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Pathways for Disposal of Commercially-Generated Tritiated Waste

Nancy V. Halverson

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EXECUTIVE SUMMARY

From a waste disposal standpoint, tritium is a major challenge. Because it behaves like hydrogen, tritium exchanges readily with hydrogen in the ground water and moves easily through the ground. Land disposal sites must control the tritium activity and mobility of incoming wastes to protect human health and the environment. Consequently, disposal of tritiated low-level wastes is highly regulated and disposal options are limited.

The United States has had eight operating commercial facilities licensed for low-level radioactive waste disposal, only four of which are currently receiving waste. Each of these is licensed and regulated by its state. Only two of these sites accept waste from states outside of their specified regional compact.

For waste streams that cannot be disposed directly at one of the four active commercial low-level waste disposal facilities, processing facilities offer various forms of tritiated low-level waste processing and treatment, and then transport and dispose of the residuals at a disposal facility. These processing facilities may remove and recycle tritium, reduce waste volume, solidify liquid waste, remove hazardous constituents, or perform a number of additional treatments.

Waste brokers also offer many low-level and mixed waste management and transportation services. These services can be especially helpful for small quantity tritiated-waste generators, such as universities, research institutions, medical facilities, and some industries.

The information contained in this report covers general capabilities and requirements for the various disposal/processing facilities and brokerage companies, but is not considered exhaustive. Typically each facility has extensive waste acceptance criteria and will require a generator to thoroughly characterize their wastes. Then a contractual agreement between the waste generator and the disposal/processing/broker entity must be in place before waste is accepted.

Costs for tritiated waste transportation, processing and disposal vary based a number of factors. In many cases, wastes with very low radioactivity are priced primarily based on weight or volume. For higher activities, costs are based on both volume and activity, with the activity-based charges usually being much larger than volume based charges. Other factors affecting cost include location, waste classification and form, other hazards in the waste, etc. Costs may be based on general guidelines used by an individual disposal or processing site, but final costs are established by specific contract with each generator.

For this report, seven hypothetical waste streams intended to represent commercially-generated tritiated waste were defined in order to calculate comparative costs. Ballpark costs for disposition of these hypothetical waste streams were calculated. These costs ranged from thousands to millions of dollars. Due to the complexity of the cost-determining factors mentioned above, the costs calculated in this report should be understood to represent very rough cost estimates for the various hypothetical wastes. Actual costs could be higher or could be lower due to quantity discounts or other factors.

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LIST OF ABBREVIATIONS/DEFINITIONS

BDF	Barnwell Disposal Facility
BPF	Barnwell Processing Facility
BUS	Bed Unloading Station
Byproduct	As defined in the Atomic Energy Act Section 11e.(2), it is the tailings or wastes produced by the extraction/concentration of uranium/thorium from any ore processed primarily for its source content.
Ci	Curie
CWF	Compact Waste Facility
DAW	Dry active waste, generally consisting of paper, plastic, cloth, rubber, wood, and small, light metal pieces, etc.
DOT	United States Department of Transportation
ECell	Electrolysis cell
Exempt Waste	"Unimportant quantities of Source Material" (uranium or thorium) (per 10CFR40.13) and other "exempt" radioactive materials, such as certain timepieces, marine compasses, balances, etc. containing tritium (per 10CFR30.15 – 20)
GTCC	Greater than Class C
ISS	Isotopic Separation System
LLW	Low-level waste
mCi	Millicurie
MLLW (sometimes LLMW)	Mixed low-level waste, waste that is both radioactive and a RCRA hazardous waste.
MWCF	Mixed Waste Combustion Facility
NARM	Naturally occurring or accelerator produced radioactive materials
NORM	Naturally occurring radioactive materials, a subset of NORM
NRC	Nuclear Regulatory Committee
PCB	Polychlorinated Biphenyl
SRNL	Savannah River National Laboratory
TiT_2	Tritium in Metal Station
WCS	Waste Control Specialists

1.0 Introduction

Tritium is a radioactive isotope of the hydrogen atom, with a half-life of 12.3 years. The most common isotope of hydrogen contains just a proton in the nucleus and has an atomic mass of 1. The nucleus of a tritium atom (abbreviated ^3H) contains a proton and two neutrons and has an atomic mass of 3. The configuration of tritium's nucleus makes it unstable and prone to radioactive decay. During this decay process, the tritium atom emits a weak beta particle and transforms into a nonradioactive helium atom.

Some tritium occurs naturally in very low concentrations. It is generated in the upper atmosphere when cosmic rays strike nitrogen molecules in the air. Tritium is also produced by man-made activities such as nuclear weapon detonation and nuclear reactor operation, and in lesser quantities by particle accelerators. In the 1950s and 1960s, man-made tritium was widely dispersed in the atmosphere by above-ground testing of nuclear weapons. More recently, sources of tritium include commercial and nuclear and research reactors, government weapons production plants, and medical research facilities. Self-luminescent commercial products, such as building exit signs, dials, gauges, luminous paints, and some wristwatches also contain tritium. It is also used in life science research and in studies investigating the safety of potential new drugs.

Because tritium is a form of hydrogen, it behaves like hydrogen. It can exist as a gas or react with oxygen to form tritiated water, with one tritium atom replacing one of the stable hydrogens in the water molecule. In the environment, tritium is most commonly found in liquid or water vapor form. In this form, tritium moves easily through the environment just like regular water. Tritium also can diffuse through porous substances and into metals or virtually any material. When these tritium-contaminated materials are exposed to air, the tritium can be released in a process known as outgassing or degassing.

Tritium can enter the body when people swallow tritiated water or inhale gaseous tritium in the air. Tritium can also be absorbed through skin. Once in the body, tritium disperses quickly and uniformly, going directly into soft tissues and organs.

From a waste disposal standpoint, tritium is a major problem. Because it behaves like hydrogen, tritium exchanges readily with hydrogen in the ground water and moves easily through the ground. Land disposal sites must control the tritium activity of incoming wastes and control its mobility to protect human health and the environment. Consequently, disposal of such wastes is highly regulated and disposal options for commercially-generated tritiated wastes are limited. Disposal and processing options for such wastes, and the potential costs required, are discussed below.

2.0 Waste Categories

General types of radioactive waste include:

- Exempt/very low-level waste – having radioactivity levels not considered harmful to people or the environment; including some sealed sources, commercial products, and materials containing natural occurring radioactive materials (NORM);
- Low-level waste (LLW) – containing small amounts of mostly short-lived radioactivity and not generally requiring shielding; suitable for shallow land disposal;
- Intermediate level waste – containing higher amounts of radioactivity and usually requiring some shielding;

- High level waste – spent reactor fuels and wastes from reprocessing spent reactor fuel; highly radioactive and requiring special handling and disposal [1-3].

LLW encompasses about 90% of the volume of all radioactive wastes, but only about 1% of the total radioactivity [2]. It includes both items contaminated with radioactive material and objects that have become radioactive due to exposure to neutron radiation. LLW is generated in nuclear reactor facilities, hospitals, research facilities, academic institutions, and various industries. It generally consists of paper products, contaminated personal protective equipment (shoe covers, gloves and clothing), rags, mops, filters, radioactive water treatment residues, equipment and tools, luminous dials, medical tubes and swabs, syringes and needles, etc. The radioactivity can range from slightly above natural background levels to highly radioactive. LLW generally does not require shielding to protect workers involved in handling and transporting the waste. This waste is usually suitable for shallow land burial and is often compacted or incinerated to reduce its volume before disposal [2, 4].

For land disposal purposes, the U.S. Nuclear Regulatory Commission (NRC) classifies LLW into four categories based on radioactivity levels for specific radioisotopes: Class A, Class B, Class C, and Greater than Class C (GTCC). Generally speaking, Class A waste has the lowest radioactivity level of the four categories and is contaminated with primarily short-lived radioisotopes. Class B waste contains generally greater levels of short-lived radioisotopes. Class C waste contains larger amounts of long- and short-lived radionuclides than Classes A or B. GTCC is the most radioactive of the four classes of LLW. Greater than 95% of the volume of all LLW is Class A waste [2, 5].

Concentrations of both long-lived radionuclides and shorter-lived radionuclides are used to determine the classification of radioactive waste. When tritium is the only measurable radioactive constituent, wastes containing no greater than 40 Ci tritium per cubic meter of waste are classified as Class A wastes. Greater amounts of tritium change the classification to Class B. Unless the waste stream also contains other radioisotopes, a tritiated waste would not be classified as Class C or GTCC. Criteria for determining classification of wastes containing other radioisotopes or mixtures of tritium and other radioisotopes can be found in NRC regulation 10 CFR Part 61.55, Waste Classification [6].

3.0 Tritiated Waste Streams

Commercial industries using or producing tritium might generate solid, liquid, and/or gaseous tritiated wastes.

3.1 Gaseous Waste

Gaseous tritiated wastes may be generated during nuclear reactor operation or reprocessing of spent nuclear fuel. It is assumed that most gaseous tritiated waste generated by an industrial process would be routed to a stripper system to recover tritium before being eventually discharged from the facility. Thus it is not covered here.

