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Cradle To Grave Lifecycle Process Analysis For Transuranic Waste Management Los Alamos National Laboratory

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CRADLE TO GRAVE LIFECYCLE PROCESS ANALYSIS
FOR TRANSURANIC WASTE MANAGEMENT
LOS ALAMOS NATIONAL LABORATORY

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Master's Program in Mechanical Engineering

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by

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ABSTRACT

Amid World War II, in the late 1930s, nuclear fission was discovered. This revolution gave way to the development of nuclear technologies, including the world's first atomic bomb; these advancements in nuclear research left behind radioactive waste. Radioactive waste is known as the byproduct of nuclear reactors, fuel processing plants, hospitals, nuclear research facilities, as well as the result from the decommissioning and dismantling of radiation-exposed buildings and materials. This byproduct may be dangerous to workers, the public, and the environment and must, therefore, be handled with utmost safety. Given this, radioactive waste must be processed, stored, and disposed of safely. This study found that radioactive waste management differed broadly by national laboratory. Hence, this study was guided based on not having a physical document devoted to the understanding of the lifecycle of transuranic waste at the Los Alamos National Laboratory (LANL).

Information was gathered through public resources, as well as from on-site documentation. Compilation of data to further understand the radioactive waste management process at the Los Alamos National Laboratory was carried out. Therefore, this study would focus on the transuranic waste lifecycle from planning and generation to its end destination for permanent isolation or disposal. The subsequent arguments guided this study:

- Study the Transuranic Waste lifecycle from generation to disposal.
- Document the processes and regulations that follow the waste management cycle.
- Analyze the current workings to enhance the waste management process.

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INTRODUCTION

Business Structure

The Los Alamos National Laboratory (LANL) encompasses two major federal entities; the National Nuclear Security Administration (NNSA) Los Alamos Field Office (NA-LA) and the Department of Energy (DOE) Environmental Management (EM) Los Alamos Field Office (EM-LA). These two federal entities both conduct oversight of the national laboratory's two significant contractors, Triad National Security, Limited Liability Company (Triad), and Newport News Nuclear BWXT Los Alamos (N3B), respectively (Figure 1 – Los Alamos National Laboratory Management Structure).

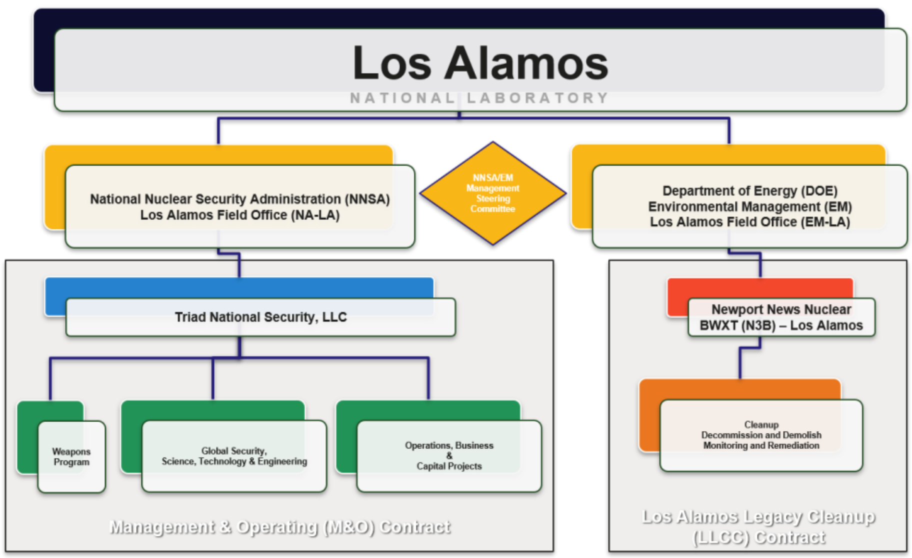

Figure 1 – Los Alamos National Laboratory Management Structure

The Triad contractor manages and operates the LANL programs, such as weapons, global security, science, technology, engineering, operations, business, and capital projects. Triad does this through a Management and Operating (M&O) contract; hence, Triad is the M&O contractor for LANL. N3B performs services for EM-LA under the Los Alamos Legacy Cleanup Contract (LLCC). The LLCC involves cleanups, decommissioning, demolishing, monitoring, and remediation of the radioactive legacy waste at LANL. N3B may conduct services for Triad, and vice versa, these may be unforeseen and must be handled through their respective federal entities. Consecutively, transuranic (TRU) waste disposed of at the Waste Isolation Pilot Plant (WIPP), which is overseen by the Carlsbad Field Office (CBFO). WIPP is the only repository for the disposal of TRU waste, which is the result or byproduct of the nation's nuclear defense program (WIPP, n.d.-a). CBFO oversees WIPP, similarly to how the LANL business organizational structure operates.

History

In the early 1900s, on December 7 of 1941, Japan attacked Pearl Harbor. On December 8, 1941, the United States of America entered World-War-II (WWII); this marked the beginning and the development of nuclear research, which later became the end of WWII (Foundation, 2019). In December of 1942, the Manhattan Project began. In January of 1942, project Y (LANL, 2019), a top-secret project meant for the development of the world's first nuclear weapon, a site known today as Los Alamos, NM. On July $16^{th,}$ 1945, the United States successfully tested the first atomic bomb at the Trinity Site on the outskirts of Alamogordo, NM. On August 6^{th} and 9^{th} of 1945, Little Boy and Fat Man were dropped on Hiroshima and Nagasaki, respectively. Thus terminating WWII after the surrender of Japan, which also meant that the Manhattan Project had come to an end.

