



US Ecology Nevada, Inc.

Highway 95, 11 Miles South of Beatty
Beatty, NV 89003
EPA ID# NVT330010000

**Petition for Site-Specific Determination of
Equivalent Treatment for Elemental Mercury
Wastes (D009 and U151) under the
Land Disposal Restrictions**

June 2021

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LIST OF ACRONYMS AND ABBREVIATIONS

AFC	alternate final cover
ASCE	American Society of Civil Engineers
BDAT	best demonstrated available technology
bgs	below ground surface
CBPC	chemically bonded phosphate ceramics
CEMP	Community Environmental Monitoring Program
CFR	Code of Federal Regulations
DET	determination of equivalent treatment
DOE	U.S. Department of Energy
EIS	Environmental Impact Statement
EMP	Environmental Monitoring Plan
EPA	U.S. Environmental Protection Agency
g/t	gram per ton
GCL	geosynthetic clay liner
gpad	gallons per acre per day
GRI	Geosynthetic Research Institute
GWPS	groundwater protection standard
HDPE	high-density polyethylene
K _{sp}	Solubility Product Constant
LCRS	leachate collection and removal system
LDR	Land Disposal Restrictions
LDS	leakage detection system
LEAF	Leaching Environmental Assessment Framework
LLDPE	linear low-density polyethylene
MCL	maximum contaminant limit
MEBA	Mercury Export Ban Act
mg/kg	milligrams per kilogram
mg/m ³	milligrams per cubic meter
mg/L	milligrams per liter
NDEP	Nevada Department of Environmental Protection
NIOSH	National Institute for Occupational Safety and Health

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

OECD	Organization for Economic Co-operation and Development
OSHA	Occupational Safety and Health Administration
POC	point of compliance
RCRA	Resource Conservation and Recovery Act
RMERC	retorting for high mercury waste
ROD	Record of Decision
SDS	safety data sheet
SEIS	Supplemental Environmental Impact Statement
SSI	Statistically Significant Increases
SU	standard units (for pH)
TCLP	Toxicity Characteristic Leaching Procedure
TWA	time-weighted average
UNEP	United Nations Environment Program
USGS	United States Geological Survey
UTS	universal treatment standards
UV	ultraviolet
WBZ	water bearing zone
WCS	Waste Control Specialists

PETITIONER CERTIFICATION PER 40 CFR 268.44(c)

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this petition and all attached documents, and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

1. INTRODUCTION

US Ecology is providing this petition to the U.S. Environmental Protection Agency (EPA) under 40 CFR §268.42(b) to apply for a determination of equivalent treatment (DET) for **elemental mercury** (CAS #7439-97-6). This application includes a demonstration that the proposed alternative treatment method can achieve a measure of performance equivalent to that achieved by methods specified in 40 CFR §268.42(a).

2. DET PETITION APPLICATION

Purpose:

Demonstrate a **DET** for **elemental mercury** for treatment and final disposal at the US Ecology Beatty, Nevada, facility.

Methodology under this DET will encapsulate mercuric sulfide, containerize, and place in a dedicated RCRA Subtitle C landfill cell in an arid location. The dedicated landfill cell will be referred to as a monofill throughout this DET petition application. The mercuric sulfide will be managed with a treatment train, and final disposal location that is demonstrated to be in compliance with federal, state, and local requirements, and is as, or more, protective of human health and the environment than current regulatory pathways for this waste today.

Applicants Name and Facility Identification Number:

Monofill Location:

US Ecology Nevada, Inc.

Highway 95, 11 Miles South of Beatty

Beatty, NV 89003

EPA ID# NVT330010000 (NDEP)

Permit # NEVHW0025

The US Ecology Nevada facility location is shown in Figure 1.

Treatment and Encapsulation Location:

US Ecology Nevada, Inc.

Highway 95, 11 Miles South of Beatty

Beatty, NV 89003

EPA ID# NVT330010000 (NDEP)

Correspondence related to this DET application should be directed to:

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3. BACKGROUND

3.1 Mercury History and Usage

Mercury is a naturally occurring element that poses serious risk to human and ecological health, through both natural and anthropogenic releases into the environment. While economic use of mercury has steadily declined with growing concerns posed by its toxicity, mercury continues to be released through industrial practices, and re-released through disruption of historically deposited mercury waste. Some of the primary sources of mercury released through industries in the United States today include mercury produced as a byproduct from the extraction process of gold in mining, as a byproduct from the production of sodium hydroxide using mercury cells in chloralkali plants, and through combustion of fossil fuels^{1 2}. Most uses of mercury have been phased out (e.g., paints and batteries) or rely on recycled/reused material (chloralkali plants). Small amounts of mercury continue to be used in commercial products such as light bulbs, thermometric devices, switches, and dental amalgam.

3.2 Excess Mercury

The current best demonstrated available technology (BDAT) specified by EPA for high-level mercury waste is retort and reuse. The distillation of mercury from the retort process produces high-purity elemental mercury of at least 99.9 percent by volume, which is suitable for reuse in commercial applications³. However, as excess elemental mercury was present in the market prior to the 2008 Mercury Export Ban Act (MEBA), and with little market for retorted mercury in the U.S., retorted mercury is currently being stockpiled/stored at various facilities across the U.S. or shipped to Canada for disposal. There is an immediate need in the U.S. for a long-term management solution for the mercury stockpile, namely permanent disposal in an engineered hazardous waste landfill.

4. REGULATORY HISTORY

Excess elemental mercury management and storage are currently regulated by the Resource Conservation and Recovery Act (RCRA; amendment of the Solid Waste Disposal Act of 1965), the Land Disposal Restrictions (LDR) program, and MEBA. Only

¹ EPA, 2017

² USGS, 2019

³ DOE, 2011

high-purity elemental mercury recovered from current treatment standards is acceptable for storage under these regulations.

Due to provisions of the LDR program, which prohibits the disposal of hazardous wastes with high levels (≥ 260 milligrams per kilogram [mg/kg]) of mercury (D009 and U151 wastes), these wastes must first be treated to remove the elemental mercury (e.g., retorting) prior to disposal⁴. While these treatment methods have been proven effective at removing the elemental mercury, and thus allowing the waste to be sent to a suitable landfill, the extracted elemental mercury must then be temporarily stockpiled at a Subtitle C (hazardous waste) facility under RCRA. The elemental mercury stored at a designated retention facility under section 3005(c) of RCRA assumes that the facility also meets all requirements of the 2008 MEBA⁵. Under MEBA, the Department of Energy (DOE) was tasked to establish and operate a facility specifically *“for the purpose of long-term management and storage of elemental mercury generated within the United States.”* DOE evaluated eight facilities which have met requirements to store excess elemental mercury for the 2011 Environmental Impact Statement (EIS) related to this mandate, with three additional facilities evaluated in the 2013 Supplemental EIS (SEIS)⁶. In 2019, DOE issued a Supplemental Analysis of the EIS in June⁷ and subsequent Record of Decision (ROD) in December, for the Long-Term Management and Storage of Elemental Mercury⁸, that kept the DOE-preferred alternative as the Waste Control Specialists (WCS) Facility near Andrews, Texas. As part of permit obligations, private facilities agree that their stored elemental mercury stockpiles will be shipped to the designated DOE facility when it becomes operational.

The primary objective of MEBA prohibits the export of elemental mercury, including that which is produced from the current treatment methods for D009 and U151 wastes. Only mercury compounds may be exported. Shipping mercury compounds to Canada, or other locations, is not a long-term solution for the growing stockpile of domestic mercury from industrial sources and retorts. The 2016 Lautenberg Act⁹, effective 1 January 2020, clarifies and strengthens export prohibitions on elemental mercury and some mercury compounds, and addresses DOE’s responsibility for designation of a long-term storage facility for mercury.

⁴ DOE 2011.