3.2 Liquid Waste

Tritium-contaminated water is a possibility in any tritium handling operation. Larger volumes of aqueous tritiated wastewater may be generated by mopping floors and decontaminating tools. Other sources may include tritium removal systems and contaminated chilled water. Smaller volumes of tritiated liquids, such as bubbler fluid or pump oil, also might be generated in a commercial process. A glovebox pressure-protection bubbler creates a confinement boundary and waste interface boundary between the glovebox atmosphere and the ambient room. Bubbler fluid may become contaminated and require periodic replacement. Vacuum pumps that do not contain pump oil would be preferable in a tritium system. However, if oil-containing vacuum pumps are used, the pump oil will need to be changed periodically, generating tritium-contaminated oil, which may be more difficult to dispose of than aqueous waste. These smaller volumes could be disposed of as liquids or be solidified at the generator's facility before disposition.

3.3 Solid Waste

Due tritium's ability to diffuse into materials, eventually anything that comes in contact with tritium, such as equipment inside a tritium glovebox, will become contaminated with tritium. Some items may last the lifetime of the process, but other, such as glovebox gloves, will be replaced much more frequently. Solid wastes might include the following:

- Job control waste items such as containment huts, plastic suits, gloves, shoe covers, wipes, rags, mops, small tools, etc.,
- Glovebox gloves,
- Small process components such as vessels, pumps, gauges, tubing, and other components that need to be periodically replaced,
- Large components that may contain void space, such as a tank or an accelerator,
- Wastes associated with receiving, storing, unpacking, and transferring tritium supply vessels into and out of a process,
- Wastes from an analytical system, such as instrument components or consumables, and
- Commercially produced items such as exit signs and some self-illuminating wristwatches or airplane instrument dials.

4.0 Disposal Options

4.1 Policies

Commercial LLW management and disposal requirements are regulated by the NRC or Agreement States, which have been granted the authority for regulating radioactive materials upon demonstrating that they have adequate regulatory programs comparable to and compatible with the NRC's program [7]. The U.S. Congress passed the Low-Level Radioactive Waste Policy Act of 1980 (P.L. 96-573) and the Low-Level Radioactive Waste Policy Amendments Act of 1985 (P.L. 99-240) which: (a) established state responsibility for providing LLW disposal facilities; (2) encouraged development of interstate compacts to facilitate this responsibility; and (3) established the right of regional compacts to prohibit disposal of LLW generated outside of the compact states. NRC Agreement States currently license all four of the active operating low-level radioactive waste disposal facilities in the United States [8].

4.2 Disposal Facilities

The United States has had eight operating commercial facilities licensed for low-level radioactive waste disposal. These were located at (1) West Valley, New York; (2) Maxey Flats near Morehead, Kentucky; (3) Sheffield, Illinois; (4) Beatty, Nevada; (5) Hanford/Richland, Washington; (6) Barnwell, South Carolina; (7) Clive, Utah; and (8) Andrews, Texas. Currently, only the latter four sites are currently receiving waste. Each of these is regulated by its state.

More information on the latter four sites is provided in the sections below and in Table 4-1. Note that the information below covers general capabilities and requirements for the facilities, but is not considered exhaustive. Each facility generally has extensive waste acceptance criteria and will require that a

Table 4-1. Low-Level Waste Disposal, and Processing Facilities.

Facility	Treatment Capability	Disposal Capability	Wastes Accepted for Processing or Disposal						Transportation Help	Notes
			Accepts LLW waste from	Class A	Class B	Class C [a]	GTCC [a]	Other		
US Ecology Washington Facility U.S. Ecology, Hanford / Richland, WA		Unlined trenches for conventional shallow-land burial of packaged waste and underground storage tanks	LLW from Northwest and Rocky Mountain compact states only: CO, ID, MT, NM NV, OR, UT, WA, and WY	✓	✓	✓		- Special Nuclear Material within limits - NORM/ NARM [b] and exempt radioactive materials/ devices accepted from <u>all</u> states. [c]		- No MLLW - No wastes containing unprocessed liquids or >10% oil - Yearly limit for tritium in unstable waste form is 100 Ci. [c]
Barnwell Waste Management Facility: Barnwell Processing Facility (BPF) and Barnwell Disposal Facility (BDF) Chem-Nuclear Systems, Barnwell, SC	Sorting, segregation, size reduction, grout encapsulation, resin dewatering, waste solidification, evaporation	Large concrete vaults located in engineered earthen trenches	Atlantic Compact states only: CT, NJ, and SC	✓	✓	✓		- Sealed sources - Special Nuclear Material - Large components - Filters and resins - Irradiated hardware (high levels of radioactivity) [d]		- Can accept sealed tritium sources ≤1000 Ci - No liquid waste at BDF, but BPF can accept aqueous waste -MLLW hazardous by characteristic only and treated to remove that characteristic may be accepted on a case-by-case basis [d]

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			Wastes Accepted for Processing or Disposal							
Facility	Treatment Capability	Disposal Capability	Accepts LLW waste from	Class A	Class B	Class C [a]	GTCC [a]	Other	Transportation Help	Notes
Clive Disposal Facility EnergySolutions, Clive, UT	- LLW: Solidification - MLLW: chemical stabilization, amalgamation, macroencapsulation, vacuum thermal desorption, and debris spray washing	Above-ground engineered disposal embank-ments	All states, though usually not from NW Compact states (WA, OR, ID, MT, WY, UT, AK & HI).	✓				- Class A MLLW - Special Nuclear Material - NORM - 11e.(2) byproduct material [e] - Large components/ oversize debris. [f]	✓	- Solid waste <1% free liquid - Accepts bulk liquid aqueous waste - Case by case review for bulk nonaqueous liquids - Containerized liquids must be solidified before disposal - No sealed sources. [f]
Texas Compact Waste Facility (CWF) Waste Control Specialists, Andrews, TX	Exempt LLW (less than 10% of the Class A disposal limit) may qualify for treatment at WCS's Hazardous Waste Facility (RCRA Landfill) [g]	Near-surface land disposal facility: Engineered steel-reinforced concrete liner system within a clay formation	All states	✓	✓	✓		- Sealed sources - Special Nuclear Material - Large components on a case by case basis - Non-containerized bulk waste from Compact states only (TX and VT) - Transuranics [g]		- State of Texas takes title of the waste - Inorganic and organic - No liquid waste. Free liquid <1% by volume in containerized waste. - No oil or petroleum products. - No MLLW in the commercial disposal facility (allowed only in the federal waste disposal facility). [g]

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Facility	Treatment Capability	Disposal Capability	Wastes Accepted for Processing or Disposal						Transportation Help	Notes
			Accepts LLW waste from	Class A	Class B	Class C [a]	GTCC [a]	Other		
NSSI, Houston, Tx	Tritium recovery/recycling; also neutralization, shredding, oxidation/reduction reactions, vacuum distillation, compaction, stabilization, mercury retort	**NA** - *NSSI sends treated wastes to other facilities for disposal.*	All states	✓	✓			- MLLW - Special Nuclear Material - Sealed Source	✓[h]	- Texas Commission for Environmental Quality (TCEQ) regulates radioactive wastes - Recycling & Recovery available on various materials with activities ranging from millicuries to "multicuries." [i] - Oxidation services for high tritium content organics currently restricted to organic waste streams containing greater than 1 Ci/L. - NSSI takes ownership of the waste.
Bear Creek Processing Facility Energy*Solutions,* Oak Ridge, TN	Volume reduction, sorting/ segregating, decontamination, recycling, compaction, incineration, metal melting, and a variety of specialty waste stream management options	**NA** - *Treated wastes are sent to other facilities for disposal.*	All states	✓[j]				- MLLW [k], - Sealed sources - Special Nuclear Material - NORM - Large components need pre-approval [l]	✓	- Additional restrictions may apply depending on the ultimate disposal facility - Accepts liquids, sludges & solids

Facility	Treatment Capability	Disposal Capability	Wastes Accepted for Processing or Disposal						Transportation Help	Notes
			Accepts LLW waste from	Class A	Class B	Class C [a]	GTCC [a]	Other		
Perma-Fix - multiple locations Services vary by facility [m]	- LLW: compaction, sorting/segregating, thermal treatment - MLLW: characterization, macroencapsulation, neutralization, stabilization, PCB and Hg treatment,	NA - *Treated wastes are sent to other facilities for disposal.*	All states	✓	✓	✓	✓	- MLLW - Sealed sources - Special Nuclear Materials - NORM/ NARM [b] - Large components ,[n]	✓[o]	- Accepts liquids, sludges & solids - Accepts organic and inorganic hazardous waste compounds [n]

[a] Class C and Greater than Class C do not have meaning for wastes containing only tritium.

[b] NORM/NARM = Naturally Occurring and Accelerator Produced Radioactive Material, such as uranium, radium, and radon (NORM) and ^{18}Fluorine, ^{123}Iodine, and ^{201}Thallium (NARM) [9].

[c] From US Ecology's Washington Radioactive Materials License [10],Waste Acceptance Criteria [11], and brochure [12].

[d] From Barnwell disposal criteria documents [13, 14].

[e] Section 11e.(2) is the tailings/wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material [15].

[f] From Energy Solutions' Clive facility waste acceptance criteria [16].

[g] From Waste Control Specialists' CWF Generator Handbook [17] and web page [18].

[h] Including on-site lab packing and labeling, design and fabrication of specialized containers for land disposal if necessary, transport, treatment, and final disposal [19].