Ending WWII gave way to the beginning of a new area, an area that is known as the Cold War, a long battle that lasted almost 46 years, from 1945 to 1991. This led to even more nuclear weapon research. During the development of the nation's nuclear stockpile, there was no path forward for TRU waste, so it was left in storage units or buried underground. This incited the government to come up with a plan to dispose of TRU waste in a manner that would be deemed safe for all the stakeholders involved. Various explorations and extensive research were conducted to identify the most effective way to dispose of or store TRU waste. In 1974, the Atomic Energy Commission (AEC), an agency now known of as DOE, chose Carlsbad, NM. Carlsbad locates geologically stable salt beds in the area. These beds found to be free of flowing water is mined easily, are impermeable, and geologically stable. The salt rock also had the characteristic of sealing fractures and openings, which meant that this was a perfect site to dispose of the metric tons of nuclear waste generated by the nation's national projects. (Foundation, 2019)

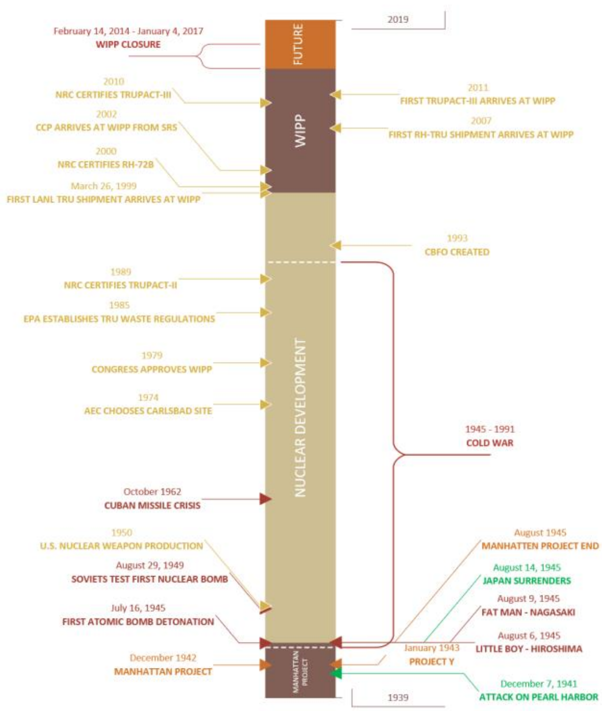

Figure 2 - Nuclear History developed using Microsoft Visio

Background

Radiation can be known as the energy given off by matter in the form of rays or energetic particles. Matter is comprised of atoms, which are conformed of protons and neutrons. The protons and neutrons are surrounded by electrons (Figure 3 - Atom Anatomy). The protons and neutrons form something called the nucleus (Britannica, 2019). The nucleus carries a positive charge, while electrons carry a negative charge. Unstable nuclei may emit energy to reach a steady-state attempting to rid of excess atomic energy; this form of energy may be referred to as radioactivity (Ministry of the Environment Government of Japan, 2018).

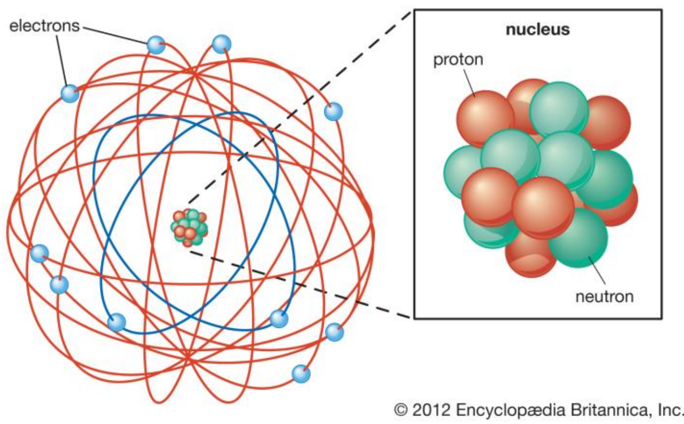

Figure 3 - Atom Anatomy (Britannica, 2019)

When these unstable atoms attempt to stabilize by emitting radiation to rid of the excess atomic energy, they are said to undergo radioactive decay (U.S. Nuclear Regulatory Commission, 2019). Some of these isotopes may decay in seconds, some in minutes, but others may decay far slower. For example, I-131 has a half-life of 8.02 days, whilst I-129 has a half-life of 15.7 million years (Table 1 – Isotope Half-life). Radioactive decay can be measured in terms of a half-life. The half-life of a radioisotope measures the time required for the unstable matter to reduce by one-half (

).

Table 1 – Isotope Half-life (United States Environmental Protection Agency, 2017)

ISOTOPE	HALF-LIFE
I-131	8.02 days
I-129	15.7 million years
Pu-240	6564 years
Pu-239	24,110 years
Pu-238	87.7 years
U-238	4.47 billion years
U-235	700 million years

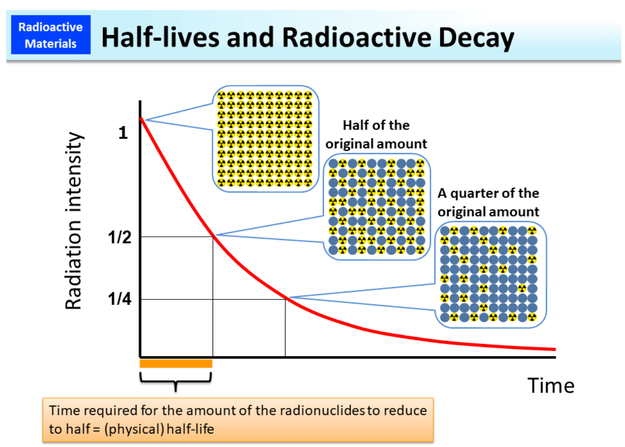

Figure 4 - Half-lives and Radioactive Decay table *(Ministry of the Environment Government of Japan, 2018)*

Moving into the electromagnetic spectrum, two different forms of radiation are evident; ionizing and nonionizing radiation. Nonionizing radiation may be described as low-energy rays or particles not having enough energy to remove an electron from an atom (National Cancer Institute, n.d.). Whereas, ionizing radiation may deposit enough energy, as it passes through a material, to displace or remove electrons from atoms by breaking molecular bonds. Ionizing radiation may be emitted as alpha particles, beta particles, or gamma rays (Figure 5 - Ionizing Radiation Spectrum). Alpha particles have the largest mass (Gordon, 2019); they can be blocked by a sheet of paper or even by a few inches of skin. Beta particles have the ability to penetrate other materials, given that they are smaller than Alpha particles. Gamma rays can travel great distances at the speed of light (U.S. Nuclear Regulatory Commission, 2017), but they may be stopped by a few layers of concrete or lead. Neutrons are the only radioactive particles capable of making objects radioactive; it requires large amounts of hydrogen-containing materials, such as water, to slow down or block neutron particles.