⁵ Clean Harbors, 2013.

⁶ DOE 2013.

⁷ DOE 2019a.

⁸ DOE 2019b.

⁹ H.R. 2576, PUBLIC LAW 114–182, June 22, 2016, Frank R. Lautenberg Chemical Safety for the 21st Century Act.

4.1 Mercury Disposal History

Mercury usage in the U.S. has steadily declined with increased regulation and advances in technology. Primary demand for mercury in the U.S. initially included batteries, thermometric devices, chloralkali manufacturing, and paint¹⁰. Today, mercury usage in these industries has either been phased out (batteries and paint) or become self-sufficient through recycling and reuse (chloralkali).

When EPA declared mercury a toxic substance and began setting regulation standards in the 1970s, mercury demand in the U.S. began to decrease¹¹. The passage of RCRA in 1978 established more significant regulations in terms of disposal of mercury-bearing waste, leading to further reductions in mercury demand in the U.S. The decreased demand for mercury and addition of new technologies in lighting has shifted primary U.S. mercury usage to switches, and dental amalgam¹².

Anthropogenic disposal of mercury predating EPA regulations largely resulted in releases of mercury wastes from mining and industrial processes. However, with the addition of RCRA and LDR, mercury wastes are categorized based on total mercury, set at a threshold value of 260 mg/kg total mercury. Low mercury wastes (<260 mg/kg total mercury), while subject to treatment to prevent leaching of mercury, are allowed disposal to a designated Subtitle C landfill. High mercury wastes (≥ 260 mg/kg total mercury) are subject to removal through retort/roasting, or incineration if organics are present. As discussed in Section 3, excess elemental mercury removed from this process is currently stockpiled/stored at designated facilities across the U.S., until DOE establishes a long-term storage facility^{2019 Final Environmental Impact Statement released by DOE examined seven of the private and government sites previously evaluated in the Draft EIS and SEIS, and in December 2019, DOE issued a ROD that designated the retention facility as the WCS Facility in Texas¹³.}

As no treatment or disposal standards for high-purity mercury have been established by EPA, no disposal alternatives have been considered by DOE for high-purity mercury. The stockpiles of high-purity (or elemental) mercury continue to grow and will only increase in the future without a permanent disposal solution.

¹⁰ DOE, 2011.

¹¹ USGS, 2013.

¹² Wienert, 2009, *in* USGS, 2013.

¹³ DOE, 2019a.

4.2 Mercury Retort and Recycling

Treatment of high-purity mercury falls to retort/roasting or incineration, dependent on the presence of organics in the mercury waste. Retorting of mercury wastes uses a thermal processing unit to volatilize mercury and distill the condensate, which results in the generation of elemental mercury¹⁴. Therefore, the process is most effective for mercury wastes containing elemental mercury carrying the waste codes D009 and U151.

Retorted mercury is either reused/recycled/reclaimed or stockpiled at various facilities across the U.S. Chloralkali plants, including facility closures, were once one of the largest consumers of mercury in the U.S.; however, as of late 2012¹⁵, only two chloralkali plants remained in operation in the U.S. Production of elemental mercury from these facilities decreased with the shift to mercury-free alternatives. Other industries using the mercury from retort process include pharmaceutical, fungicides/bactericides, and the gold mining (mercury byproduct)¹⁶. Mercury that is recovered from closure and cleanup of chloralkali properties was available for export or use in these other industries, such as gold mining, although after 2013 the chloralkali plants have been required to store mercury at a site approved by EPA for long-term mercury storage under MEBA.

While the retort process is effective at reclamation of elemental mercury, it is no longer a viable final treatment for mercury, as the product derived from this process no longer has a market. Rather, the retort process is a technology-specific LDR standard that is not a final or permanent treatment method. The reclaimed elemental mercury that is not recycled requires long-term storage under MEBA, and the Lautenberg Act further restricts export of some mercury compounds that had previously been exported for long-term storage. As the domestic market for elemental mercury continues to decline, stockpiles will continue to grow.

Therefore, other options are necessary to facilitate treatment and permanent disposal of mercury. Permanent disposal of treated mercury in a monofill will provide a final solution to the problem of growing mercury stockpiles.

5. PROPOSED ACTION FOR DET

US Ecology proposes to reduce the growing elemental mercury stockpiles by providing a permanent disposal solution. The proposed action starts with elemental mercury that has been converted to mercuric sulfide. The next step in this process is the encapsulation

¹⁴ Science Applications International Corporation, 1998.

¹⁵ USGS, 2013.

¹⁶ USGS, 2013.

of mercuric sulfide with linear low-density polyethylene (LLDPE), packaging the encapsulated waste within high-density polyethylene (HDPE) closed head drums, and final disposal of the drums in a monofill at the US Ecology Beatty, Nevada, facility. The facility is in an arid environment, where only small amounts of leachate are intermittently generated in landfill cells at the facility. The proposed mercury disposal process flow diagram is provided as Figure 2, and the proposed monofill and landfill schematic is provided in Figure 5. The process and monofill design will be described in more detail in Sections 8 and 9.

This proposed action combines a treatment solution for elemental mercury that is permanent and secure, with a disposal solution that is functionally superior to stockpiling, while providing a high level of protection for human health and the environment.

6. APPLICABLE WASTE CODES

Mercury waste codes applicable for this application are D009 and U151 (elemental mercury) for source materials.

7. ENGINEERING DISCUSSION LDR TREATMENT STANDARDS

This section discusses current LDR treatment standards for mercury waste and presents an overview of the waste management options for mercury waste where current LDR treatment standards are inappropriate and cannot be met.

7.1 Applicable LDR Standards

Current mercury treatment in the U.S. is based on two basic LDR Standards:

- Technology-specific standards which require the use of a specific treatment technology (e.g., RMERC - retorting for high mercury wastes); and
- Numerical standards (concentration-based) thresholds for the concentration of hazardous constituents in the treated residuals.

Where a waste cannot meet the LDR standards, EPA established equivalent treatment and treatability variance procedures, including the following:

- Equivalency petition: DET, applicable to LDR standards expressed as a specific technology (e.g., retorting, containment, stabilization); requirements in 40 CFR 268.42(b); treatment standards expressed as specified technologies; and
- Treatability variance: applicable to numerical LDR standards (e.g., different treatment or analytical method for the leachate tests); requirements for treatability variance petitions are contained in 40 CFR 268.44.

This application will focus on the DET for elemental mercury, since mercury generated from the retort process (RMERC) is no longer re-used and is accumulating in storage/stockpiles. As summarized in Giannotto and Brewer (2014)¹⁷, “*There is no concentration-based treatment LDR for elemental mercury. See 40 C.F.R. § 268.40. Theoretically, there is a technology-based LDR for high-mercury waste with a concentration of greater than 260 ppm total mercury... While RMERC works for removing mercury from wastes that contain high, but less than 100%, concentrations of mercury, retorting or roasting elemental mercury can only produce more elemental mercury, which, under the regulations, would then have to be retorted or roasted again, ad infinitum.*” The concentration based LDR standards for treated mercury (i.e., encapsulated mercuric sulfide) can be subject to compliance with the numerical standards by conducting leaching tests and evaluating the concentration of mercury in the leachate.

This DET application demonstrates:

¹⁷ Giannotto and Brewer, 2014.

- That the proposed alternative treatment technology- stabilization, encapsulation, and containment within a monofill - can achieve a measure of performance equivalent to that of the treatment standards specified in 40 CFR 268.40; and
- Compliance with federal, state, and local requirements that are protective of human health and environment.

7.2 Basis for EPA Treatability Standards

Non-wastewater mercury wastes have two concentration-based universal treatment standards (UTS) found in 40 CFR 268.48:

- Residues from retort (RMERC) - 0.20 milligrams per liter (mg/L) Toxicity Characteristic Leaching Procedure (TCLP); and
- All other mercury – 0.025 mg/L TCLP.