[i] Materials may include organic and aqueous liquids, organic and flammable gases, various types of metals, various capture beds, neutron generators, electron capture detectors, luminous devices, tritium contaminated mercury, gases, and light or heavy water, etc. [19]

[j] With added restrictions: Material that does not meet the WAG may be approved and accepted after evaluation of data prior to shipment of waste [20].

[k] Subject to approval of the Mixed Waste Profile [21].

[l] From Energy Solutions' Waste Acceptance Guidelines [20].

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[m] Diversified Scientific Services, Inc. (DSSI) in Kingston, TN; Materials & Energy Corporation (M&EC) in Oak Ridge, TN; Perma-Fix Northwest, Inc. (PFNW) in Richland, WA; Perma-Fix of Florida, Inc. (PFF) in Gainesville, FL.

[n] From Perma-Fix's web pages for Radioactive and Mixed Waste Services [22].

[o] Including sampling, characterization and analysis assistance.

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generator develop a waste profile (i.e. thoroughly characterize their waste) to ensure their license parameters are not exceeded. Facilities typically require a generator to enter into contractual agreement with the facility before they will accept waste for processing or disposal. The generator may also be required to obtain various site or state permits. In addition, the shipping organization will typically be required to have a radioactive waste transport permit valid in the state where the disposal or processing facility is located and any state through which the waste will be transported. The disposal facilities may inspect shipments to verify compliance with Department of Transportation regulations and may collect and analyze samples to confirm radiologic and chemical constituents.

4.2.1 US Ecology, Hanford/Richland, Washington

US Ecology, Inc. has several decades of experience with radioactive waste disposal. They have RCRA subtitle C landfills in several states, which include Idaho, Michigan, Texas and Nevada. These facilities are highly engineered, multiple-liner cells that can accept a wide variety of low-activity wastes, including NORM from various industries, accelerator-produced radioactive materials, mixed (both radioactive and hazardous) low-level radioactive waste (MLLW), exempt byproduct material, exempt special nuclear materials and sealed sources, and other exempt materials and devices meeting US Ecology's exempt waste guidelines [23, 24].

US Ecology also operates a commercial LLW disposal facility at the Department of Energy Hanford facility in southeastern Washington, west of Richland. The facility is located on 100 acres of federal land leased to the State of Washington and has been operating since 1965. Disposal facilities include unlined trenches for conventional shallow land burial of packaged waste and underground storage tanks for treatment and disposal of liquid LLW resins. The facility is licensed by the State of Washington to receive Classes A-C LLW from only the eleven Northwest and Rocky Mountain compact states. The Northwest Compact includes Washington, Oregon, Idaho, Montana, Wyoming, Utah, Alaska and Hawaii. The Rocky Mountain Compact includes Nevada, Colorado and New Mexico [12, 25]. Though the facility cannot accept LLW from out-of-Compact states, it can accept various other waste streams from all 50 states, including NORM/NARM, high activity radium waste, exit signs, smoke detectors, and other exempt items [12].

Waste generators are required to meet U.S. Department of Transportation (DOT) and NRC requirements. Prohibited wastes include MLLW, wastes capable of generating toxic gases/vapors/fumes, pyrophoric/explosive/water-reactive wastes, wastes containing unprocessed (unsolidified) liquids, wastes containing special nuclear material (exceeding certain levels, and wastes containing greater than 10% oil by weight [11].

US Ecology can also provide transportation services for their customers from the point of generation to the disposal site. US Ecology is licensed in most states and their fleet of vehicles can transport from small lab packs to bulk solids and liquids. They also have rail car management capabilities and can provide rail-to-truck and truck-to-rail transfers at both ends of the journey [26].

4.2.2 Chem-Nuclear Systems/EnergySolutions, Barnwell, South Carolina

Chem-Nuclear Systems, LLC, a subsidiary of EnergySolutions, operates the Barnwell Waste Management Facility in Barnwell County, South Carolina. The facility itself is owned by the state of South Carolina. The Barnwell Waste Management Facility consists of two facilities for processing and disposal of LLW: the Barnwell Disposal Facility and the Barnwell Processing Facility.

4.2.2.1 Barnwell Disposal Facility

The Barnwell Disposal Facility (BDF) has been in operation since 1971. Since that time, about 90% of the available disposal volume has been used [27]. Formerly, the Barnwell Waste Management Facility accepted waste from most of the United States. Beginning in 2008, however, they accept waste only from the Atlantic Compact states, comprised of Connecticut, New Jersey, and South Carolina [8].

The BDF is licensed by the State of South Carolina to receive wastes of Classes A-C. The facility provides shallow land burial, in which sealed waste containers are placed in multiple concrete vaults located within an engineered earthen trench. The trenches are as much as 30 feet below grade and are equipped with a drainage-collection system to keep the waste dry to reduce the possibility of radioactive materials migrating into the environment. When the vaults and trench are full, an engineered cap consisting of multiple layers of material is installed to cover the trench area and help isolate it from rainwater infiltration [27, 28].

The facility accepts waste by public highway only, not by rail. Wastes must be must be packaged in wood, plastic or metal containers or a state-approved high integrity container, unless another container is previously authorized. Wastes containing isotopes with greater than 5-year half-lives, such as tritium, and a total specific activity ≥ 1 μCi/cc must be stabilized before shipping it to the BDF. The facility accepts dry active wastes. Liquids must be solidified before shipment to the BDF, but the Barnwell Processing Facility can accept and process aqueous wastes. Solidified wastes containing non-hazardous scintillation chemicals may be acceptable if approved by the state. Low quantities of PCBs may be accepted. Only trace amounts of absorbed oil are allowed in a waste package. Irradiated hardware and various large components, such as steam generators and reactor pressure vessels, can be accepted. MLLW is not allowed, but if it is hazardous by characteristic only and has been treated to remove the hazardous characteristic, it will be considered on a case-by-case basis. Sealed tritium sources may be accepted if approved by the NRC and if they contain ≤1,000 Ci per package in a stable or stabilized form [13, 27].

4.2.2.2 Barnwell Processing Facility, EnergySolutions, Barnwell, South Carolina

In additional to the disposal facility, EnergySolutions' facilities in South Carolina include the Barnwell Processing Facility (BPF) for various wastes that may need processing before disposal. The BPF processes high activity filters and other wastes from the nuclear industry and other generators. It can remotely handle and process the filters and can perform remote sorting, segregation, size reduction, and grout encapsulation of wastes such as soil, sludge, and filters. The BPF is also capable of performing resin dewatering, waste solidification, and evaporation processes [27].

The waste acceptance criteria for the BPF are similar, but not the same as the BDF. The facility accepts waste by rail or highway. The facility accepts dry active wastes in bags, drums/boxes or sealand containers. Some wastes may require a state-approved high integrity container. The BPF can accept and process aqueous liquids, sludges, and concentrates. Dewatered resins and aqueous filter media can be accepted. Low quantities of PCBs may be accepted. MLLW is not allowed, but if the waste is hazardous by characteristic only and has been treated to remove the hazardous characteristic, it will be considered on a case-by-case basis. Sealed tritium sources may be accepted if the sources are approved by the NRC and if they are packaged so that they do not exceed 1,100 Ci per package in a stable or stabilized form. Note, however, that the Barnwell *Disposal* Facility can accept only up to 1,000 Ci of tritium per container [14, 27].

4.2.3 Clive Disposal Facility, EnergySolutions, Clive, Utah

EnergySolutions, headquartered in Salt Lake City, Utah, is a large privately-owned nuclear waste disposal company. It was founded in 2006 with the merger of four waste disposal companies: Envirocare, Scientech D&D, BNG America, and Duratek. EnergySolutions provides LLW management services that include waste characterization, facility decommissioning and decontaminating, waste processing, volume reduction, transportation and disposal [29, 30].

EnergySolutions owns and operates a licensed landfill for disposal of LLW in Clive, Utah, approximately 60 miles west of Salt Lake City. The facilities at Clive are privately owned and are comprised of regulated, above-ground engineered disposal embankments, also known as a secure landfill. Their facilities include a bulk waste facility, a containerized waste facility, and a treatment facility [16]. The Clive facility accepts waste from all regions of the United States [8].

The facilities are licensed by the State of Utah and permitted to dispose of Class A LLW, NORM, Class A MLLW, and 11e.(2) material (byproduct material from processing ore) [30]. The company receives Class A LLW from commercial nuclear power plants, medical facilities, research organizations, and contaminated sites undergoing remediation. Wastes received and disposed of include dirt and debris, contaminated material, protective clothing worn by nuclear facility workers, large components such as steam generators from nuclear facilities, resins, and radioactively contaminated medical waste. Oversize debris (at least one dimension greater than 12 feet or no dimension less than 10 inches) can be accepted, but is placed in a different area of the disposal embankment [16, 27, 30].

Liquid LLRW must be solidified with an approved solidification agent, resulting in as little free standing and non-corrosive liquid as is reasonably achievable [31]. The treatment facility can perform solidification of liquid LLW. Additional treatment capabilities are available for MLLW, including chemical stabilization, amalgamation, macroencapsulation, vacuum thermal desorption, and debris spray washing [16].

EnergySolutions also provides transportation services. Their services include obtaining any required local and federal licenses and permits, loading and bracing items and containers, conducting radiation surveys, and actually shipping the waste by rail, truck, or barge. EnergySolutions owns dozens of licensed Type A and B shielded shipping casks for customer use. They can transport large contaminated components and smaller items. Their transportation services cover exempt waste, hazardous material, low-level waste, intermediate-level waste, and high-level waste [27].