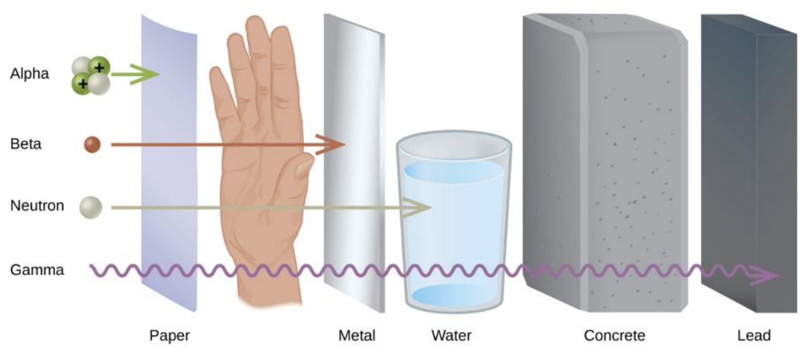

Figure 5 - Ionizing Radiation Spectrum (Gordon, 2019)

Dosimetry

Dosimetry can be defined as the amount of material (e.g., administered dose or exposure) in the environment or body (Philbert & Sayes, 2010). In terms of radiation, the radiation dose is "…the amount of energy deposited in a given mass of a medium by ionizing radiation…" (L'Annunziata, 2012). These dosimeters may be worn by anyone who may be exposed to radiation. Dosimeters then measure the radiation exposure of the beholder and record the dose, ensuring the individual does not receive a radiation dosage larger than permitted. Depending on the radiation exposure expected, there is a specific dosimeter for every case. LANL utilizes five general dosimeter types (Figure 6 – Dosimetry): Thermoluminescent Dosimeter (TLD), Track-etch, Wrist Dosimeter, Personnel Criticality Dosimeter (P-nad), and the Los Alamos Criticallity Dosimeter (LACD) (LASL UC, 1981).

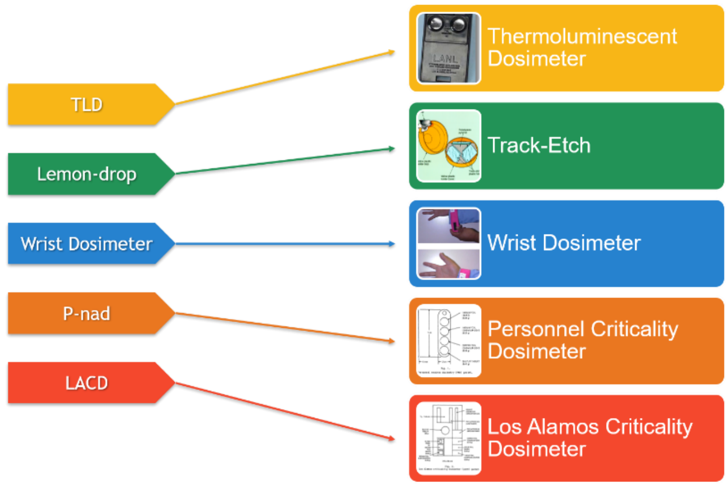

Figure 6 – Dosimetry at Los Alamos National Laboratory

Thermoluminescence caries a physical characteristic in which particular crystalline structures, called phosphors, absorb energy from ionizing radiation and release it in the form of light when heated up to 100˚C to 200˚C (IAEA, 2004). The intensity of the light may then be related to the radiation dose of the phosphor crystalline material. TLD's, also known as Whole-Body Dosimeters, detect slow energy neutrons. The Track-etch measures high-energy neutrons. Both the TLD and the Track-Etch must be worn simultaneously for an accurate dose reading, placed in the torso region without any barriers. Similar to the TLD, Wrist Dosimeters detect low, slow energy neutrons. In special cases, non-uniform radiation exposure may be present; therefore, the Wrist Dosimeters are worn at the extremities. P-nad and LACD measure critical doses of radiation in the event of a nuclear criticality accident. The P-nad is worn similarly to the TLD and Track-etch above the waist but below the neck, while the LACD is a facility or ambient radiation detector which makes it stationary. Dosimetry is a vital aspect of radioactive waste management. This is especially important for workers, the public, and the environment to ensure they are protected from accidental exposures.

Radioactive Waste

There are three major types of radioactive waste classifications: High-Level Waste (HLW), Low-Level Waste (LLW), Mixed Waste, and Transuranic Waste (TRU). HLW results from the reprocessing of spent nuclear fuel (U.S. Department of Energy, 1999). LLW is byproduct material or naturally reoccurring radioactive materials. (U.S. Department of Energy, 1999) TRU waste is waste that contains materials with elements with an atomic weight heavier than uranium; hence, the term trans-uranic. TRU waste contains 100 nanocuries or more of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years (U.S. Department of Energy, 1999). The curie is simply a measure of the activity of a radioactive source (Enderle & Bronzino, 2012). HLW will, at every point, be considered Mixed Waste, whereas LLW and TRU will only be considered Mixed Waste unless it contains Hazardous Waste (Figure 7 - Radioactive Wast). TRU waste consists primarily of tools, rags, protective clothing, sludges, soil, and other materials contaminated with radioactive elements, which are the byproduct of the nation's nuclear defense program (WIPP, n.d.-d). Mixed waste is defined by the DOE Manual 435.1 as "...waste that contains both source, special nuclear, or by-product material subject to the Atomic Energy Act of 1954, as amended, and a hazardous component is also subject to the Resource Conservation and Recovery Act (RCRA), as amended. (U.S. Department of Energy, 1999)