These non-mercury UTSs are evaluated by analysis of leachate generated by TCLP. Retort residues are required to be treated such that the concentrations of mercury in the waste leachate produced from TCLP is less than 0.20 mg/L, where other low-mercury wastes must be treated to leach less than 0.025 mg/L. Use of the 0.20 mg/L limit for mercury in leachate produced from TCLP of retort (RMERC) residues is used as a threshold in this DET to evaluate the stabilized and encapsulated mercuric sulfide, since this is the threshold used by other mercury treatment variances previously approved by EPA.¹⁸

8. CHARACTERIZATION OF INITIAL WASTE STREAM AND TREATMENT RESIDUALS

This section provides an overview of current mercury waste generation, how that waste is characterized, the rate it is generated, and how it is currently treated and stored.

8.1 Current Mercury Waste Generation Process

The primary sources of mercury waste in the United States are from gold mining, chloralkali plants, dental uses, and recycling (lights, switches, batteries, paint)¹⁹. A brief summary of each waste source is described below:

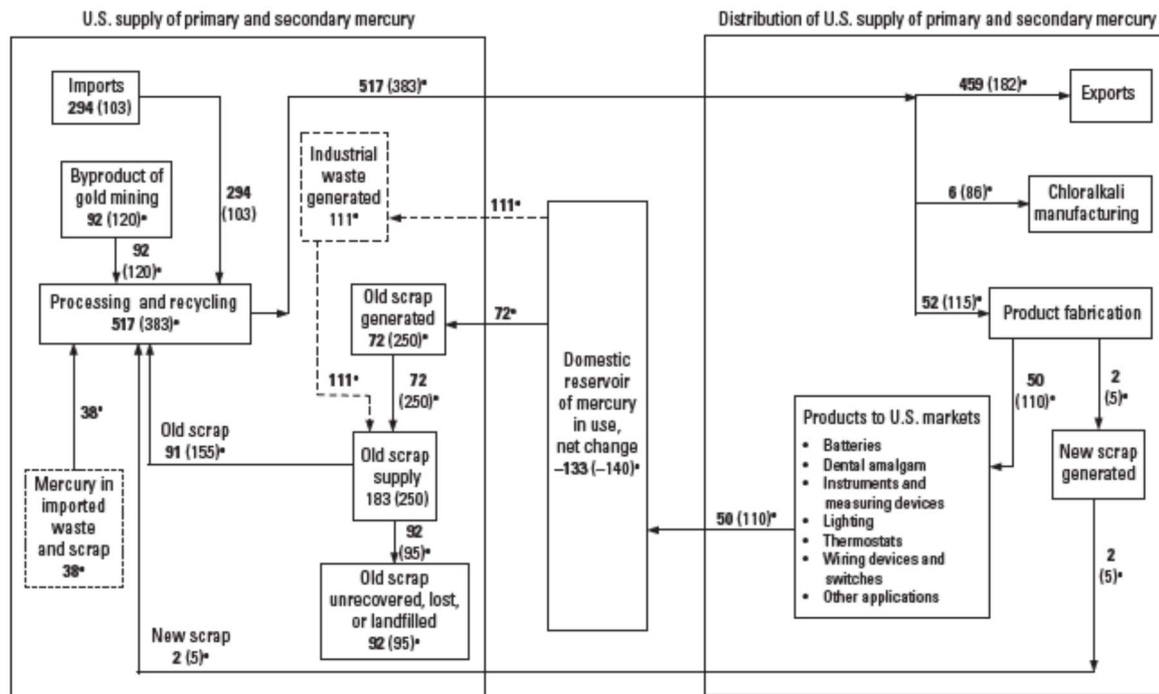
¹⁸ EPA, 1999.

¹⁹ USGS, 2013.

- **Gold mining** – Secondary mercury commonly appears naturally within gold bearing ores found in Nevada gold mines. Mercury is produced as a byproduct during the gold extraction process. Elemental mercury is recovered directly from roasting the ores, or from additional treatment methods to remove elemental mercury.
- **Chloralkali plants** – Chloralkali plants produce chlorine and sodium hydroxide through electrolysis of sodium chloride. Mercury has historically been used as the cathode in the electrolysis process and sodium amalgamates to the mercury. Mercury waste generated from this process is retorted to recycle/reuse the mercury. Chloralkali plants using mercury have steadily declined, and most are shut down or use another process. Mercury is still being reclaimed from these closed plants as they undergo decommissioning and cleanup.
- **Dental amalgam** – Mercury used to amalgamate other alloys such as silver, tin, and copper to form a strong durable filling continues to be used today, though several alternatives are being used due to safety concerns. Waste generated from dental amalgam is typically from recycling.
- **Recycling** - Currently, recycled mercury produces the largest volume of mercury containing waste, though available data on the annual production are poorly understood²⁰. Recycled products include laboratory packs, thermometric devices, lighting (bulbs), switches and relays, batteries, and paint. In addition, mercury is recovered from cleanup of contaminated soil and water from closed chloralkali plants.

²⁰ USGS, 2013.

Quantities of the U.S. supply of primary and secondary mercury in 2000 and 2010 were neatly summarized in the 2013 United States Geological Survey (USGS) report, excerpted below.



The flow of mercury in the United States in 2000 and 2010. Quantities are in metric tons of contained mercury. Values in bold reflect quantities in 2010; values in parenthesis reflect quantities in 2000 as reported by Matos and Brooks (2005). Industrial waste derived from soils from chloralkali plants that have been closed, industrial process waste, and waste imported from Canada were not reported in 2000. Values exclude dissipative losses. e, estimated.

8.1.1 Waste Generation Sources and Generation Rates

Industries that generate the primary sources of mercury waste are described in more detail in the following sections. The waste generation rates for each industry are summarized below, with more details documented in the 2013 USGS study²¹. More recently (2019), USGS also summarized mercury domestic production, use, and import and export quantities in the mineral commodity summary²².

²¹ USGS, 2013.

²² USGS, 2019.

8.1.1.1 Nevada Gold Mines

Several gold mines in Nevada contain mercury as part of the mineral assemblages in their respective ore complex. When roasting ore to remove sulfides and carbon, mercury is produced as a byproduct. Elemental mercury is then recovered from pollution control devices and mercury condensate from the retort process²³. Depending on the mine and nature of the processing method, mercury-bearing wastes and sludges are also produced, requiring further treatment to extract elemental mercury.

Current gold mine ores show varied concentrations of mercury, but on average contain 1 gram of mercury per ton (g/t) of ore²⁴. With Nevada gold production included as one of the world's top producers, mercury will continue to be generated annually from active mining, with an average annual production of 96 metric tons²⁵, although more recent production data are not reported²⁶ and likely declined. Extracted mercury from mining is typically sent to U.S. mercury recyclers, although some mercury-containing mining waste (e.g., calomel) is also shipped to Canada for treatment and disposal.

8.1.1.2 Chloralkali Plants

Most chloralkali plants have transitioned to mercury-free options or closed due to changing regulations and costs. Mercury use in chloralkali plants decreased up to 98% from 1996 to 2010 through plant closures, technology advancements, and recycling²⁷. However, plant closures and transitioning to new technology results in mercury waste generation from the plants' existing mercury supply. Only two mercury cell chloralkali facilities in the U.S. were in operation as of 2018, with the facilities committed to transition to alternative methods by 2020²⁸; ^{29,30}.

8.1.1.3 Dental Amalgam

Dental amalgams remain a source of mercury, although technological advances are reducing the use of mercury. Mercury from dental amalgams can enter the environment from poor waste practices at dental offices and, consequently, treated wastewater from the improperly disposed of mercury waste. One of the largest sources of mercury waste,

²³ USGS, 2013.