4.2.4 Texas Compact Waste Facility, Waste Control Specialists, Andrews, Texas

Waste Control Specialists (WCS) operates four disposal facilities on 1,338-acres in western Andrews county Texas. It is owned and licensed by the state of Texas and operated by Waste Control Specialists (WCS). The four facilities include the Compact Waste Facility (CWF), the Federal Waste Facility, the Hazardous Waste Facility (a RCRA-permitted Subtitle C landfill that can accept exempt waste), and the Byproduct Disposal Facility. Together they provide treatment, storage and disposal of LLW and MLLW, though MLLW is accepted only at the Federal Waste Disposal Facility [18, 32, 33] .

The CWF accepts commercially-generated LLW, regulated PCB waste, and federally generated waste. MLLW is not accepted. The facility has been operational since 2012 and is licensed to accept and dispose of up to 9,000,000 cubic feet or 3,890,000 curies of commercially-generated Class A, B and C wastes. The facilities incorporate a custom designed and engineered 7-ft. thick liner system, which includes a one-foot thick steel-reinforced concrete layer with a geosynthetic liner, located within a 1,200-ft thick nearly-impermeable clay formation [17, 18, 32].

The CWF accepts waste from the generators in Texas Compact states (Texas and Vermont). The CWF also accepts LLW from generators in 34 states that do not have an operating compact with advance permission from the Texas Low-Level Radioactive Waste Disposal Compact Commission. Non-compact waste is limited by the state of Texas to 30% of the licensed capacity. Waste generators sending LLW to the CWF include nuclear power plants, medical facilities and research centers. The State of Texas takes title to LLW disposed in the CWF, which eliminates future liability for the generator [8, 17, 32].

Special wastes accepted with various restrictions at the CWF include:

- Organic waste streams
- Debris
- Sealed sources
- Large components on a case-by-case basis [17]

The Hazardous Waste facility can accept various commercially generated nonradioactive wastes and exempt radioactive waste, which cannot go to the CWF. The Federal Waste Disposal Facility accepts LLW and LLMW from the federal government, only. The By-product Material Disposal Facility is not accepting wastes at this time [33].

5.0 Processing & Recycling Options

For waste streams that cannot be disposed directly at one of the four commercial LLW disposal facilities, other facilities offer various forms of LLW processing and treatment, and then transport and dispose of the residuals at a disposal facility. These processing facilities may remove and recycle tritium, reduce waste volume, solidify liquid waste, remove hazardous constituents, or perform a number of additional treatments. More information on various processing and recycling facilities is provided in the sections below and in Table 4-1, above.

5.1 NSSI, Houston, Texas

NSSI, in Houston, Texas, was established in 1971, manufacturing radioactive tracers and sealed sources and offering services and products for chemical and radioactive decontamination, leak testing, radiation instrument calibration, and waste processing/disposal. The waste processing/disposal portion of the business has grown to become NSSI's primary activity, encompassing treatment, storage, and disposal services for hazardous and non-hazardous wastes, radioactive waste, and mixed waste [19].

NSSI obtained a RCRA Part B permit as a hazardous and mixed waste treatment and storage facility in 1990. The facilities are regulated by the Texas Commission for Environmental Quality (TCEQ). NNSI provides storage and treatment of LLW and MLLW, and then ships the residues to permitted offsite facilities for land disposal or incineration. They are permitted to accept a full spectrum of EPA waste codes and all radionuclides, including special nuclear material, from generators in all states. NSSI also accepts and treats compressed gases, including those with radioactive constituents, and accepts sealed sources for consolidation and packaging for land disposal. NSSI can perform waste treatability studies for radioactive, mixed, and hazardous waste materials. NSSI also can design and fabricate specialized containers for land disposal of sealed sources and can provide personnel and equipment to help with packaging and transporting radioactive wastes at customer sites [19].

NSSI's waste storage facilities include covered, concrete-bermed areas for drum storage and bulk liquid stainless steel storage tanks. Treatment equipment includes an acid/base neutralization tank, slow speed mechanical shear shredder, oxidation/reduction reactor, vacuum distillation unit, dry waste compactor, stabilization system, and a continuous mercury retort system [19].

NSSI also operates a tritium recycling/recovery system as an alternative to the land disposal of materials with high tritium content. Land disposal sites limit the amount of tritium they can accept. Consequently, it may be preferable to remove and recycle tritium from certain higher-activity waste streams, from both economic and waste management perspectives. NSSI's tritium recycling/recovery system can accept tritiated materials with activities ranging from millicuries to "multicuries," including organic and aqueous liquids, organic and flammable gases, various types of metals, various capture beds, neutron generators, electron capture detectors, luminous devices, tritium contaminated mercury, gases, and light or heavy water [19, 34, 35].

NSSI's tritium recycling/recovery facility is comprised of the Tritium in Metal Station (TiT_2), the Mixed Waste Combustion Facility (MWCF), the Bed Unloading Station (BUS), the Electrolysis cell (ECell), and the Isotopic Separation System (ISS). The facility can recover greater than 99% of the tritium contained in those materials [19, 34, 35]. The TiT_2 process can decontaminate a variety of tritiated metals, including mercury, gallium, titanium, nickel, scandium and others, using a high-activity tritium gas handling station with a furnace that can heat to 900° C. Tritium gas driven from the metals is collected and further processed downstream. The MWCF is an EPA-approved process for destruction of MLLW that captures 99.99% of the incoming tritium on a molecular sieve while destroying the organic EPA hazards via catalytic furnace. The BUS uses compressed air, nitrogen, argon, hydrogen or helium gas to unload and condition tritium capture and storage beds including, but not limited to, molecular sieve beds, zirc-iron beds, copper beds, and nickel beds. The ECell is an alkaline electrolysis cell that breaks down both light and heavy water into its component hydrogen and oxygen, then directs the tritiated hydrogen to a liquid-phase catalytic exchange column, where the tritium is concentrated in water. The process is repeated until the tritium gas concentration reaches a target level. Then the gas is sent to the ISS. The ISS uses a thermal diffusion column to separate the heavier tritium gas, which settles to the bottom of the column, from the lighter hydrogen gas, which rises to the top. When the lower gas reaches a concentration of up to 5% pure tritium, it is removed to a metal hydride getter bed, which is shipped to a user facility for further enrichment and reuse [34, 35].

5.2 Bear Creek Processing Facility, EnergySolutions, Oak Ridge, Tennessee

The Bear Creek Processing Facility, located near Oak Ridge, Tennessee, is operated by Energy*Solutions*. Bear Creek is regulated by the state of Tennessee's Department of Environment and Conservation Division of Radiological Health, in cooperation with the NRC [27].

Bear Creek provides processing and packaging of radioactive material, then transports the waste for disposal at another facility. Their waste processing services generally focus on reducing waste volume and repackaging. Wastes can be sorted and segregated to reduce volume and separate wastes into fractions that can be compacted, incinerated, recycled, or repackaged for transportation and disposal. Compaction can reduce volume to about $1/20^{th}$ of the original volume. Some wastes can be incinerated to reduce volume by a ratio of up to 200 to 1 if the radionuclide content allows emissions to be within permitted limits. A smelter melts metals and recycles them to the nuclear industry by forming them into shield blocks. Bear Creek also has bulk waste assay capabilities for determining "green-is-clean" non-detection, which can allow potentially radiologically contaminated metals to be assayed and found clean enough to be released for salvage. Another process, "Safe Check," allows some non-recyclable materials to be cleared for disposal in a Tennessee RCRA Subtitle-D landfill, a less expensive option than disposal to a licensed Class A LLW disposal facility [27].

Bear Creek generally accepts Class A wastes, including liquids, sludges and solids. Liquid wastes may be either aqueous waste for evaporation (volume reduction) or oil to burn. Solids may be dry active waste (DAW) or metals. The waste acceptance guidelines for Bear Creek's Commercial Waste Processing facility state that the radionuclide concentration per package shall not exceed 0.03 $\mu Ci/cm^3$ for tritium and carbon-14 combined. Higher waste classifications or wastes that do not meet the waste acceptance guidelines, including some MLLW, may be accepted with special approval [20, 21]. Bear Creek can accept waste from anywhere in the United States, and can act as a waste broker, picking up wastes from the generator facility, for generators located in the eastern half of the country [36].

5.3 Perma-Fix, Various Locations

Perma-Fix, with their network of fully licensed and permitted radioactive and hazardous waste processing facilities in various states, can provide a number of waste management and transportation services for Class A, B, C and GTCC wastes. Since 1990 they have managed and treated wastes to meet waste acceptance criteria and land disposal requirements of various disposal facilities. Perma-Fix has a research and development lab to develop treatment protocols for difficult to manage wastes. They also provide transportation of the treated wastes to the major federal and commercial radioactive disposal facilities in the United States. Their clients include hospitals, research laboratories, institutions, nuclear utilities and various federal agencies [22].