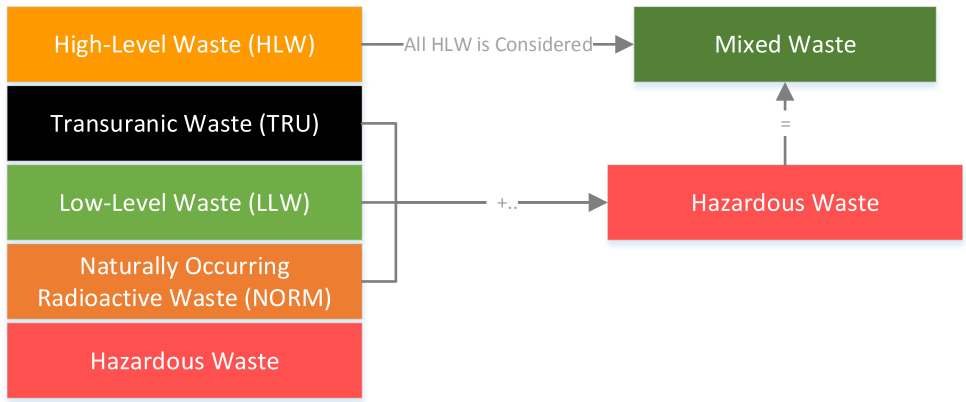

Figure 7 - Radioactive Waste is classified as HLW, LLW, and TRU. Aside from these are NORM and Hazardous Waste. TRU, NORM, and LLW mixed with Hazardous Waste are classified as Mixed Waste All HLW is considered mixed waste per DOE M 435.1 (U.S. Department of Energy, 1999).

PROBLEM

The Office of Enterprise Assessments (EA) conducts revision assessments ever so often at each national laboratory or site. When it became LANL's turn, the Radioactive Waste Management process was to be assessed. Throughout the assessment, visitors, which were foreign to the waste management process at LANL, asked, how does LANL manage radioactive waste? This is where the problem sprung; no document could assess which specified how radioactive waste is managed at LANL. The research was done in trying to identify or locate possible files through all parties involved in TRU waste management at LANL, but the result was a bundle of documents, not specifying the TRU waste management process. There are Subject Matter Expert's (SME) that have a general idea of how radioactive waste is managed, but relying on each SME for answers is not as efficient as if there were a background document expressing this matter.

Moreover, the task was set to understand the radioactive waste management process at LANL and consolidate all the information into a single document. Given that each type of waste is managed differently, this study would be focusing on the TRU waste lifecycle, to begin with. The study would embrace TRU waste from its planning phase up to its end destination for permanent isolation at the WIPP national repository. The final product would then be the consolidation of the information gathered through the cradle to grave study and develop a process flow analysis of the entire TRU waste management process. Data was collected through public sources, as well as from on-site unclassified documentation.

SOLUTION ALTERNATIVES

Radioactive waste is managed and administered in the following stages (LANL Procedures, 2019):

- Planning and Identification
- Generation
- Packaging
- Handling
- Characterization
- Treatment
- Storage
- Certification
- Transportation/Shipping
- Disposal

They are tracked from planning to disposal by means of an internal software called Waste Compliance and Tracking System (WCATS). The peculiar thing about managing waste is that there is no specific generalized route for any type of waste. Therefore, it must all be tracked and managed according to each specific needs and requirements. In instances where waste does not possess a disposal path, it must meet specific requirements before it can be generated. (EPC-WMP ADESH-AP-TOOL-300, 2017).

Specifically, for TRU waste there are a couple of entities that ensure waste is managed correctly; Nuclear Process Infrastructure (NPI-7), ensures that all activities in nuclear facilities are conducted in compliance with applicable environmental regulations and Laboratory policies; Central Characterization Program (CCP): characterizes and certifies TRU waste containers for shipping; Environmental Protection and Compliance Waste Management Program (EPC-WMP): provides support to waste generators and oversight of institutional waste management processes to ensure compliance with applicable policies, orders, and regulations. These are some of the essential entities at LANL who are involved in managing waste. The disposal aspect of it, such as characterization, is governed by WIPP/CBFO.

Generation

Radioactive waste generated at LANL can be further subdivided into legacy and new-gen waste. Legacy waste is waste that was generated during the cold war era; much of this waste must be repackaged or reprocessed to meet WIPP certification criteria for disposal, given that WIPP did not exist at the time of generation. Most of this waste is TRU, but portions are LLW (EM-LA, n.d.). Alternatively, New Gen waste, is all waste that was packaged or generated after July of 1999 and is compliant with WIPP. Nearly all this waste is TRU and knowledge of the generation process can proceed with documentation.

Retrieval

Radioactive waste retrieval pertains to waste classified as Legacy Waste; EM manages this at LANL through their LLCC contractor N3B. This Legacy Waste must be cleaned up due to public and environment health concerns. There are over 2,100 identified contaminated sites at LANL, which is recognized for action, and over half of them (1,100) are closed as of 2019 (U.S. Department of Energy, n.d.). These contaminated sites range from small spill sites with only several cubic feet of contaminated soil to large landfills encompassing several acres. Cleanup locations include sites of former LANL buildings, hillsides, canyon bottoms, and old landfills. Surface and groundwater monitoring and remediation, removing contaminated soil, and decontaminating and decommissioning surplus process-contaminated structures must be performed to ensure traces of harmful radiation are recovered and disposed of safely. TRU waste recovered is packaged, certified, and shipped to WIPP for disposal.