²⁴ Miller, 2007, in USGS, 2013.

²⁵ USGS, 2013

²⁶ USGS, 2019.

²⁷ USGS, 2013.

²⁸ USGS, 2019.

²⁹ UNEP, 2019.

³⁰ EPA 2009.

however, are the fillings themselves, which are estimated at 290 metric tons in the U.S. population³¹. Projected deaths and cremations of individuals with mercury amalgam fillings accounts for the largest contributor of mercury waste into the environment as a result of dental amalgam use. Despite the steady decrease in usage, a 2010 estimate by Concorde showed an estimated annual usage of 30 metric tons of mercury in the dental practice, and up to a 33% disposal rate of purchased mercury due to inefficiencies in application and the volume of prepackaged ampoules³².

8.1.1.4 Recycling

Companies nationwide have continued to reduce the number of mercury-containing products in their supply, and thus recycle more of the products containing mercury described above. Overall, annual production of mercury-containing waste from recycling and reclamation is estimated to be 5 metric tons per year³³, although prior documents estimated between 50 to 265 metric tons per year³⁴. Recycled products have historically included both domestic and imported goods, with most imported products ceasing in 2008 with the enactment of MEBA.

In 2018, materials collected for recycling and mercury reclamation via retorting included automobile switches, barometers, dental amalgam, fluorescent bulbs, computers, and medical devices³⁵. Since mercury is no longer present in most paints and batteries, recycling of these products has declined. The recycling rate for mercury-containing materials has been low and is declining (10% in the US and <10% worldwide³⁶), and storage costs will have further disincentivized recycling. However, with the enactment of the European Union mercury export trade ban in 2011 and MEBA in 2013, recycling rates may increase, although storage will still be a consideration. Reuse of recycled/retorted mercury in the US markets is declining, and there is an excess supply, meaning some mercury must remain in long-term storage.³⁷

8.1.2 Waste Characterization

Waste characterization and analytical methods for mercury waste typically include one or more of the following:

³¹ Concorde East/West Sprl, 2012.

³² Concorde East/West Sprl, 2012.

³³ DOE, 2019b.

³⁴ USGS, 2013.

³⁵ USGS, 2019.

³⁶ USGS, 2013

³⁷ EPA, 2020.

- SW846 Test Method 1311: Toxicity Characteristic Leaching Procedure (TCLP);
- SW846 Test Methods 1313, 1314, 1315, or 1316 for Leaching Environmental Assessment Framework (LEAF);
- SW846 Test Method 7470A Mercury in Liquid Waste (Manual Cold-Vapor Technique);
- SW846 Test Method 7473 Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry; and
- Generator Knowledge.

8.1.3 Description of Current Waste Treatment Process

Waste treatment processes for mercury include recycling of materials as noted above, through collection and processing of mercury-containing equipment; disassembly; and retorting (or roasting) to recover elemental mercury. Wastes containing higher concentrations of elemental mercury have been treated by retorting, with some quantities exported for disposal (i.e., to Canada). A conceptual schematic depicting the current mercury waste generation, collection, and treatment/storage processes in the U.S. is provided in Figure 4.

Following retorting, the waste goes through a distillation process to further purify the elemental mercury. Historically, this was a triple distillation process, but current single distillation methods can achieve a purity of 99.9% mercury. For more complex mercury waste streams, such as calomel, additional treatment is required prior to distillation.

Following distillation, elemental mercury is converted into mercuric sulfide in conversion blenders. The mixing process is computer controlled to achieve the exact conditions within narrow thresholds for complete and consistent reaction of the mercury and sulfur. Distilled, converted mercuric sulfide is either stockpiled or sent to Canada for disposal. Retorted and converted mercury can be stabilized by mixing with cement or a cement slurry that can be placed to harden in a landfill. In Canada, this slurry can be land-applied, whereas, in the U.S., the material is limited to recycling and long-term storage.

Implementation of the Lautenberg Act (passed 2016, effective 1 January 2020) prohibits the export of some mercury compounds, including mercuric sulfide, although it does allow export of the mercury compounds to the Organization for Economic Co-operation and Development (OECD) member countries for environmentally sound disposal.³⁸ Even

³⁸ 2019 TSCA Amendment Public Law 116-92, Section 12(D): ENVIRONMENTALLY SOUND DISPOSAL.

with export options, the disposal, storage, and stabilization solutions for retorted mercury are not as secure as the permanent disposal presented in this DET. Canada could cease importing mercury waste at any time, leaving the U.S. with a growing mercury stockpile.

8.2 Proposed Mercury Waste Treatment

The proposed mercury waste treatment process described in this petition begins with mercuric sulfide, either produced or received by US Ecology, followed by encapsulation, accomplished by mixing with LLDPE and extruding as pellets. The pellets will be placed into an HDPE container. The encapsulated and containerized mercuric sulfide will be disposed of as hazardous waste in a secure mercuric sulfide monofill. The monofill liner system and final cover system will be designed to meet the 40 CFR 264 Subpart N requirements. An overview of the mercury conversion and disposal process is provided in Figure 5.

The proposed monofill location and design further minimize the potential for mercury migration or leaching. Similar to the most suitable disposal sites identified in the DOE EIS³⁹, US Ecology is considering a monofill facility at a semi-arid or arid site. US Ecology's Beatty, Nevada, facility is currently proposed herein.

8.2.1 Mercuric Sulfide Encapsulation Process

Mercuric sulfide will be encapsulated through a three-step process. First, the mercuric sulfide will be thoroughly mixed with LLDPE powder. Second, the mixed product will be heated to the melting point of the LLDPE (approximately 240-275°F (115-135°C) as shown on the Safety Data Sheet (SDS) for an example LLDPE product provided in Appendix A), ensuring a homogenous mixture. In the final step, the heated and homogenous mixture will be extruded into small pellets, referred to throughout this document as LLDPE-encapsulated mercuric sulfide.

After encapsulation, the LLDPE-encapsulated mercuric sulfide will be placed into closed head, HDPE, 55-gallon drums. The drums will be filled to capacity, and the bung replaced and sealed. These measures will provide structural stability of the drums as they are stacked. The total weight of each full drum is estimated to be approximately 500 pounds. Manufacturer's specifications for the HDPE drums indicate that the maximum top load on a filled drum will not exceed 2,000 pounds in a free-standing application. A specification sheet for an example closed-head HDPE drum is provided in Appendix A.

³⁹ DOE, 2011.

A schematic depicting the mercuric sulfide waste treatment process and placement into the mercuric sulfide monofill is shown in Figure 5

8.2.1.1 Process Variability

The encapsulation unit is computer controlled such that conditions stay within operating parameters and variation from this process is minimal.

The LLDPE polymer is obtained from a vendor, and material quality is within manufacturers' specifications (see LLDPE SDS sheet in Appendix A). LLDPE is created by polymerization of ethylene with short-chain olefins, such as butene, hexene, or octene, to create a long-chain molecule with a number of short branches. Similar to HDPE products, such as geomembrane and plastic pipe, commonly used for containment of hazardous wastes and materials, the LLDPE that is used to encapsulate the mercuric sulfide is required to be formulated primarily (e.g., >99%) of LLDPE resin with <1% short-term processing stabilizers and long-term antioxidants to retard oxidative reduction. Variability in the LLDPE material is unlikely to include trace amounts of other constituents.

The LLDPE-encapsulated mercuric sulfide was tested using LEAF 1313 methodology (Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure) across a pH range that spans the soil pH measured at the Beatty, Nevada, facility (8.3 to 9.4 standard units (SU); Table 2). The tested pH range includes 7, 9, 10.5, and 12 SU. Analytical results for mercury are summarized in Table 1. Based on these results, the potential variability from the production of the mercuric sulfide and encapsulation with LLDPE had little impact on mercury leachability.

