization resins (RWDMRES) and secondary system resins (SSYSRES)

Water cleanup, radioactive waste demineralizer, and secondary system resins are ion-exchange resins used extensively by utilities to maintain and control high water quality in reactor systems. The resins are made from styrene-divinyl benzene polymers, and are used in the form of small beads or powdered resins. The density of the spent resins ranges between 37 and 56 pounds per cubic foot.

Resins remove either cations or anions from liquid, and are used alone, in sequence, or simultaneously as a mixture of cation and anion resins. The resins are usually packed in cylindrical tanks, and the contaminated liquid passes through the tank. As the liquid flows through the resin bed, dissolved radionuclides chemically replace (exchange with) ions in the resin. Resins are kept in service until their ion-exchange capacity is exhausted or until other criteria (e.g., radiation level) are reached. Spent resins are either replaced or regenerated. Resins designated for replacement are transferred from the cylindrical tanks to shipping containers in the form of slurry. The free water is removed before shipment by dewatering. Dewatered resins typically contain about 50 percent water, mainly bound within the resin, and are immobile. To be approved for disposal, solid waste may not contain more than 1 percent free standing and noncorrosive liquid by volume (10 CFR Section 61.56).

The nature and quantity of the chemical species present in these resins, and their level of radioactive contamination, will vary with the liquid being processed. Sulfur oxides and gases such as carbon dioxide and nitrogen may be generated in spent resins due to chemical decomposition and radioactive decay. These processes may also be augmented by biological decomposition.

Decontamination Resins (DECONRS)

Utilities produce spent decontaminated resins from infrequent decontamination of primary coolant systems. The components in the decontaminated systems include the reactor core, the reactor pressure vessel, coolant system piping, various pumps, and turbines. The purpose of decontamination is to reduce in-plant occupational radiation exposures by removing crud accumulated on surfaces that are in contact with the primary coolant.

The physical characteristics of decontaminated resins are similar to the ion exchange resins discussed above. However, they may contain higher concentrations of multivalent cations of iron, nickel, chromium, manganese, cobalt, copper, zinc, and other transition elements found in the reactor grade steel used in reactor components and fuel cladding. The waste resins may also contain large quantities of chelating agents. It is assumed that decontaminated resins are dewatered before shipment for disposal in order to meet state of Texas disposal requirements.

Floor drain filter sludge (FLDRFSL), Fuel pool filter sludge (FPFILSL) and Condensate filter sludge (CONDFSL)

Utilities regularly generate several types of filter sludges. These include condensate filter demineralizer sludge, floor drain filter sludge, and fuel pool filter sludge. Filter sludge is waste produced by pre-coat filters and consists of filter aids and waste solids retained by the filter aids. Common filter aids include diatomaceous earth; powdered mixtures of cation and/or anion exchange resins; and high purity cellulose fibers. These materials are slurried and deposited (pre-coated) as a thin cake on the initial filter medium (e.g., wire mesh, cloth). The filter cake removes suspended solids from liquid streams. Pre-coat filters using powdered resins also remove dissolved solids. However, they are not as effective as deep bed demineralizers (mixed bed ion exchange columns), due to the shorter period of contact between the liquid and the resin. Pre-coat filtration may be used either with ion exchange columns and evaporation, or as the only form of treatment for removing suspended solids from a particular liquid stream.

The average density of unsolidified filter sludge is about 54 pounds per cubic foot. Small quantities of carbon dioxide and other gases may be generated from powdered resin and cellulose sludge due to chemical attack, biological attack, and/or radiation damage. Diatomaceous earth is composed of silica (SiO_2), which is more resistant to these types of attack. Crud and dirt are the predominant types of filtered solids. Sludges from filter demineralizers also contain species not removed from liquid waste by ion exchange. Filter sludges may be dewatered or solidified before shipment for disposal. The chemical characteristics of the various filter sludges will vary depending upon the source of the waste undergoing filtration.

Process filters (PROCFIL)

This waste is process filter waste. Process filters are from the primary coolant loop. The primary coolant is filtered continuously to maintain high water quality. The process filters may contain both activation products and fission products. The filter elements are constructed of styrene polymers, wound or woven fabric, or pleated paper and may be supported internally by wire or mesh. The fabric filters are usually made of cotton or nylon. Paper elements are often impregnated with epoxy. Some process filters remove only particles and others have ion exchange capability. Process filters made of natural materials are subject to decomposition and microbial degradation. No hazardous components are expected in this waste stream. This waste stream must be dewatered or solidified before disposal.

Low activity waste (LOWASTE)

Low activity waste generally is produced by industrial sources (e.g., pharmaceutical companies, and universities). Low specific-activity waste is often a composite of small amounts of biological waste, absorbing liquid, and liquid scintillation vials. The properties of low specific-activity waste are similar to those of compactable trash, although the latter has a higher density and moisture content.

Biological waste (BIOWAST)

Biological waste is generated primarily through research programs at universities and medical schools. The waste consists of animal carcasses, tissues, animal bedding, and excreta, as well as vegetation and culture media. Radioactive excreta from humans undergoing diagnostic or therapeutic procedures that use radioactive materials are excluded from the biological waste stream since virtually all such materials may be, and commonly are, discharged to municipal sewer systems.