Handling

There are two types of radioactive waste handling methods; contact handled (CH) and remote handled (RH). CH pertains to around 96 percent of the volume of transuranic waste discarded at WIPP is contact handled, meaning crew members handle waste containers manually. This waste transmits primarily alpha and beta radiation, which can be securely taken care of under controlled conditions without special shielding. The 55-gallon metal drums and boxes are plentiful protection from this sort of radiation. The RH transuranic waste emits penetrating gamma radiation that must be handled and transported in lead and steel-shielded transportation containers. This type of waste is handled with machinery and at a distance to prevent or minimize worker exposure. RH has recently been denied shipment to WIPP due to exposure concerns.

Treatment

Treatment can be defined as “any method, technique, or process designed to change the physical or chemical character of waste to render it; less hazardous; safer to transport, store, or dispose of; or reduce its volume” (EM - Office of Environmental Management, 1988). These types of treatments include, but are not limited to, cementation, pH control, compaction, solidification, incineration, and overpacking (LANL INSIDE, 2019).

Treatment must be authorized under the LANL Hazardous Waste Facility Permit (HWFP) or must be exempt from permitting requirements before waste generator or Treatment and Storage Facility (TSF) engagement. In the case of waste treatment, those who plan on engaging in any activity which may constitute treatment must first contact the Environmental

Protection Division Compliance Programs group. Refer to: ADESH-AP-TOOL-901 Elementary Neutralization; ADESH-AP-TOOL-902 Sorption without a Permit; and ADESH-IG-TOOL-906 Treatment by the Waste Generator. Waste treatment may is conducted under LANL HWFP or interim status documents as outlined in the: ADESH-IG-TOOL-903 LANL HWFP TA-55 Storage in Tanks and Treatment by Stabilization; ADESH-IG-TOOL-904 Treatment by Open Burning; ADESH-IG-TOOL-905 Treatment by Open Detonation; and ADESH-IG-TOOL-907 Stabilization Containers. (LANL Procedures, 2019)

Characterization

At generator sites, crews use various methods to ensure that waste destined for WIPP meets the stringent criteria for TRU waste emplaced in the repository. The following is a list of characterization methods used at LANL (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018):

- Acceptable Knowledge (AK):
    - Documents radiological and hazardous waste characterization of waste given an approved Sampling and Analysis. AKs may be substituted for analytical data if complete and documented appropriately. AK may include but is not limited to: Source Information; Gross Radiation Measurements; Calculations; Surface Contaminated Objects (SCOs). (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018)
- Non-destructive Assay:
    - Delivers measurement of radioactive and nuclear materials for characterization purposes. Non-destructive Assay may include but is not limited to radiological waste container characterization, assessments of the material hold-up in process

equipment, confirmation and verification measurements of special nuclear materials for safeguard processes, and quantification of fissile materials for criticality safety purposes. Only LLW and TRU waste utilize NDA, and Release and Clearance of Property may not. (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018)

- Sampling and Analysis:
    - Sampling and Analysis utilizes ADESH-AP-TOOL-111 Waste Characterization and the Data Quality Objective Process. In the case that none of these become applicable, the data will be considered acceptable knowledge. (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018)
- Release and Clearance of Property:
    - Release of property, soil, rubble, and debris from demolition or remediation activities. Material may contain low levels of radioactivity, which is higher than the background, but below radiological release limits. The release of this goes through EPC-ES-TP-016 Environmental Radiation Protection Program under DOE O 458.1. If the criteria from the said DOE Order are to meant to establish, then utilize ADESH-AP-TOOL-317 Authorized Release Limits Proposal Process. Evaluation undergoes EPC-ES-FSD-004 Environmental Radiation Protection. (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018)
- Re-characterization of Waste Stream:
    - Waste characterization must undergo updates in the following cases (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018):

    - There is a change to the waste-generating processes or operations; analytical results indicate a discrepancy in the waste stream description; new characterization information becomes available.
    - There is a change in the ownership of a waste stream profile (WSP); loss of process controls that are in place to ensure generated waste remains within the bounds of the WSP
    - Inconsistencies in the AK documentation are identified; waste is repackaged and no longer matches the characterization in the WSP
    - Annual notification of AK waste streams indicates the waste does not match the waste specified by the waste generator
    - Inspection reveals that the waste does not match the identity of the waste determined by the waste generator or a manifest or shipping paper.
- AK Briefings:
  - Groups directly involved in the generation, characterization, and management of TRU waste streams and containers are expected o participate in the AK briefings by CCP and/or LANL. (EPC-WMP ADESH-AP-TOOL-314 Rev. 1, 2018)

Other characterization methods may be but are not limited to, Flammable Gas Analysis, Enhanced Acceptable, Visual Inspection, and Non-destructive Examination.

CCP conducts the waste certification of LANL; WIPP/CBFO manages this program. WIPP receives waste and utilizes a set of documents to verify and certify appropriate waste characterization. These are controls documented in the WIPP WAC Appendix H; captured in the interface agreement; and developed by CCP per CCP-TP-005 CCP Acceptable Knowledge Documentation reviewed in accordance to CCP-TP-200 Chemical Compatibility Evaluation

Memorandum and Acceptable Knowledge Assessment Review; these are the following documents (LANL NPI-7, 2019):

- Interface Waste Management Documents List (IWNDL):
    - These record documents relevant to waste generation, characterization, management, packaging, remediation, and treatment for each respective waste stream.
- Acceptable Knowledge Assessment (AKA):
    - AKAs document additional waste scrutiny and assess neglection or errors in the process.
- Chemical Compatibility Evaluation Memo (CCEM):
    - This document and communicates the evaluation and conclusion of the potential for chemical incompatibility. CCEM provides a basis for placing an administrative hold on the affected waste via the issuance of a CPP Nonconformance Report (NCR).
- Basis of Knowledge (BoK):
    - BoK relates to the evaluation of oxidizing chemicals in TRU waste streams to determine acceptability or need for treatment.
- Acceptable Knowledge (AK) Summary Report:
    - Provide defensible and auditable records of AK for waste streams. The revision of this documentation determines if the description of the waste stream appears complete and accurate.