8.2.1.2 Geochemistry and Physical Material Treatment

Naturally occurring mercury is encountered predominantly as mercury sulfide or cinnabar with trace amounts of elemental mercury. Mercury is a transition metal, and element 80 on the periodic chart. It is unique as it is the only metal that is stable in liquid form at standard pressure and temperature. Mercuric sulfide/cinnabar is bright red in color and typically forms near hydrothermal vents associated with volcanic activity or hot springs (epithermal deposits). Mercuric sulfide/cinnabar occurs as alpha- (the most stable, and the form that will be encapsulated), beta- (also known as metacinnabar or black cinnabar), and hypercinnabar that forms at higher temperatures. Although generally considered insoluble in water, the water solubility of red mercuric sulfide (e.g., $K_{sp} = 3.0 \times 10^{-53} \text{ M}^2$) is lower than the solubility for black mercuric sulfide (e.g., $K_{sp} = 1.9 \times 10^{-15} \text{ M}^2$).

Mercury is also commonly encountered as a trace element, or as impurities in other minerals.^{40 41} Mercuric sulfide is stable and insoluble in its mineral form under most environmental conditions, but weathering of other mercury ore deposits and mercury salts, and complexation of mercury with organic compounds, can lead to an accumulation of mercury in the environment.

Mercury readily forms amalgams or alloys with other metals, or complexes with anions such as chlorine or sulfides, to form chlorine salts (e.g., calomel) or mercuric sulfide (cinnabar)⁴². Mercury is abundant in the environment via weathering/erosion and emissions and readily forms inorganic salts or organic methylmercury, both of which can sorb onto dust particles and become airborne. Inorganic and organic forms of mercury can be highly toxic to humans and organisms.⁴³ Methylmercury bioaccumulates or biomagnifies up the food chain, beginning with aquatic organisms.

Production of mercuric sulfide creates a very fine, red-colored powder. Leachability testing of the mercuric sulfide alone has been demonstrated to be below the 0.2 mg/L TCLP threshold. A summary of the pilot study TCLP results is provided in Table 7. The LLDPE encapsulation process further reduces the leachability of mercury. Even though the LLDPE-encapsulated mercuric sulfide meets the TCLP criterion, the containment of the mercuric sulfide is increased even further by placing the encapsulated product within HDPE drums that are buried within the monofill.

Linear polyethylene materials such as LLDPE and HDPE have only short branches along their polyethylene chain, resulting in close packing of molecules and relatively dense materials. HDPE has less chain branching than LLDPE, producing a highly crystalline polymer. The structural properties of LLDPE and HDPE provide the low permeability and relatively high strength that result in their excellent resistance to ultraviolet (UV) radiation and chemical-induced degradation.^{44 45} With its greater branching, LLDPE is more flexible than HDPE. HDPE, in turn, has better UV and chemical resistance than LLDPE.

The service life of LLDPE and HDPE materials is dependent on their formulations and their exposure conditions. For instance, the service life of polyethylene geomembranes exposed to atmospheric conditions with UV radiation, high temperatures, and oxygen is

⁴⁰ <https://www.earthmagazine.org/article/mineral-resource-month-mercury>

⁴¹ <https://www.epa.gov/mercury/basic-information-about-mercury>

⁴² https://chem.libretexts.org/Chemistry_of_Mercury

⁴³ <https://www.epa.gov/mercury/basic-information-about-mercury>

⁴⁴ Brydson, 1999.

⁴⁵ Islam et al., 2011.

anticipated to be shorter than that of buried geomembranes.^{46/47} Because of their excellent durability for the mercury treatment process described herein, there is little potential for exposure of the LLDPE encapsulation material to UV radiation, because the treated product will be placed into sealed HDPE drums prior to transport to the monofill. Further, when placed in the monofill, the LLDPE material will be contained in HDPE drums and will not be in contact with water (precipitation, leachate, or groundwater), which could cause chemical-induced degradation. Further, after the drums are isolated from the ambient environment by soil cover, the LLDPE will be protected from thermal mechanisms of degradation. While the HDPE drums may be subjected to UV radiation, or high temperatures, while they are being transported and placed in the monofill, after they are covered with soil, this degradation mechanism ceases. These drums will not come into contact with any significant amount of liquids. Groundwater at the site lies at about 300 feet below ground surface (bgs), which is well below the depth of the proposed monofill of up to 20 feet bgs, so the only water that will contact the drums will be small quantities of precipitation. As such, weathering or long-term degradation of the HDPE drums and LLDPE-encapsulated mercuric sulfide will be minimized to the extent possible. Further, the antioxidants added to the LLDPE and HDPE protect the materials from degradation.

Given that the LLDPE encapsulation material and HDPE drums are not anticipated to have significant exposure to UV radiation or chemicals, the environmental condition that has the most effect on the service life of these products is service temperature. The proposed monofill will be constructed in a shallow excavation at the Beatty, Nevada, facility. As the mercuric sulfide is not anticipated to undergo reactions that generate heat in the monofill, the temperature of the waste placed in the monofill will approach the ground temperature. Groundwater temperature versus depth data have been collected from 166 wells by USGS in Nye County, including locations near the US Ecology Beatty facility⁴⁷. Temperatures measured from 19 to 40 feet bgs ranged from about 66°F to 73°F. Based on long-term research on HDPE geomembrane sponsored by EPA and others, the predicted service life of HDPE geomembranes in contact with water on one side and air (e.g., unsaturated soil) on the other side is approximately 450 years at 68°F and 260 years at 77°F.⁴⁸ The HDPE drums that contain the encapsulated mercuric sulfide are manufactured with a higher density resin than an HDPE geomembrane and are thicker than the 60-mil HDPE geomembrane evaluated in the EPA studies. Therefore, the drums are anticipated to have a longer service life than the above estimate for HDPE

⁴⁶ GRI (Koerner et al.), 2011.

⁴⁷ USGS, 2007.

⁴⁸ Koerner et al., 2011.

geomembranes. LLDPE has a lower resin density than HDPE and is anticipated to have a somewhat shorter service life than a similar product manufactured with HDPE.^{49 50}

8.2.1.3 Mercuric Sulfide Monofill

The RCRA Subtitle C landfill for the encapsulated and contained mercuric sulfide will be a nonreactive monofill that accepts only this type of waste. This operational constraint eliminates the potential for other waste to react with the mercuric sulfide. The monofill will be located at US Ecology's Beatty, Nevada, facility, a hazardous waste treatment, storage, and disposal facility which is sited in an arid region of the country. The arid environment has a very low precipitation rate, limiting the potential for leachate generation, and a very low chance for introduction of other chemicals (such as organics or other materials) from rainwater. The facility has the added advantage of being located approximately 11 miles from the nearest residence.

A facility plan showing the proposed siting for the mercuric sulfide monofill is presented in Figure 3. The proposed monofill will be constructed in an area northwest of the other Subtitle C landfills at the facility (i.e., closed Trenches 10 and 11 and active RCRA-designed Trenches 12 and 13). The existing Subtitle C landfills are double lined with a leachate collection and removal system (LCRS), HDPE geomembrane primary liner, leakage detection system (LDS), and composite secondary liner consisting of an HDPE geomembrane overlying a compacted clay layer or geosynthetic clay liner (GCL). Proposed drawings of the monofill can be found in Appendix D, and final design work will be completed during the State of Nevada's permitting process. The LCRS and LDS drainage layers above the liners remove any leachate that makes its way to the liners, and the liners improve the efficiency of the drainage layers. This type of liner system provides a very high level of long-term containment (i.e., 99.9% or more of the leachate that flows to the leachate collection system is collected and removed) and minimizes the potential for the migration of leachate through the liner system. For facilities located in arid desert climates, like US Ecology Beatty, Nevada, only small amounts of precipitation occur, and the potential for leakage through a double liner system that includes a composite liner is extremely low.