Biological waste has some pathogenic potential and may contain carcinogenic compounds, labeled with suitable radionuclides. However, the radionuclide concentrations of such compounds are generally extremely low. Carcasses are normally shipped for disposal after being packed with absorbent material and lime inside a steel drum. This drum is often placed inside a slightly larger overpack drum and the space between the drums is filled with an absorbent material.

Absorbed Liquids (ABSLIQD)

Absorbed liquid waste streams are aqueous and organic liquids generated by diverse preparatory and analytical procedures, radioimmunoassay procedures (a technique for quantifying minutely small amounts of biological substances such as enzymes, hormones, steroids, and vitamins in blood, urine, saliva, or other body fluids), and tracer studies. The chemical characteristics of the waste depend upon the nature of the process responsible for the waste's generation. It is an industry practice to absorb liquids by providing twice the necessary absorbent material prior to any shipment of LLRW.

Decommissioning Waste

Federal and state regulations require facilities that have ceased operations involving the use of radioactive materials to be decontaminated and decommissioned before they can be released for unrestricted use. Contaminated waste material results from the disposition of radioactive material in or on the surfaces of facility components or structures. For example, in nuclear power plants, suspended corrosion products and dissolved particles, activated by the reactor core neutron flux, are deposited on the surfaces of the plant’s piping systems. Thus, the reactor coolant system surfaces become contaminated. As a result, large quantities of waste materials are often generated as a result of such decontamination and decommissioning activities.

Decontamination and decommissioning activities generally fall into several stages. Once a decommissioning plan has been established, the contamination has been characterized, and sufficient funding is available, the decommissioning proceeds through decontamination, dismantling, segmentation, demolition, and reclamation

activities. Most LLRW generated from decommissioning activities will fit into one of the dry or process waste streams listed above. If not segregated, decommissioning waste could be a composite of several waste streams.

Initial decontamination is conducted on surfaces that are reasonably accessible. Decontamination generally is performed using chemical washes, high-pressure water lances, electro-polishing, ultrasonic decontamination, and abrasive scrubbing. Each of these methods generates waste with unique requirements. For example, effluent from chemical washes and high-pressure water lances must satisfy liquid waste processing requirements for LLRW.

Once initial surfaces are cleaned, metallic components are segmented using an arc saw, plasma arc, oxygen burning lance, thermite reaction lance, laser cutting, or remote cutting with power nibblers and shears. Segmented equipment can consist of piping, tanks, ancillary components, steam generators, reactor vessels, pumps, and valves. This equipment can vary dramatically in size. For example, a typical boiling water reactor vessel is cylindrical in shape and is approximately 73 feet (22.2 meters) in height and 22 feet (6.7 meters) in diameter (NRC, 1980, NES, 1980). Similarly, a typical reactor vessel for a pressurized water reactor also is cylindrical in shape and is approximately 41 feet (12.6 meters) high with a 15-foot (4.6 meters) outer diameter (NRC, 1978).

Once the equipment has been decontaminated and removed, the associated buildings must also be decontaminated and/or demolished. Common buildings on a nuclear utility reactor site include the containment building, fuel building, auxiliary building, control building, turbine building, cooling tower, and other minor structures. Decontamination of buildings generally consists of demolishing structures and then breaking up the concrete into rubble. Overall, these procedures can result in large volumes of LLRW. All projected decommissioning waste by the Texas Compact Utilities was included in the volume and activity totals for the 15-year license term and the 35-year site life span and this includes the numbers projected for future units. This assumption gives the most conservative case for the licensed time span.

Appendix B: Volume Reduction Techniques

1) Compaction:

Compactors can range from low-force compaction systems (~5 tons or more) through to presses with a compaction force over 1000 tons, referred to as supercompactors. Volume reduction factors are typically between 3 and 10, depending on the waste material being treated. Low-force compaction is typically applied to the compression of waste, in order to facilitate packaging for transport either to a waste treatment facility, where further compaction might be carried out, or to a storage/disposal facility. In the case of supercompactors, in some applications, waste is sorted into combustible and non-combustible materials. Combustible waste is then incinerated whilst non-combustible waste is supercompacted. In certain cases, incinerator ashes are also supercompacted in order to achieve the maximum volume reduction. Low-force compaction utilizes a hydraulic or pneumatic press to compress waste into a suitable container, such as a 200-liter drum. In the case of a supercompactor, a large hydraulic press crushes the drum itself or other receptacle containing various forms of solid LLRW. The drum or container is held in a mold during the compaction stroke of the supercompactor, which minimizes the drum or container outer dimensions. The compressed drum is then stripped from the mold and the process is repeated. Two or more crushed drums, also referred to as pellets, and are then sealed inside an over-pack container for interim storage and/or final disposal. A supercompaction system may be mobile or stationary in concept, supplied as a basic system manually controlled, with a minimum of auxiliary equipment, to an elaborated computer controlled system which selects drums to be processed, measures weight and radiation levels, compresses the drums, places the crushed drums in over-pack containers, seals the over-packs, records the drums and over-packs content via a computerized storage system. Every year worldwide, tens of thousands of drums are volume-reduced and stored, with waste generally being reduced in volume by up to a factor of 5.[17]