- Waste Stream Profile Form (WSPF):
  - A review of these is to verify the information provided is complete and accurate.

CCP uses two types of flow analysis for characterization for previously certified containers and newly certified containers (Figure 8 - CCP Certification flow for Previously Certified Containers (left) and Newly Certified Containers (right)). Previously Certified Containers refers to those containers certified prior to the 2017 WIPP Waste Acceptance Criteria (WAC). These containers must be recertified to meet WIPP requirements prior to shipment. Newly Certified Containers are those containers that were newly generated and require certification.

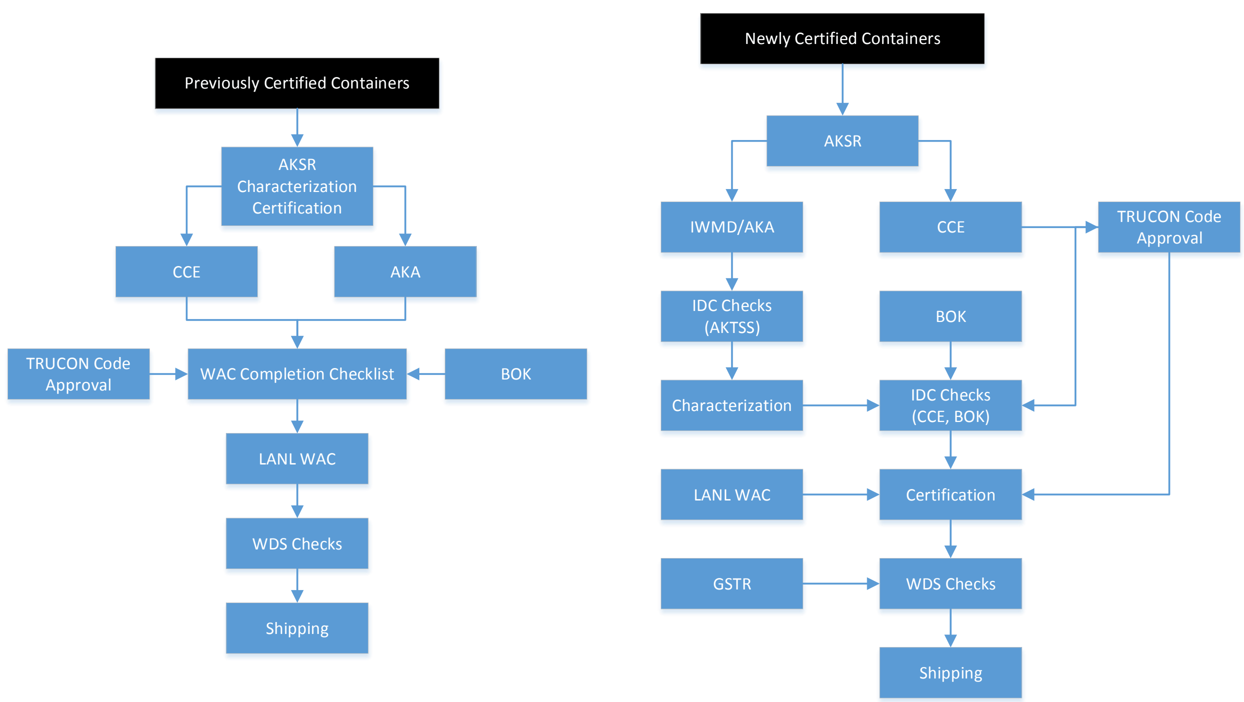

Figure 8 - CCP Certification flow for Previously Certified Containers (left) and Newly Certified Containers (right) (LANL, n.d.)

Packaging

LANL ships TRU waste to WIPP in different types of containers; 55, 85, 100 -gallon drums, in a 7, 4, 3 -pack respectably (WIPP, n.d.-c), as well as large containers for large dimension waste (Carlsbad Field Office, 2017).

Transportation/Shipping

Waste containers are certified before shipment to WIPP by CCP meeting LANL WAC and WIPP WAC, among other certification criteria (Figure 11). Highly qualified drivers, using predetermined routes, transport TRU waste in certified casks, called TRUPACTs designed to withstand a variety of worst-case scenarios. There are two primary TRUPACTs used; TRUPACT-II (Figure 9 - TRUPACT-II) and HalfPACT (Figure 10 – HalfPACT).