The proposed monofill will have a double liner system similar to the existing RCRA Subtitle C landfills, with an LCRS, 80-mil HDPE geomembrane primary liner, LDS, and 60-mil HDPE geomembrane/GCL composite secondary liner. This design will be

⁴⁹ Koerner et al., 2011.

⁵⁰ Islam et al., 2011.

reviewed and approved under the existing RCRA Hazardous Waste Management Permit administered by the NDEP.

The existing RCRA Subtitle C landfills are designed to accept wastes with much higher toxicity than mercuric sulfide (e.g., other hazardous materials), and routine monitoring and reporting procedures are already in place for the landfill trenches. The active RCRA Subtitle C-designed landfills have been monitored since they were opened in 1990, and no releases from the landfills have been observed. The design, operation, and monitoring of these modern engineered Subtitle C landfills effectively minimizes and mitigates potential releases of landfilled constituents into the environment.

8.2.2 Proposed Compliance Testing

To demonstrate compliance testing, LEAF 1313 / 7470 was performed at Eurofins Analytical Laboratory in Pittsburgh, Pennsylvania. Results from ten different batches within the determined pH range (described above) are summarized in Table 1.

To ensure compliance with this DET, each batch of mercuric sulfide will be encapsulated in LLDPE using an extruder. At the initial process start-up, the first 20 batches of encapsulated mercuric sulfide will be tested using LEAF method 1313/7470 to ensure that the technology, as described in the DET, is operating properly. After demonstrating that the technological performance is consistently meeting the expectations of the DET, the encapsulated batches will be tested following the schedule in the table below:

Step	Batch Number Range	LEAF 1313 Testing Schedule
1	1-20	Every batch will be tested
2	21-200	Every 10 th batch will be tested
3	201+	1 test per calendar quarter

Each sample will be submitted for analytical testing via LEAF 1313/7470 and tested at pH values of 8, 9, and 10.5 SU, including the method-prescribed quality control. This pH range brackets the soil pH range (8.3 to 9.4 SU) measured at the Beatty, Nevada, facility. Testing will be performed at the analytical laboratory at the US Ecology Beatty, Nevada, facility or an equivalent laboratory. In order to meet the requirements of this DET, the encapsulated mercuric sulfide, when tested using LEAF 1313/7470, must not exceed the results of 0.20 mg/L. Any batch tested that exceeds this threshold will be retreated through the process or disposed of in a compliant manner outside this DET. In order to graduate to the next step of the testing schedule, the pass rate of the previous step must be equal

to, or exceed 90% . If the pass rate is less than 90%, the step must be repeated, and the 90% pass rate met, before moving to the lower testing frequency.

Preliminary leachability testing of large monolithic samples of LLDPE encapsulated mercuric sulfide using SW846 LEAF 1315 was conducted at the beginning of this project. The two studies, that can be found in Appendix C, resulted in no detected leachable mercury. While the final treated waste from this proposed process results in small pellets, not procedurally allowed by the test, LEAF 1315 was abandoned as this DET's point of compliance testing for LEAF 1313, since the procedure allows for a small, pelletized matrix.

8.2.3 Proposed Waste Generation Rate

US Ecology has designed capacity to process approximately 1,500 tons of mercury per year into encapsulated mercuric sulfide. This volume of waste can easily be managed at the Beatty, Nevada, facility, as it only represents approximately 320 to 2,000 500-lb drums per year.

8.2.4 Health Risks

Potential health risks for personnel involved in the proposed process could include issues from handling the LLDPE-encapsulated mercuric sulfide. Protective measures will be used by US Ecology during the mercuric sulfide encapsulation with LLDPE (creation of the pellets). Engineering controls and personal protective equipment will be used to minimize potential exposures, and maintain levels below industry Occupational Exposure Limits (OELs)

Direct contact/dermal exposure to mercuric sulfide is mitigated by LLDPE encapsulation. The encapsulation occurs within computer-controlled equipment, without direct human contact. The LLDPE-encapsulated mercuric sulfide is extruded and placed into HDPE drums, also without direct human contact due to the use of personal protective equipment. In the unlikely event of a spill or break of a drum where direct contact could occur, personal protective equipment will be used to clean up/pick up spills.

To reduce potential air/inhalation hazards, the mercuric sulfide powder will be encapsulated with LLDPE, and the pellets will be placed within HDPE drums. Containment within HDPE drums further restricts the LLDPE-encapsulated mercuric sulfide, reducing the potential for airborne emission.

Significant weathering of the LLDPE encapsulation material or HDPE drums may increase the potential for exposure to mercuric sulfide; however, this scenario is unlikely, as the LLDPE-encapsulated mercuric sulfide will be placed into HDPE drums that will

be promptly placed within the engineered containment system of the monofill and covered with soil.

Potential health risks via exposure pathways listed above will be further mitigated and reduced during operations by placing clean soil around and over the HDPE drums.

8.2.5 Stormwater

Stormwater flow will be very limited at the mercuric sulfide monofill location due to: 1) the arid climate: the recent (2010-2019) 10-year average annual precipitation is 3.8 inches, based on a site meteorological station; 2) the undisturbed unsaturated desert landscape around the proposed monofill location, which absorbs a significant amount of rainfall and limits the potential for stormwater run-on; and 3) the adjacent flat terrain, which provides little natural potential for stormwater run-on by gravity flow.

The monofill will be designed with a perimeter berm to prevent run-on to the monofill. In addition, the limited amount of stormwater falling directly on the monofill will be contained within the footprint of the monofill, precluding run-off. Based on US Ecology's experience with the other landfills at the facility, it is expected that precipitation on the monofill will be fully absorbed by and then evaporated from the cover soil of the liner system and the soil material placed around the HDPE drums. However, there may be times that some precipitation may flow into and be recovered from the LCRS. The recovered water will then be reused for dust control on the active monofill. This is only expected to occur following unusually large storm events and after normal storm events where precipitation falls on the newly constructed landfill liner or during the early stages of landfill operation when there is insufficient cover material to absorb all the precipitation.

8.2.6 Leachate

As described above, for the very little precipitation that occurs in the arid environment, most of the precipitation will evaporate and will not flow to the LCRS. The water that does reach the LCRS is expected to infiltrate. Treatment and encapsulation of the waste, along with containerization of the waste in HDPE drums, significantly limits the potential for the treated waste to encounter precipitation. Further, in the unlikely event that water enters an HDPE drum, the LLDPE-encapsulation of the mercuric sulfide significantly reduces its leachability below that of current LDR requirements for mercury-containing wastes.

8.2.7 Results of Literature Review

This section presents the findings from a targeted review of documents pertaining to elemental mercury treatability. Background on mercury regulations, disposal rules, and studies were discussed in Sections 3 and 4 above. A summary of documents reviewed is provided in Tables 3, 4, and 5.

Historically, elemental mercury has been treated using stabilization, solidification, and encapsulation techniques⁵¹ or a combination of these. Treatment and encapsulation of mercury or other wastes has been a subject of numerous studies (Tables 4 and 5). Some of the materials used for stabilization, solidification, and/or encapsulation include:

- Sulfur polymer cement.
- Chemically bonded phosphate ceramics (CBPC);
- Polyethylene encapsulation; and
- Other: asphalt, polyester and epoxy resins, synthetic elastomers, polysiloxane (ceramic silicon foam), Sol-Gels (polycerams), and Dolocrete™, cements/Pozzolans/lime.