Perma-Fix's nuclear waste services facilities include Diversified Scientific Services, Inc. (DSSI) in Kingston, TN, the Materials and Energy Corporation (M&EC) in Oak Ridge, TN, Perma-Fix of Florida (PFF) in Gainesville, FL, and Perma-Fix Northwest in Richland, WA. Waste services, which vary at each facility, include:

- Waste handling/minimization procedure development
- Waste sampling, analysis, characterization, and completion of waste profile forms for disposal
- Waste treatability studies
- On- and off-site waste packaging/repackaging
- Waste brokerage, manifesting, and transportation logistics services
- Radioactive, hazardous, and mixed waste treatment
- Radioactive decontamination
- Decay in storage
- Transuranic waste management
- PCB & Toxic Substances Control Act treatment
- Metal recycling
- Handling of large components [22]

Waste treatment services cover organic and inorganic LLW and MLLW, including all RCRA waste codes. LLW treatment processes include compaction, sorting and segregating of solid wastes, and thermal treatment of both liquid and solid wastes. MLLW treatment processes include decay in storage, macroencapsulation, neutralization, thermal treatment (including thermal destruction of Class A - C resins), mercury treatment, compaction, and other processes. The thermal treatment of LLW and MLLW can result in volume reductions of 30:1 for a mixture of solid wastes, and up to 100:1 for job-control types of waste (protective clothing, paper, etc.) [22]. The reduction of volume gained due to compaction or thermal treatment could lead to reduction of disposal costs.

Perma-Fix also provides transportation/waste brokerage services. Their transportation management team has agreements with a number of nationally recognized/approved transportation companies, providing waste transport to a number of LLW disposal facilities. Perma-Fix can assist with waste sampling, characterization, analysis, and certification, and they can prepare any required waste profile forms for the designated disposal facility. They can provide certified brokers to prepare required transportation documents to ensure that wastes are properly and accurately classified, marked, labeled, manifested and shipped [22].

6.0 Waste Brokerage & Transport services

Waste brokers offer many LLW and MLLW management and transportation services, which can be especially helpful for small quantity generators such as universities, research institutions, medical facilities, and some industries. Some brokerage companies provide services to waste generators across the nation while others focus on certain regions. Services provided vary from one company to the next, but common services include:

- Evaluating waste being produced and determining the appropriate disposal facility,
- Preparing a waste characterization and any required quality assurance documents,

- Preparing waste manifests,
- Providing containers and licensed and insured vehicles,
- Packaging or segregating and repackaging wastes,
- Marking and labeling waste packages,
- Inspecting and surveying containers,
- Loading and transporting wastes to final disposal destination,
- Providing some source processing , macro-encapsulation, or volume reduction,
- Scheduling routine regional "milk runs" to pick up wastes from multiple generators in an area to reduce transportation and disposal costs,
- Providing onsite support and services, such as development of waste management and minimization programs, and
- Providing Health Physics support [37-39].

Brokers can eliminate the need for waste generators to obtain individual licenses and certifications or to become experts in the field of waste disposal. Use of a waste broker may be advantageous for some generators because they:

- Know the requirements for completing and reviewing the packaging, marking and labeling of radioactive materials,
- Maintain radiological and regulatory expertise and logistics management to ensure compliance with DOT, NRC, state and local regulations,
- Maintain licenses and certifications that otherwise the waste generator would need to obtain, such as advanced-level certifications for public highway transportation through multiple states,
- Maintain contractual relationships and waste generator certification with every waste processing and disposal site in the nation,
- Assist the customer's waste management team to identify the best and most cost-effect approach for waste management and disposition,
- Provide routine regional "milk runs" to pick up wastes, reducing the storage time of materials at the generator's site and reducing the transportation cost, and
- Provide dedicated or emergency waste pick up service if service is needed outside of the scheduled "milk run." [37-39].

There are too many waste brokerage companies operating in the United States to discuss individually here. The LLW Forum, Inc. and the Southeast Compact Commission maintain a national directory of waste brokers and processors [40]. Some LLW disposal sites can provide a list of waste brokers approved for delivering waste to their disposal facility.

7.0 Representative Costs

Costs for tritiated waste processing and disposal vary based on where the waste is generated, the chosen disposal facility, and a number of factors related to the waste itself, such as:

- Volume and/or weight,
- Waste classification,
- Waste form/substrate,
- Specific isotopes,
- Other hazards in the waste,
- Whether categorized as MLLW,
- Total radioactivity of the waste stream or radioactivity per container,
- Size of container,

- Dose to the handler,
- Processing needed, and
- Whether the waste generator is from a state that is part of the disposal site's regional compact.

Costs may be based on general guidelines used by an individual disposal or processing site, but final costs are established by specific contract for each broker/generator or shipment to take into account all the case-by-case details of the waste. Some disposal facilities publish price guidelines. These can be used to calculate ballpark, budget-level estimates that do not necessarily take into account taxes, quantity discounts, and other factors that would be determined on a case-by-case basis. Published prices and other ballpark estimates generally apply only to wastes that strictly meet the facilities waste acceptance guidelines; additional fees would be charged for specially-approved wastes that exceed the guidelines in order to cover possible changes to the normal procedures and processes to handle higher activities and hazards.

In many cases, wastes with very low radioactivity are priced primarily based on volume or weight. For higher activities, costs are based on both volume and activity, with the activity-based charges usually being much larger than volume-based charges.

7.1 Disposal, Processing and Recycling Facilities Pricing

Disposal charges for the US Ecology facility in Hanford/Richland, Washington, are documented in a schedule of charges. The 24th revision became effective on May 1, 2016 [41]. The cost schedule for US Ecology is shown in Appendix A. Fees for waste disposal include a site availability fee, plus costs based on volume, number of shipments, number of containers, and exposure rate, plus other special surcharges.

As a Compact waste facility, the charging structure for the Barnwell Waste Processing Facility is produced and published annually to define the costs associated with use of that facility [42]. The charges are listed as the maximum charges that Chem-Nuclear may charge to generators from Atlantic Compact states. Charges are set annually by the South Carolina Office of Regulatory Staff and are based on various criteria, including waste density, dose rate, and activity, plus various surcharges. The maximum charges for fiscal year 2016 are shown in Appendix B.

Disposal rates for EnergySolutions' Clive facility are not published, but are negotiated on a case-by-case basis. A generic unit cost quote for various Class A LLW wastes from nuclear reactor decommissioning was published in the NRC's Report on Waste Burial Charges in 2013 [43]. The rates addressed only a cost per unit volume of various waste streams and assumed no volume discounts or activity surcharges. The costs for the Clive facility are shown in Appendix C along with an estimated updated cost per unit volume, using two different potential inflation factors. Actual costs may be quite different when radioactive content, dose rate, taxes and other factors are considered. A minimum charge of about $20,000, to cover the administrative costs that are independent of waste volume, may be assumed to apply [44].

The minimum charges that Waste Control Specialists must charge waste generators outside of the Texas Compact states (Texas and Vermont) are set by the Texas Commission on Environmental Quality in the Texas Administrative Code, Title 30, Rule §336.1310 [45], which became effective February 26, 2015. These charges are shown in Appendix D. Charges are based on volume, activity, weight and dose, plus other surcharges. Disposal fees charged to generators outside of the Texas Compact states must be greater than these charges. Disposal fees charged to generators located in the Texas Compact states must be equal to or less than these charges.

Budget-level pricing estimates for several waste types were obtained from NSSI for their tritium recycling facility. As noted with other facilities, the costs provided were ballpark estimates only. Actual pricing for a waste generator would be established by contract and might be very different than what is shown here depending on a variety of factors. Special runs would require additional charges to set up equipment. Some of the estimated costs include:

- Solvents: $2,500 per curie plus $250 - $500 per liter;
- Light and heavy water $150 - $2,500 per curie plus $250 - $500 per liter;
- Targets and foils: $2,000 - $3,500 per curie plus additional charges if disassembly or special handling is required;
- Uranium storage bed: $150 - $2,500 per curie (one curie minimum), plus $3,500 - $6,500 per run for setup, plus $2,900 per gram for uranium deactivation;
- Carbon/molecular sieve traps: $2,500 per curie, plus $3,500 per run for setup, plus $700 for heater modification;
- Electron capture device: $500 - $2,000;
- Commercial exit sign: $400 (unbroken) - $2,500 or more (broken) per sign;
- Tritium contaminated mercury: $350 per millicurie plus $500 per pound [46];
- Molecular sieve beds: Accepted on a per case basis. Acceptability and cost will be determined by the activity and agent [47].

Costs for the various waste processing companies are not published and are highly variable depending on the waste stream and the types of processing required. Costs for waste processing would be based on a number of factors, including those used to determine waste disposal costs, because the fees charges by the processing company would generally include the ultimate disposal fees. Processing facilities may limit the amount of tritium they accept to comply with their various permits, though exceptions may be granted on a case-by-case basis. For rough estimating purposes, costs may be approximately $5 to $7 per pound plus an additional per-millicurie fee for anything more than very low levels of activity. About $5 per millicure was mentioned by one processor as a representative per-millicurie fee. One facility estimated average fees of $1,500 to $15,000 per shipment for tritiated wastes up to one curie of activity, and a range of $15,000 per curie down to $6,000 per curie for higher levels of radioactivity [36, 48-50]. Facilities may have a minimum fee established to ensure their costs for preparing the considerable amount of paperwork involved are covered. These are very general estimates to provide an idea of the costs involved. The actual pricing for a specific waste stream and waste generator would be established by contract and could be very different than what is shown here depending on a variety of factors. These prices include both the processing and final disposition of the waste, and may also cover transportation costs.