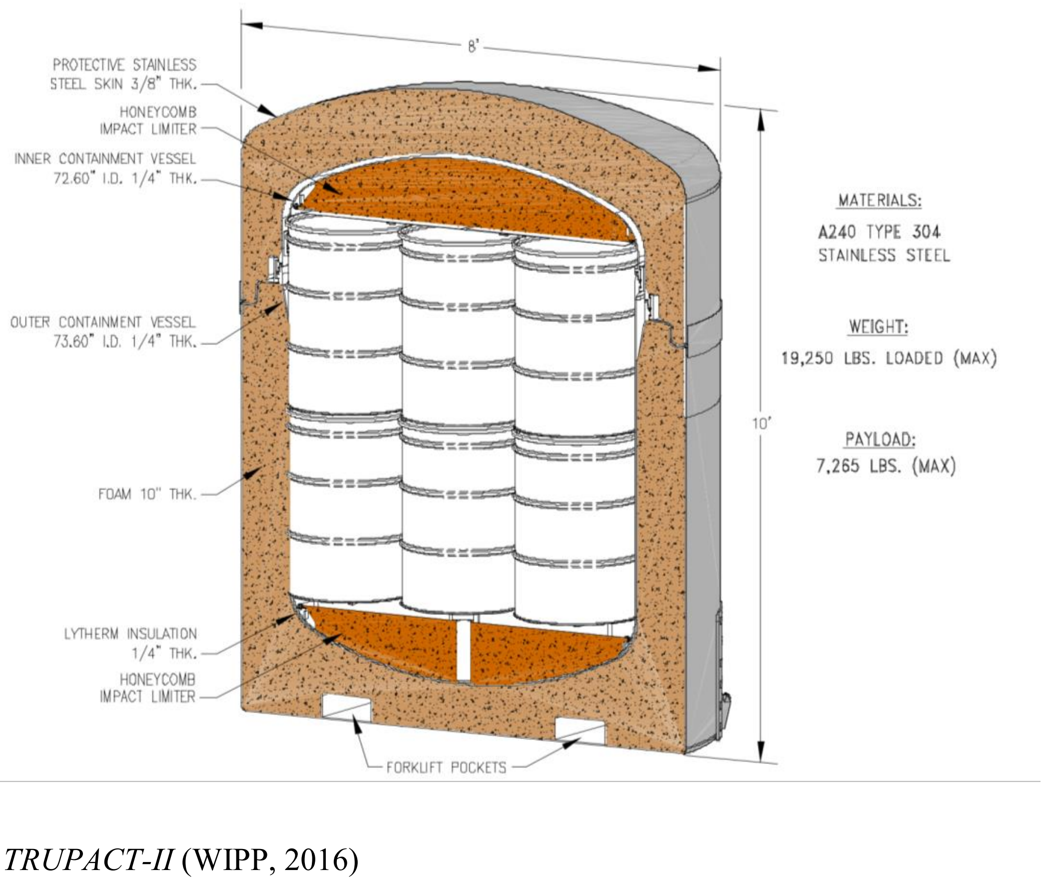

Figure 9 - TRUPACT-II (WIPP, 2016)

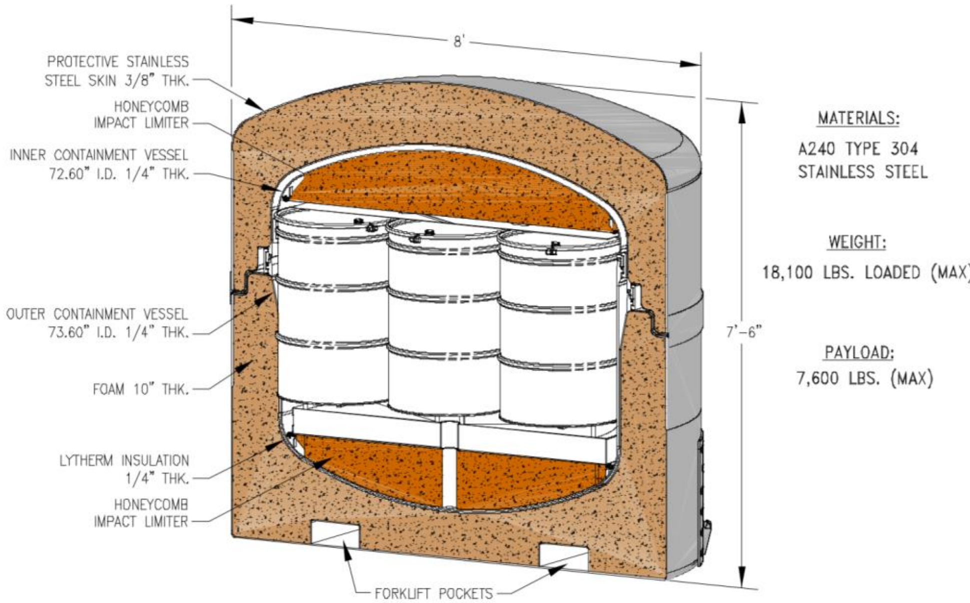

Figure 10 – HalfPACT (WIPP, 2016)

Both the TRUPACT-II and the HalfPACT are tested and certified by the Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT) (WIPP, n.d.-b). Also, during transportation, compliance must be met with laws, requirements, regulations, and agreements from federal, state, local, and tribal entities. They are tested to meet the following criteria and testing to ensure safe transport and delivery to WIPP (WIPP, n.d.-b):

- Free-Drop Test: the transportation cask is dropped from 30 feet onto a flat, unyielding surface (such as a steel-reinforced concrete pad), striking the surface at the weakest point.
- Puncture Test: next, the transportation cask is subjected to a 40-inch free drop onto a six-inch diameter steel bar at least eight inches long.
- Burn Test: the transportation cask is drenched with jet fuel and ignited, subjecting it to a temperature of 1,475 degrees Fahrenheit for 30 minutes.

- Immersion Test: conducted by utilizing specialized analyses, a separate transportation cask of the same design subject to external pressure equivalent to being immersed under 50 feet of water.

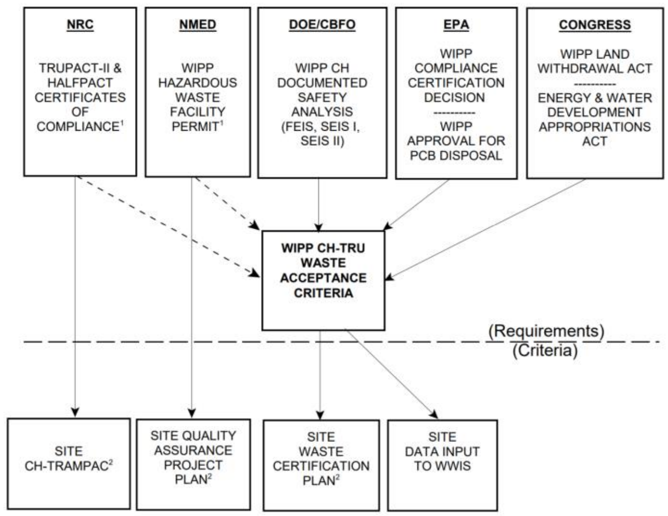

Figure 11 - WIPP WAC regulatory agency’s' requirements and criteria for CH waste. *(WIPP, 2018)*

Disposal/Emplacement

All TRU waste is destined to be disposed of at WIPP in the underground repository located 2150 ft below ground level. Underground, TRU waste is escorted by trained crews to the disposal panel, where it will remain, safely isolated from the environment, forever.