This review of prior studies was conducted to evaluate the effectiveness of mercury stabilization, solidification, and encapsulation techniques and resultant leachability of mercury. Our review identified a key critical flaw in some of the past studies, in that mercuric sulfide stabilization is needed prior to encapsulation. Leachate was generated from treatability studies designed to test the efficacies of these materials, and mercury was detected in some leachates. The related TCLP data are summarized in Randall and Chattopadhyay 2004⁵² and states: “*TCLP results of stabilized/solidified sulfur polymer leachates ranged from <0.009 to >0.40 mg/L. CBPC TCLP results ranged from <0.00004–0.01 mg/L. Polyethylene encapsulation TCLP results ranged from <0.009 to 1.07 mg/L...* ”.

Some of this testing was completed before the reaction of elemental mercury to mercuric sulfide was complete. In these cases, the mercuric sulfide reaction was not isolated (or controlled), and the elemental mercury, sulfur compounds, and stabilization/encapsulation materials were mixed together. Therefore, several of these treatment methods may require a pretreatment or stabilization step to chemically fix mercury into a highly insoluble form, such as mercuric sulfide, prior to encapsulation. The mercuric

⁵¹ Chattopadhyay and Condit, 2002.

⁵² Randall and Chattopadhyay, 2004.

sulfide conversion described herein creates a stable form of mercuric sulfide prior to encapsulation.

9. PROPOSED FINAL DISPOSAL FACILITY – BEATTY, NEVADA

9.1 Mercuric Sulfide Monofill Design

A dedicated monofill will be constructed in the northwest portion of the existing Beatty, Nevada, facility (Figure 3). The sealed HDPE drums containing the LLDPE-encapsulated mercuric sulfide will be placed into the proposed monofill with additional layers of control (i.e., a double liner system and final cover system). As previously discussed in Section 8.2.2.3, the proposed monofill design will utilize a design similar to US Ecology’s current design for their active Subtitle C landfills, as approved under the existing RCRA Hazardous Waste Management Permit administered by the NDEP. Proposed drawings of the monofill can be found in Appendix D.

Only small quantities of leachate are generated in the active landfills at the Beatty, Nevada, facility due to the low average annual precipitation and high evaporation of the region. The leachate generation rates for these landfills provide an indication of the leachate generation rates and quantities expected at the proposed mercuric sulfide monofill. Leachate generation rates for landfills in the western U.S. are significantly less than those for landfills in the more temperate regions. In an EPA study of the performance of modern double-lined landfills in the U.S., LCRS flow rates from active hazardous waste landfills in the western U.S. included in the study ranged from approximately 0.1 to 410 gallons per acre per day (gpad) and averaged 100 gpad. Average semi-annual leachate generation rates for Trenches 12 and 13 at the Beatty, Nevada, facility are summarized in Table 6. For Trench 12, LCRS and LDS flows are combined and then measured; therefore, the LDS and LCRS data could not be presented separately. For Trench 13, both LCRS and LDS flow data are available and are presented.

The average LCRS generation rates for the active landfills at the Beatty, Nevada, facility during 2018 and 2019 gallons^{53,54,55} ranged from approximately 6 to 31 gpad (Table 6) and fell within the middle of the range from the EPA study. Average LDS flow rates were very low, less than 0.1 gpad for the Trench 13 phase, and were within the range of values of 0 to 0.1 gpad reported in the EPA study for landfills with geomembrane/GCL primary liners. The relative hydraulic performance of the top liner for Trench 13 was calculated

⁵³ US Ecology, 2018.

⁵⁴ US Ecology, 2019.

⁵⁵ US Ecology, 2019.

using the “apparent liner hydraulic efficiency” parameter, E_a , introduced by Bonaparte et al.⁵⁶, and defined as:

$$E_a (\%) = (1 - \text{LDS Flow Rate} / \text{LCRS Flow Rate}) \times 100$$

The higher the value of E_a , the smaller the flow rate from an LDS compared to the flow rate from an LCRS. The calculated apparent efficiency of the primary liner for Trench 13 ranged from 99.0 to 100%. Based on the data presented in the EPA study, the efficiency of geomembrane/GCL composite primary liners is expected to be 99.0% or higher. This efficiency is high and indicative of very good leachate containment capability.

Management of leachate includes monitoring the levels in the sumps, pumping leachate to keep depths below the permitted levels, testing leachate for concentrations of Chemicals of Potential Concern (COPCs), testing leachate for quarterly permit parameters, disposing of leachate, and reporting leachate management metrics to the permitting agencies. Leachate levels are checked weekly in the LCRS and LDS sumps of active disposal Trenches 12 and 13, and will similarly be checked within the new monofill sumps. Both LCRS and LDS sumps are checked in the event the facility receives more than ¼ inch of rainfall in a 24-hour period. Leachate is pumped and removed in accordance with action levels established in the Permit. Records are maintained for each pumping event and indicate leachate levels before and after pumping, the volume pumped, and the on-site dispensation of the leachate.

Disposal of leachate consists of applying it for dust control from the cell of landfill from which it came (Trenches 12 and 13). Leachate from the new monofill will similarly be used for dust control for the monofill.

9.2 Mercuric Sulfide Monofill Monitoring

The US Ecology Betty, Nevada, facility is currently monitored for protection of groundwater from potential landfill releases by a network of 33 monitoring wells: 27 wells in the upper aquifer; and 5 wells in the lower aquifer. Four of the wells are considered background wells, and 29 wells are downgradient point of compliance (POC) wells. Potential releases from active cells are also monitored via a network of leachate sumps, one per each landfill cell, for a total of seven sumps. The sump at each cell has a pair of access pipes, the upper one for the LCRS and the lower one for the LDS. The wells and sumps are sampled quarterly. Additional monitoring wells, at least one additional background and one POC, will be added to monitor the monofill prior to waste placement

⁵⁶ Bonaparte et al., 1996.

in this unit. The actual number of new wells will be determined during the monofill permitting process administered by the NDEP.

The existing RCRA Permit for the facility requires quarterly sampling at the upper aquifer wells to assess potential releases from the existing landfill cells. Analytical data are compared to Groundwater Protection Standards (GWPSs) established in the approved Permit. The GWPS values can be found in the Site's RCRA Permit, in Tables 10.3 A-D (Section 10 - Groundwater Detection Monitoring). The Environmental Monitoring Plan (EMP) also contains the details of the required quarterly monitoring. The monitoring program allows Statistically Significant Increases (SSIs) to be identified when two consecutive concentrations of regulated analytes greater than the applicable GWPS are detected (i.e., a 1 of 2 sampling protocol is utilized). Such exceedances are evaluated to determine if they represent releases from the landfill cells or are attributable to some other source or cause, such as background chemistry or analytical variation or error. This same monitoring and evaluation process will also apply to the mercuric sulfide monofill. The EMP will be revised to include specific additional monitoring requirements for the monofill via the permitting process administered by the NDEP.

Concentrations of COPCs monitored in groundwater are routinely compared to the GWPS values to determine if an SSI has occurred. The Permit has already established a GWPS for mercury of 0.0002 mg/L. Additionally, the potable water supply is subject to compliance with the federal EPA maximum contaminant limit (MCL) for mercury in drinking water of 0.002 mg/L. The results of the quarterly sampling are documented in semi-annual reports (due September 30 and March 30 of each year) and submitted to both the NDEP and EPA. The monofill groundwater monitoring data will be included in these reports. To date, mercury has not exceeded either the GWPS or the MCL in groundwater.

Air monitoring is conducted at the existing landfills to meet Occupational Safety and Health Administration (OSHA) and/or industry recognized Occupational Exposure Limits (OELs) requirements, and mercury monitoring in air is conducted every three years at eight different locations/personnel across the facility. Similar monitoring and reporting will be conducted at the mercuric sulfide monofill. Air samples are collected using a pump over an 8-hour time-weighted average (TWA). Air monitoring results from 2018 were below detection limits that ranged from <0.00094 to <0.0015 milligrams per cubic meter (mg/m^3) (<0.00011 to <0.00013 parts per million). Air monitoring results are compared to the industry standard for measurement of exposure rates, which is typically the lowest allowable OSHA limit of $0.1 \text{ mg}/\text{m}^3$ and National Institute for Occupational Safety and Health (NIOSH) limit of $0.05 \text{ mg}/\text{m}^3$ based on a TWA. Detection limits for the air monitoring results are well below these limits.