7.2 Waste Broker Pricing

Costs for the various waste brokerage companies also are not published and are highly variable depending on the generator location, waste streams, waste volume and activity, and the final destination, among other factors. Each broker has different methods for calculating their charges, and the final charge would be determined on a case by case basis with a waste generator. General rule-of-thumb brokerage costs may be assumed to be about $5 to $8 per pound of waste. Additional pass-through costs from a disposal facility may be assumed to be from a few cents to $5 per millicurie for wastes with higher levels of tritium. An additional $1,800 to $4,000 may be added just for the transportation itself [51-54].

7.3 Calculation of Costs for Hypothetical Waste Streams

For the purposes of this report, hypothetical waste streams are defined so that costs can be compared from one waste management option to another. Hypothetical wastes are assumed to be in four categories:

- Low activity job control or DAW wastes, such as containment huts, plastic suits, gloves, shoe covers, wipes, rags, mops, small tools, etc.

- Medium activity scrap metal items such as valves, gauges, pumps, instruments, piping, discarded empty vessels, etc.,
- Higher activity items such as molecular sieves, and
- Aqueous waste such as bubbler fluids and wastewater from decontamination processes.

In all cases, tritium is assumed to be the only radionuclide present. For the low activity job control waste, it is assumed the waste would be Class A (<40 Ci/m^3). However, three different activity levels are assigned to trigger different cost categories at the various waste processing and disposal facilities. For the scrap metal wastes, different hypothetical waste streams are established for a Class A and a Class B waste stream. For the molecular sieve waste stream, it is assumed that that the beds would be disposed of when they reach 1,000 Ci to avoid exceeding the 1,100 Ci limit [55, 56] for a Type A shipping container. The hypothetical wastewater is assumed to be Class A (<40 Ci/m^3) waste and is assigned an activity of half the Class A limit. The resulting seven hypothetical waste streams are shown in Table 7-1.

Ballpark cost estimates for disposal of the hypothetical wastes at each of the four commercial low-level waste disposal facilities are shown in Table 7-2. Ballpark costs for processing (followed by disposal of) the seven hypothetical wastes at three commercial low-level waste processing facilities are shown in Table 7-3. Note that these are just rough estimates of potential fees based primarily on published guidelines and cost data (See Appendices A, B, C and D) for the waste disposal sites and on rough budgeting estimates provided by the processing facilities (discussed in Section 7.1). Actual costs would be established by specific contract between a generator and a disposal facility. Prices listed here do not necessarily take into account taxes, quantity discounts, and other site- and waste-specific factors.

Using the rough estimating guidelines discussed in Section 7.2, ballpark estimates of waste brokerage fees for these seven hypothetical waste streams are shown in Table 7-4. Note that these are just estimates of what brokerage fees might be based on verbally-obtained rough budgeting estimates provided by a few companies. Again, actual costs would be established by specific contract between a generator and a waste broker. Prices listed here do not necessarily take into account taxes, quantity discounts, generator facility location, and other site- and waste-specific factors.

Table 7-1. Hypothetical Commercial Tritiated Waste Streams

Waste Stream	Waste Class	Number of Containers per year	Assumed Actual Annual Waste Volume, m^3/yr (yd^3/yr)	Assumed Activity (Ci/m^3)	Assumed Density, kg/m^3 (lb/yd^3)	Total Annual Weight. kg (lb)
Job control waste, reduced activity, <1% Class A limit	Class A	4 B-25s [a]	10 (13)	0.03	300 (500)	3,000 (6,600)
Job control waste, <10% Class A limit	Class A	4 B-25s [a]	10 (13)	0.1	300 (500)	3,000 (6,600)
Job control waste, >10% Class A limit	Class A	4 B-25s [a]	10 (13)	5	300 (500)	3,000 (6,600)
Scrap metal waste, lower activity	Class A	3 drums [b]	0.62 (0.81)	39 [c]	1,400 (2,400)	900 (1,900)
Scrap metal waste, higher activity	Class B	3 drums [b]	0.62 (0.81)	1,600	1,400 (2,400)	900 (1,900)
Molecular sieve beds (one per drum)	Class B	20 drums [b]	4.2 (5.4)	4,800 [d]	400 (700)	1,700 (3,700)
Nonhazardous aqueous waste	Class A	~19 drums [b,e]	3.8 (4.9) [d]	20	1,000 (1,700)	3,800 (8,500)

NOTE: Surface dose rate for all containers is assumed to be <<1R/hr.

[a] B-25 waste containers hold approximately 2.5 m^3.

[b] Assuming 55 gal drums.

[c] Waste was assumed to be Class A, so it must be <40 Ci/m^3.

[d] Assuming the sieve bed is disposed of when it reaches 1,000 Ci, activity per unit volume would be 1,000 Ci/drum x 1 drum/55 gal x 264 gal/m3 = 4,800 Ci/m^3.

[e] Assumed annual wastewater volume was 1,000 gal/yr, which would require nineteen 55 gal containers, though they would not all be full. Calculations were based on the 1,000 gal/yr volume, not 19 full drums.

Table 7-2. Ballpark Estimates of Commercial Low-Level Waste Disposal Costs for Seven Hypothetical Waste Streams

Waste Stream	Waste Class	**US Ecology, Hanford** [a] (Northwest and Rocky Mountain Compact States Only)	**Barnwell** [b] (Atlantic Compact States Only)	**Clive** [c]	**Waste Control Specialists** [d] (Cost Assumes the Generator is in Texas)
Job control waste, reduced activity, <1% Class A limit	Class A	$128,000	$213,000	$213,000 to $264,000	<<$35,000
Job control waste, <10% Class A limit	Class A	$128,000	$214,000	$213,000 to $264,000	<<$36,000
Job control waste, >10% Class A limit	Class A	$128,000	$242,000	$213,000 to $264,000	$63,000
Scrap metal waste, lower activity	Class A	$43,000	$30,000	$3,400 to $4,200	$15,600
Scrap metal waste	Class B	$43,000	$245,000	Does not accept Class B	$242,000
Molecular sieve beds (one per drum)	Class B	$207,000	$317,000	Does not accept Class B	$367,000
Nonhazardous aqueous waste	Class A	Do not normally process liquid wastes	Cost info. not available	$15,000 to $18,000 [e]	Do not normally process liquid wastes

NOTE: These are not actual costs. These are just rough estimates of possible disposal fees based on published guidelines and cost data. Actual costs would be established by specific contract between a generator and a disposal facility. Prices listed here do not necessarily take into account taxes, quantity discounts, and other site-specific factors.

[a] Based on the US Ecology Washington, Inc. schedule of charges [41].

[b] Based on the Maximum Uniform Rate Schedule for Atlantic Compact Regional Waste [42], which sets a permanent ceiling on disposal rates applicable to Atlantic Compact waste.

[c] Rates calculated and updated from 2012 values reported in the 2013 NRC Report on Waste Burial Charges [43].

[d] Based on the rate schedule published in 30 Texas Administrative Code (TAC) §336.1310 [45]. These are the maximum rates that can be charged to generators located in states included in the Texas Compact (Texas and Vermont). Generators located outside of these states would be charged rates higher than shown here.

[e] The only liquid waste stream in the cost estimate information from the Clive facility was for evaporator bottoms. Price was listed only as cost per gallon. It is likely that costs per unit of activity would be added to this volume-based cost.

Table 7-3. Ballpark Estimates of Waste Processing Costs at Various Low-Level Waste Processing/Recycling Facilities for Seven Hypothetical Waste Streams

Waste	Waste Class	Bear Creek (Includes Brokerage and Disposal)	Perma-Fix (Includes Disposal)	NSSI (Includes Disposal)
Job control waste, reduced activity, <1% Class A limit	Class A	$40,000	$47,000	Doesn't offer treatment
Job control waste, <10% Class A limit	Class A	$43,000 + rad surcharge if waste is approved	$55,000	Doesn't offer treatment
Job control waste, >10% Class A limit	Class A	$288,000 + rad surcharge if waste is approved	$490,000	Doesn't offer treatment
Scrap metal waste, lower activity	Class A	$134,000 + rad surcharge if waste is approved [a]	Doesn't offer treatment	$25,000 [b]
Scrap metal waste	Class B	Expected to exceed rad limits [c]	Doesn't offer treatment	Expected to exceed rad limits
Molecular sieve beds (one per drum)	Class B	Expected to exceed rad limits [c]	Doesn't offer treatment	Costs determined on a case by case basis
Nonhazardous aqueous waste	Class A	$413,000 + rad surcharge if waste is approved	$722,000	$958,000 to $2,080,000

NOTE: These are not actual costs. These are just rough estimates of possible fees for processing and disposal. Actual costs would be established by specific contract between a generator and a processing facility. Prices listed here do not necessarily take into account taxes, quantity discounts, and other site-specific factors.

Sources: Personal communication with personnel from each facility [36, 47-50] and a price list specially prepared for this project from NSSI [46].

[a] Assumes the waste can be compacted.

[b] Cannot accept metals in excess of a few inches in any dimension. Price based on quoted price for tritium targets and foils.

[c] Exceptions may be possible on a case by case basis.