2) Incineration:

Waste is incinerated in a specially engineered kiln up to around 1000°C. Any gases produced during incineration are treated and filtered prior to emission into the atmosphere and must conform to international standards and national emissions regulations. Following incineration, the resulting ash, which contains the radionuclides, may require further conditioning prior to disposal such as cementation or bituminization. Compaction technology may also be used to further reduce the volume, if this is cost-effective. Volume reduction factors of up to around 100 are achieved, depending on the density of the waste. Incineration technology is subject to public concern in many countries as local residents worry about what is being emitted into the atmosphere.
However, modern incineration systems are well engineered; high technology

17 Treatment and Conditioning of Nuclear Wastes. World Nuclear Association. Retrieved July 2012 from http://www.world-nuclear.org/info/inf04ap1.html

processes designed to completely and efficiently burn the waste while producing minimum emissions[18].

3) Vitrification:
Vitrification is a process during which low-level radioactive waste is mixed with glass-making material and heated. The temperature is typically greater than 1200 degrees Celsius (2192 F). The mixture melts, and the melted material is used to make glass "beads" or disks about one inch in diameter and one quarter inch thick. One advantage of vitrified waste is that the radioactive material is bound up in the glass and is not easily released, even if water comes in contact with the waste after it is placed in a disposal facility[19].

4) Steam Reforming:
Steam reforming is a thermal treatment technology classified as “pyrolysis,” which differs significantly from an open-flame incineration/combustion process. When used for reduction of nonmetal filter cartridges in a tank conversion reformer, this process is referred to as “conversion reforming.” The pyrolysis process is essentially the same for both of these processes – the only significant difference between conversion reforming and steam reforming is the equipment used for volume reduction. Steam reforming uses a dry (high quality) steam heat steam to reform or reduce waste to small gas-size particles which can then be burned in a special reactor void of oxygen. Therefore, it is a two-stage process in which hydrocarbons are vaporized from the waste in one chamber and injected into a secondary reaction chamber with superheated steam. Within the reaction chamber, organics are converted to CO_2, CO and H_2 and the remaining waste product consists primarily of metal oxides, salts, and other impurities removed from the waste generator/processors in-plant coolant and liquid waste systems. The resultant steam reformed waste residue appears as a dry granular media which can be disposed in liners or high integrity containers. Steam reforming is ideally suited for processing mixed wastes and wastes exhibiting high activity levels, such as resin and nonmetal filter media. Steam reforming is capable of accepting wastes up to and, in special cases, exceeding a dose rate of 100 R/hr (1 Sv/hr). However, the potential remains for concentrating the waste so as to produce a waste form which exceeds the acceptance criteria of disposal facilities due to certain nuclide concentrations (i.e., could produce waste that is greater than Class C (GTCC) waste.) Typically, this limitation is mitigated by blending high and low activity wastes prior to steam reforming to ensure a disposable end product. It is stated that the high and low activity wastes are from the same waste classification in order to prevent dilution, which is prohibited in Texas.

Steam reforming is the preferred method for volume reduction of high activity wet waste, which can be very costly to ship unprocessed due to poor packing efficiencies and void spaces. Another benefit of this type of processing is that it greatly reduces the water content of the wet waste, which can lead to stability

18 Treatment and Conditioning of Nuclear Wastes. World Nuclear Association. Retrieved July 2012 from http://www.world-nuclear.org/info/inf04ap1.html
19 RER-50 What Is Being Done to Reduce the Volume of Low-Level Radioactive Waste? Fentiman, A., Karam, P., Meyers, R. The Ohio State University. Retrieved July 2012 from http://ohioline.osu.edu/rer-fact/rer_50.html

issues in the future. The volume reduction efficiency of the as-generated waste is primarily dependent upon the inorganic content of the waste: the higher the inorganic fraction, the greater the final disposed waste volume and the lower the net volume reduction efficiency. For steam reforming of resin, the volume reduction efficiency is directly proportional to the activated corrosion and wear product deposited in the resin (also called the crud loading) and the percentage of inorganic media. Most spent resin contains from 3% to 20% metal oxides, salts, and other impurities which originate in the nuclear plant liquid process stream which translates to a volume reduction between 33:1 and 5:1. Unlike resin, most filter cartridges are constructed using a combination of organic and inorganic materials. For example, nonmetal filters commonly employ some type of plastic as the construction media, which is an organic material. Plastic is essentially solidified oil (a solidified organic), so it results in a 100% volume reduction efficiency. On the other hand, some filters contain fiberglass, which is not normally reduced by steam reforming. Construction materials which do not perform well in the pyrolysis process will increase the volume of the final end product, thereby reducing the net volume reduction efficiency. Thus, one challenge in determining the net disposal volume reduction efficiency for conversion reforming of filters is to determine the additional contribution from filter construction materials to the reformed end product.