SUMMARY AND CONCLUSIONS

This thesis has demonstrated the broad extent of how the Los Alamos National Laboratory performs its radioactive waste management through documentation, processes, and parties involved. This research aimed to explain the transuranic waste management at the Los Alamos National Laboratory. Consolidation of information may assist in future works aimed towards developing transuranic waste management documentation from the planning phase up to its end destination for permanent isolation at the Waste Isolation Pilot Plant. The result is this very thesis, which is the compilation of information for the development of a document that may serve as an introduction or guidance to visitors of the national laboratory who may be interested or may have the need to know of transuranic waste management from the cradle to the grave standpoint.

LIST OF REFERENCES

Britannica, E. (2019). Atom. Retrieved from Encyclopædia Britannica, inc. website: https://www.britannica.com/science/atom/Rutherfords-nuclear-model

Carlsbad Field Office. (2017). *National TRU Program Document*.

EM-LA. (n.d.). *Radioactive Waste*.

EM - Office of Environmental Management. DOE 5820.2A. , U.S. Department of Energy § (1988).

Enderle, J. D., & Bronzino, J. D. (2012). *Introduction to Biomedical Engineering - A volume in Biomedical Engineering*. https://doi.org/https://doi.org/10.1016/C2009-0-19716-7

EPC-WMP ADESH-AP-TOOL-300. (2017). *Radioactive Waste Management*.

EPC-WMP ADESH-AP-TOOL-314 Rev. 1. (2018). *Radioactive Waste Characterization*.

Foundation, A. H. (2019). Atomic Timeline. Retrieved from https://www.atomicheritage.org/history/timeline

Gordon, E. (2019). *Ionizing Radiation and Non-ionizing Radiation*. Retrieved from https://chem.libretexts.org/Courses/Furman_University/CHM101%3A_Chemistry_and_Global_Awareness_(Gordon)/05%3A_Basics_of_Nuclear_Science/5.04%3A_Ionizing_Radiation_and_Non-ionizing_Radiation

IAEA. (2004). Practical Radiation Technical Manual. *IAEA*, (Rev. 1), 61. Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/PRTM-2r1_web.pdf

L'Annunziata, M. F. (2012). *Handbook of Radioactivity Analysis* (Third Edit). https://doi.org/https://doi.org/10.1016/C2009-0-64509-8

LANL. (n.d.). Reduce the Cycle Time to Ship TRU Solid Waste Debris Containers from TA-55. *BNI-EVSH-14-000005 LA-UR14-29672*.

LANL. (2019). Our History. Retrieved from https://www.lanl.gov/about/history-innovation/index.php

LANL INSIDE. (2019). *Treating and Processing Waste*.

LANL NPI-7. (2019). *Waste Management Program Review of Central Characterization Program (CCP) Documents EPC-WMP-AP-007 Rev. 1*.

LANL Procedures. (2019). *LANL Waste Management P409 Rev. 5*. (7).

LASL UC. (1981). *The Los Alamos Personnel and Area Criticality Dosimeter Systems*.

Ministry of the Environment Government of Japan. (2018). Half-lives and Radioactive Decay. *Internal Exposure and Radioactive Materials*, *Vol. 1*. Retrieved from https://www.env.go.jp/en/chemi/rhm/basic-info/1st/01-02-07.html

National Cancer Institute. (n.d.). *NCI Dictionary of Cancer Terms Title*. Retrieved from https://www.cancer.gov/publications/dictionaries/cancer-terms/def/non-ionizing-radiation

Philbert, M. A., & Sayes, C. M. (2010). Nanotoxicology. *Elsevier*, 707–715.

U.S. Department of Energy. (n.d.). *Legacy Cleanup*. Retrieved from https://www.energy.gov/em-la/services/legacy-cleanup

U.S. Department of Energy. (1999). *Radioactive Waste Management Manual 435.1*. II–5. Retrieved from https://www.nrc.gov/docs/ML1502/ML15022A083.pdf

U.S. Nuclear Regulatory Commission. (2017). Radiation Basics. Retrieved from https://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html#neutron

U.S. Nuclear Regulatory Commission. (2019). Radiation/Nuclear. Retrieved from https://www.nrc.gov/reading-rm/basic-ref/glossary/radiation-nuclear.html

United States Environmental Protection Agency. (2017). Radiation Protection - Radionuclides. *EPA*. Retrieved from https://www.epa.gov/radiation/radionuclides

WIPP, U. S. D. of E. (n.d.-a). National Transuranic (TRU) Program. Retrieved from https://www.wipp.energy.gov/national-tru-programs.asp

WIPP, U. S. D. of E. (n.d.-b). *Packaging*. Retrieved from https://wipp.energy.gov/packaging.asp

WIPP, U. S. D. of E. (n.d.-c). *Title 40 CFR Part 191 Subparts B and C Compliance Recertification Application 2014 for the Waste Isolation Pilot Plant*. Retrieved from https://wipp.energy.gov/library/CRA/CRA-2014/CRA/Appendix_DATA_Attachment_B/Appendix_DATA_Attachment_B.htm

WIPP, U. S. D. of E. (n.d.-d). *Transuranic (TRU) Waste*. Retrieved from https://wipp.energy.gov/tru-waste.asp

WIPP, U. S. D. of E. (2016). *TRU Waste Transportation Plan*. Retrieved from https://wipp.energy.gov/library/TRUwaste/DOE-CBFO-98-3103_Rev_4.pdf

WIPP, U. S. D. of E. (2018). *Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*. Retrieved from https://wipp.energy.gov/library/wac/DOE-WIPP-02-3122_Rev_9_FINAL.pdf

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