Table 7-4. Ballpark Estimates of Waste Broker Costs, Including Disposal Costs, for Seven Hypothetical Waste Streams

Waste	Waste Class	Company A	Company B	Company C
Job control waste, reduced activity, <1% Class A limit	Class A	$38,000 to $40,000	$53,000	$53,000
Job control waste, <10% Class A limit	Class A	$38,000 to $40,000	$53,000	$54,000
Job control waste, >10% Class A limit	Class A	$38,000 to $40,000	$83,000	$103,000 to $152,000
Scrap metal waste, lower activity	Class A	$18,000 to $136,000	$30,000	$40,000 to $64,000
Scrap metal waste	Class B	$262,000 to $5,000,000	Cost is much greater for Class B. Cannot provide general value.	$1,000,000 to $2,000,000
Molecular sieve beds (one per drum)	Class B	$5,000,000 to $100,000,000	Cost is much greater for Class B. Cannot provide general value.	$20,000,000 to $40,000,000
Nonhazardous aqueous waste	Class A	$66,000 to $430,000	Did not obtain info.	$141,000 to $216,000

NOTE: These are not actual costs. These are just rough estimates of possible fees. Actual costs would be established by specific contract between a generator and a waste broker. Costs will vary depending on whether the waste is picked up as part of a routine regional "milk run" or whether a special, dedicated transport is required.

Sources: Personal communication with various waste brokerage companies [51-54], not necessarily in the same order as shown in the table.

8.0 Conclusions

Disposal of tritiated low-level wastes is highly regulated and disposal options are limited. Potential waste transportation, processing and disposal possibilities should be investigated to ascertain that a disposal pathway exists before the waste is generated.

The information contained in this report covers general capabilities and requirements for the various disposal/processing facilities and a handful of brokerage companies, but is not considered exhaustive. Typically each facility has extensive waste acceptance criteria and will require the waste generator to thoroughly characterize their wastes and enter into a contractual agreement before waste is accepted. Options for Class A tritiated wastes are more numerous and less expensive than for Class B wastes, underlining the importance of waste management and contamination control strategies at the generator facility. Often transportation, processing and disposal companies can assist waste generators in this endeavor.

Costs for tritiated waste transportation, processing and disposal vary based a number of factors. For this report, seven hypothetical waste streams intended to represent commercially-generated tritiated wastes are defined in order to calculate comparative costs. Assumptions are made for waste type (job control waste, contaminated equipment, molecular sieve bed, aqueous waste), volume (ranging from 0.6 to 10 m^3/yr), density (300 to 1,400 kg/m^3), and tritium activity (0.03 to 4,800 Ci/m^3) so that costs can be calculated.

Actual waste volumes, densities and activities can vary from these values, significantly affecting the actual waste costs. In many cases, costs for wastes with very low radioactivity are based primarily on volume or weight. For higher activity wastes, costs are based on both volume and activity, with the activity-based charges usually being much larger than the volume based charges. Other factors affecting cost include location, waste classification and form, other hazards in the waste, etc. Costs may be based on general guidelines specific to an individual disposal or processing site, but final costs are established by contract with each generator.

Ballpark costs calculated for the hypothetical waste streams range from thousands to millions of dollars. Due to the complexity of the cost-determining factors mentioned above, the costs calculated in this report should be understood to represent very rough cost estimates for the various hypothetical wastes. Prices listed here do not necessarily take into account taxes, quantity discounts, generator facility location, and other site- and waste-specific factors. Waste compaction could reduce the cost for facilities that charge primarily by waste volume. Other factors for reducing costs could include waste minimization, waste segregation, contamination control at the source, fewer shipments with larger volumes, combining wastes with other generators via waste brokers, or decontaminating equipment before disposal.

9.0 References

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Appendix A: Schedule of Charges for US Ecology's Hanford/Richland Facility

US ECOLOGY WASHINGTON, INC.
WASHINGTON NUCLEAR CENTER
RADIOACTIVE WASTE DISPOSAL

Twenty-fourth Revision
Effective May 1, 2016

SCHEDULE A
Disposal Charge

Note: Rates in this Schedule A are subject to adjustment in accordance with the rate adjustment mechanism adopted in the Commission's Sixth Supplemental Order in Docket No. UR-950619 as extended by Commission Order in Docket Nos. UR-010623 and UR-010706 and TL-070848.

A. SITE AVAILABILITY CHARGE

1. Rates

Block	Block Criteria	Annual Charge per Generator
0	No site use at all	$282
1	Greater than zero but less than or equal to 10 ft³ and 50 mR/h	539
2	Greater than 10 ft³ or 50 mR/h* but less than or equal to 20 ft³ and 100 mR/h*	1,035
3	Greater than 20 ft³ or 100 mR/h* but less than or equal to 40 ft³ and 200 mR/h*	1,986
4	Greater than 40 ft³ or 200 mR/h* but less than or equal to 80 ft³ and 400 mR/h*	3,813
5	Greater than 80 ft³ or 400 mR/h* but less than or equal to 160 ft³ and 800 mR/h*	7,323
6	Greater than 160 ft³ or 800 mR/h* but less than or equal to 320 ft³ and 1,600 mR/h*	14,045
7	Greater than 320 ft³ or 1,600 mR/h* but less than or equal to 640 ft³ and 3,200 mR/h*	26,968
8	Greater than 640 ft³ or 3,200 mR/h* but less than or equal to 1,280 ft³ and 6,400 mR/h*	51,771
9	Greater than 1,280 ft³ or 6,400 mR/h* but less than or equal to 2,560 ft³ and 12,800 mR/h*	99,399
10	Greater than 2,560 ft³ or 12,800 mR/h* but less than or equal to 5,120 ft³ and 25,600 mR/h*	140,839
11	Greater than 5,120 ft³ or 25,600 mR/h*	140,839

* For purposes of determining the site availability charge, mR/hour is calculated by summing the mR per hour at container surface of all containers received during the year.

2. Exemptions

a. As to waste which is generated for research, medical or educational purposes, educational research institutions shall be placed in a rate block for the site availability charge which is one (1) lower than what would otherwise apply through application of the block criteria shown above. ***"Educational research institution" means a state or independent, not-for-profit, post-secondary educational institution.***

b. As to waste which arises as residual or secondary waste from brokers' provision of compaction or processing services for others, if application of the block criteria shown above would place a broker in a rate block for the site availability charge which is greater than Block No. 7, such broker shall be placed in the rate block which is the greater of (i) Block No. 7, or (ii) the block which is two (2) lower than what would otherwise apply through application of the block criteria shown above. "Brokers" are those customers holding the "broker" classification of site use permits issued by the Department of Health.

3. Payment Arrangements

a. Initial Determination

Initial determination as to the applicable rate block for each customer shall be based on projections provided by customers prior to the beginning of each calendar year. For those customers who do not intend to ship waste to the facility during the calendar year (those assigned to block No. 0) and for those customers who are initially determined to fall into block Nos. 1-2, the entire site availability charge for the year will be due and payable as of January 1. For those customers who are initially determined to fall into block Nos. 3-8, the entire site availability charge will also be due and payable as of January 1, although those customers may make special arrangements with the Company to pay the charge in equal installments at the beginning of each calendar quarter. For those generators who are initially determined to fall in block Nos. 9-11, 1/12 of the site availability charge will be due and payable as of the beginning of each calendar month. These customers may pay in advance if they wish.

b. Reconciliation

The site availability charge is assessed on the basis of actual volume and dose rate of waste delivered during each calendar year. Assessment of additional amounts, or refunds of overpaid amounts, will be made as appropriate to reconcile the initial determination regarding applicable rate block with the actual volume and dose rates during the calendar year.

SCHEDULE A (Continued)	US ECOLOGY WASHINGTON, INC. RICHLAND, WASHINGTON FACILITY RADIOACTIVE WASTE DISPOSAL RATES	EFFECTIVE MAY 1, 2016

B. DISPOSAL RATE

1.	Volume:	$114.00 per cubic foot	
2.	Shipment:	$13,510 per manifested shipment	
3.	Container:	$7,790 per container on each manifest.	
4.	Dose Rate:		
	Block No.	Dose Rate at Container Surface	Charge per Container
	1	Less than or equal to 200 mR/h	$24
	2	Greater than 200 mR/h but less than or equal to 1,000 mR/h	1,706
	3	Greater than 1,000 mR/h but less than or equal to 10,000 mR/h	6,750
	4	Greater than 10,000 mR/h but less than or equal to 100,000 mR/h	10,050
	5	Greater than 100,000 mR/h	169,300

EXTRAORDINARY VOLUMES

Waste shipments qualifying as an "extraordinary volume" under RCW 81.108.020(3) are charged a rate equal to 51.5% of the volume disposal rate.

NUCLEAR DECOMMISSIONING WASTE

The volume disposal rate applicable to waste from the decommissioning of nuclear generating units shall be 80% of that set forth above; provided, however, that such waste must satisfy the quantity requirements for "extraordinary volume" under RCW 81.108.020(3).

SCHEDULE B
Surcharges and Other Special Charges

ENGINEERED CONCRETE BARRIERS

72" x 8' barrier	$12,549.00 each
84" x 8' barrier	$13,779.00 each

SURCHARGE FOR HEAVY OBJECTS

US Ecology Washington, Inc. shall collect its actual labor and equipment costs incurred, plus a margin thereon of 25%, in handling and disposing of objects or packages weighing more than seventeen thousand five hundred (17,500) pounds.

SCHEDULE C
Tax and Fee Rider

The rates and charges set forth in Schedules A and B shall be increased by the amount of any fee, surcharge or tax assessed on a volume or gross revenue basis or collected by US Ecology Washington, Inc., as listed below:

Perpetual Care and Maintenance Fees	$1.75 per cubic foot
Business & Occupation Tax	3.3% of rates and charges
Site Surveillance Fee	$26.00 per cubic foot
Surcharge (RCW 43.200.233)	$6.50 per cubic foot
WUTC Regulatory Fee	1.00% of rates and charges

Source: US Ecology's Rates for Disposal of Low-Level Radioactive Waste at Richland, WA [41].

Appendix B: Rate Schedule for the Barnwell Facility

Pursuant to 48-46-40(A)(2), S.C.C.

Uniform Schedule of Maximum Disposal Rates for Atlantic Compact Regional Waste

EFFECTIVE JULY 1, 2016

The Uniform Schedule of Maximum Disposal Rates for Atlantic Compact Regional Waste is a permanent ceiling on disposal rates applicable to Atlantic Compact waste that is adjusted each year in accordance with the Producer Price Index. South Carolina may charge Atlantic Compact generators less than the Uniform Maximum schedule, but cannot charge regional generators more than this rate.

THE MINIMUM CHARGE PER SHIPMENT, EXCLUDING SURCHARGES AND SPECIFIC OTHER CHARGES, IS $1,000.00

1. WEIGHT CHARGES (not including surcharges)

A. Base weight charge

	Density Range	Weight Rate
i.)	Equal to or greater than 120 lbs./ft^3	$ 7.589 per pound
ii.)	Equal to or greater than 75 lbs./ft^3 and less than 120 lbs./ft^3	$ 8.348 per pound
iii.)	Equal to or greater than 60 lbs./ft^3 and less than 75 lbs./ft^3	$ 10.246 per pound
iv.)	Equal to or greater than 45 lbs./ft^3 and less than 60 lbs./ft^3	$ 13.283 per pound
v.)	Less than 45 lbs./ft^3	$ 13.283 per pound multiplied by: (45 ÷ pounds per cubic foot of the package)

B. Dose multiplier on base weight charge

Container Dose Level			Multiplier on Weight Rate, above
0 mR/hr	-	200 mR/hr	1.00
>200 mR/hr	-	1 R/hr	1.08
>1R/hr	-	2R/hr	1.12
>2R/hr	-	3R/hr	1.17
>3R/hr	-	4R/hr	1.22
>4R/hr	-	5R/hr	1.27
>5R/hr	-	10R/hr	1.32
>10R/hr	-	25R/hr	1.37
>25R/hr	-	50R/hr	1.42
>50R/hr			1.48

C. Biological Waste: Add $1.705 per pound to rate calculated above

Pursuant to 48-46-40(A)(2), S.C.C.

2. SURCHARGES

A. Millicurie surcharge — $0.569 per millicurie*

*In lieu of above, generator may opt for an alternative millicurie charge of $1.135 per millicurie applicable only to millicuries with greater than 5-year half-life. Such election must be provided in writing to the disposal site operator prior to July 1, 2015.

MAXIMUM MILLICURIE CHARGE IS $228,451 PER SHIPMENT (400,000 MCI).

B. Irradiated Hardware Charges (See Note B under Miscellaneous) — $86,253 per shipment

C. Special Nuclear Material Surcharge — $17.247 per gram

D. Atlantic Compact Commission administrative surcharge — $6.00 per cubic foot *(Subject to change during year)*

NOTES

A. Surcharges for the Barnwell Extended Care Fund and the Decommissioning Trust Fund are included in the rates.

B. Irradiated hardware: As a general rule, billing as irradiated hardware pertains to shipments of exceptionally high activity that require clearing of the site and special off-loading into a slit trench. These generally include TN-RAM and other horizontally offloaded cask shipments. In addition to items of irradiated hardware, shipments considered irradiated hardware, for purposes of disposal, have included certain sealed sources and materials with exceptionally high levels of radioactivity.

C. Large components (e.g., steam generators, reactor pressure vessels, coolant pumps)

Disposal fees for large components (e.g., steam generators, reactor pressure vessels, reactor coolant pumps, or items that will not fit into standard sized disposal vaults) are based on the generally applicable rates, in their entirety, except that the weight and volume used to determine density and weight related charges is calculated as follows:

1. For packages where the large component shell qualifies as the disposal vault per DHEC regulations, weight and volume calculations are based on all sub-components and material contained within the inside surface of the large component shell, including all internals and any stabilization media injected by the shipper, but excluding the shell itself and all incidental external attachments required for shipping and handling; and

2. For packages with a separate shipping container that qualifies as the disposal vault per DHEC regulations, weight and volume calculations are based on the large component, all sub-components and material contained within the inside surface of the shipping container, including any stabilization media injected by the shipper (including that between the large component and the shipping container), but excluding the shipping container itself and all incidental external attachments required for shipping and handling.

Pursuant to 48-46-40(A)(2), S.C.C.

D. Co-mingled shipments from brokers and processors: For containers that include waste from different generators (DHEC permittees), the weight and density of the waste from each generator will be assessed separately for purposes of the weight charge in I.A . The dose of the container as a whole will be used to assess the dose multiplier in I.B. The millicurie charge 2.A. above, applies individually to each portion of waste in the shipment from each generator. The disposal site operator will provide guidelines for application of this method.

E. Transport vehicles with additional shielding features may be subject to an additional handling fee which will be provided upon request.

F. In certain circumstances, the disposal site operator may assess additional charges for necessary services that are not part of and are additional to disposal rates established by the State of South Carolina. These include decontamination services and special services as described in the Barnwell Site Disposal Criteria.

G. The disposal site operator has established the following policies and procedures which are provided herein for informational purposes:

i. Terms of payment are net 30 days upon presentation of invoices. A per-month service charge of one and one-half percent (1½%) shall be levied on accounts not paid within thirty (30) days.

ii. Company purchase orders or a written letter of authorization and substance acceptable to CNS shall be received before receipt of radioactive waste material at the Barnwell Site and shall refer to CNS Radioactive Material License, the Barnwell Site Disposal Criteria and subsequent changes thereto.

iii. All shipments shall receive a CNS shipment identification number and conform to the Prior Notification Plan.

Source: South Carolina Office of Regulatory Staff [42]

Appendix C: Estimated Costs for EnergySolutions' Clive Facility

Generic Class A LLW Disposal Costs Estimates for the Clive Disposal Facility

Component Class	2012 Cost[a]	Estimated 2016 Cost[b]	Per Unit
Large Components	$350	$370 to $455	ft^3
Debris	$145	$150 to $190	ft^3
Oversize Debris	$165	$175 to $215	ft^3
Resins/Filters	$460	$485 to $600	ft^3
Combustibles	$575	$605 to $750	ft^3
Evaporator Bottoms	$14	$15 to $18	gal

[a] 2012 costs are from the 2013 NRC Report on Waste Burial Charges [43]

[b] Costs were adjusted to 2016 equivalent using 1) an inflation factor (1.05) derived from the most recent annual U.S. Department of Commerce's Implicit Price Deflator for Gross National Product [57]., and 2) the same average four-year (2008-2012) rate of increase in the alternative burial cost adjustment factor (1.3) seen from the NRC Report on Waste Burial Charges [43].

Appendix D: Rate Schedule for Waste Control Specialists' Compact Waste Facility

§336.1310. Rate Schedule

Fees charged for disposal of party-state compact waste must be equal to or less than the compact waste disposal fees under this section. Additionally, fees charged for disposal of nonparty compact waste must be greater than the compact waste disposal fees under this section.

Figure: 30 TAC §336.1310

Disposal Rate for the Compact Waste Disposal Facility

1. Base Disposal Charge:

1A. Waste Volume Charge	Charge per cubic foot ($/ft3)
Class A LLW - Routine	$100
Class A LLW - Shielded	$180
Class B and C LLW	$1,000
Sources	$500
Biological Waste (Untreated)	$350

1B. Radioactivity Charge	
Curie Inventory Charge ($/mCi)	$0.55
Maximum Curie Charge (per shipment) (excluding C-14)	$220,000/shipment
Carbon-14 Inventory Charge ($/mCi)	$1.00
Special Nuclear Material Charge ($/gram)	$100

2. Surcharges to the Base Disposal Charge:

2A. Weight Surcharge - Weight (lbs.) of Container	Surcharge ($/container)
10,000 to 50,000 lbs	$10,000
Greater than 50,000 lbs	$20,000

2B. Dose Rate Surcharge - Surface Dose Rate (R/hour) of Container	Surcharge per cubic foot ($/ft3)
1-5 R/hour	$100
Greater than 5 to 50 R/hour	$200
Greater than 50 to 100 R/hour	$300
Greater than 100 R/hour	$400

2C. Irradiated Hardware Surcharge	
Surcharge for special handling per shipment	$75,000/shipment

2D. Cask (Shielding Waste) Surcharge	
Cask handling surcharge per cask	$2,500/cask

Adopted February 4, 2015 Effective February 26, 2015

Source: 30 Texas Administrative Code (TAC) §336.1310 [45] These are the maximum rates that can be charged to generators located in states included in the Texas Compact (Texas and Vermont). Generators located outside of these states would be charged rates higher than shown here.