9.3 Site Characteristics – Nevada Facility

This section describes the geography, climate, and general setting of the US Ecology Beatty, Nevada, facility.

9.3.1 Topography

The mercuric sulfide monofill will be located on a slight rise in desert terrain formed by an alluvial fan. The topography in the immediate area of the monofill is flat. The flat desert terrain extends for long distances to bordering mountain ranges, except on the east about three miles where the terrain rises gently to the Bare Mountain range.

9.3.2 Surface Water

Surface water resources near the facility consist of ephemeral riverbeds and washes, which flow only during rare heavy rain events. The Amargosa River channel is the closest surface water body, which is approximately 1.5 miles to the west. The Amargosa River channel is dry in the vicinity of the facility, except during rare heavy rain events.

9.3.3 Climate

Nevada's main climatic features are bright sunshine with high solar radiation, low annual precipitation, and large daily temperature ranges. The average percentage of possible sunshine in southern Nevada is more than 80 percent. The high solar radiation, low humidity, and windy days in this region account for an average annual evaporation of approximately 70 inches of shallow open water⁵⁷. The monthly daily average temperature ranges from 41.1°F in December to 80.2°F in July. On average, there are 26 days of 100°F+ highs, 97 days of 90°F+ highs, and 38 days where the high remains at or below 50°F; the average window for freezing temperatures is November 2 to April 6.

The Beatty, Nevada, region is located in the Amargosa Desert, one of the driest locations in Nevada and, consequently, in the United States. On average, only 13.28 days a year have 0.1 inches of rain or more. The average number of days with rain for the State of Nevada is 22.11; the U.S. average is over 66. The Community Environmental Monitoring Program (CEMP⁵⁸) maintains a weather station near Beatty, Nevada. Since 2010 (10-year average), Beatty has averaged 3.8 inches of rain per year (Figure 6). The climate is Mediterranean, with a majority of precipitation occurring in the winter months. Several

⁵⁷ Nevada Department of Conservation & Natural Resources, 2010.

⁵⁸ <https://cemp.dri.edu/cemp/>

atypical heavy rain events occurred in February and March 2019, and the annual 2019 total precipitation was 5.1 inches, up from the 3.2-inch total in 2018.

9.3.4 Geology

Details on the nature of the unconsolidated strata beneath the facility have been determined from the various borings and well installations that have been completed at the facility since 1961. Extensive hydrogeologic investigations have been conducted to evaluate the soil properties and hydrologic characteristics. Stratigraphic information derived from the site characterization and monitoring well installation programs describes a sequence of sedimentary deposits consistent with alluvial fan and playa depositional processes.

Deposits from the ground surface to a depth of approximately 300 feet are alluvial sediments consisting predominantly of gravelly sands with poorly sorted gravel or discontinuous sand interbeds. The gravelly sand extends approximately 300 feet bgs beneath the Site and extends up to 350 feet bgs at the southwestern area of the Site.

Indurated playa deposits consisting of silt, clay, and sand underlie the gravelly sands and are approximately 50 to 150 feet in thickness, or 350 to 400 feet bgs up to 450 to 500 feet bgs. These fine-grained sediments are typical of playa deposits that may change composition relatively quickly with depth. The upper surface of the silt-clay unit appears to be relatively flat beneath the northern half of the Site and deepens to the southwest (like the gravelly sands). Beneath the silt-clay playa deposit is an older, deeper unit consisting of gravels, cobbles, and boulders that represent a higher energy, fluvial environment.

Although the Carrara Fault has been mapped near the Site, the USGS has not recorded any activity along this fault in the last 10,000 years. The nearest major fault zones are the Death Valley Fault Zone and the Las Vegas Fault Zone, 20 miles and 100 miles from the Site, respectively. Published data list no record of any historic earthquake epicenter in the area around Beatty for the period (since 1800) that records have been kept. A resistivity study was conducted at the Site in 2018 to better understand the Carrara Fault, and the results identified low-resistivity sediments and preferential groundwater flow to the southeast along secondary fractures. More discussion regarding the study is provided in the First Half 2019 Environmental Monitoring Report⁵⁹.

⁵⁹ USE, 2019b.

9.3.5 Hydrogeology

Two saturated, water bearing zones, the Upper water bearing zone (WBZ) and the Lower WBZ, have been encountered beneath the Site, at approximately 300 and 600 feet bgs. Drilling investigations indicate that the Upper WBZ occurs near the contact of the silt-clay playa deposits with the overlying gravelly sands. Beneath this, a confined aquifer, the Lower WBZ, occurs in a sandy gravel formation underlying the silt-clay deposits. This sandy gravel generally becomes coarser as it extends to depths exceeding 650 feet below ground level.

The surface drainage area of the Amargosa Desert covers about 2,600 square miles and is part of two regional groundwater systems. These two groundwater systems converge in the Amargosa Desert and likely continue to the south into Death Valley. Groundwater flow directions in the Amargosa Desert are generally to the southeast and southwest. The closest public drinking water supply well is located in Beatty, approximately 11 miles to the north of the Site. Aside from the well that supplies process water to the facility, the nearest private water well is located approximately 10.5 miles north of the facility at the Vanderbilt Mine.

Saturation in the Upper WBZ begins near the top of a 50- to 150-foot thick sequence of partially cemented to well-indurated clays, silts, and sand. The depth to saturation from the ground surface ranges from near 285 feet on the north side of the site to > 360 feet at the southwest corner of the facility. The interbedding of clays and cemented silts and sands at these depths serves to separate the Upper WBZ from the confined Lower WBZ beneath resulting in discrete hydrogeologic units.

The Lower WBZ is encountered beneath the fine-grained deposits at a depth of 380 feet or more. It consists of sandy gravel with some cobbles and boulders and is > 250 feet thick at the southern boundary of the site. The piezometric level measured in this aquifer occurs near 315 feet bgs, indicating a confined condition, based on wells and borings drilled into this unit. The groundwater gradient in both the upper saturated zone and confined gravel aquifer is southward, following the trend of the Amargosa Valley. This gradient is consistent with regional data.

Numerous studies conducted by US Ecology estimate hydraulic conductivities and transmissivities for the facility. The Upper WBZ is estimated to have a hydraulic conductivity of 57.3 feet per day (ft/day)⁶⁰ and an estimated effective porosity of 0.35. The hydraulic conductivity for the Lower WBZ is estimated to be 2.4 ft/day, also with an

⁶⁰ USEN, 2016.

effective porosity of 0.35⁶¹. The measured hydraulic conductivities are consistent with sample lithologies and are considered representative of the upper and lower saturated zones. Based on the presumed hydraulic values, the horizontal flow velocities are reported to range from 1,800 to 2,500 feet per year in the Upper WBZ and 0.11 to 0.12 feet per day in the Lower WBZ.

The potential for contaminant transport by water flow through the vadose zone is minimal under the conditions observed at the facility. An environmental pathways analysis performed for the Beatty Facility used physical property data of site sediments and assumed a conservative recharge rate of 0.04 inches per year. Calculated travel times for flow of vadose zone water from trenches to the Upper WBZ ranged from 13,000 to 24,000 years.

Pumping test data from earlier studies indicate that the Lower WBZ has a transmissivity ranging from about 1,900 to 3,000 gallons per day per foot. A groundwater flow velocity of about 30 to 50 ft/year is considered typical of the confined aquifer. The heterogeneity of the sediments in the confined aquifer suggests somewhat smaller or larger velocities may be possible on a local scale.

9.4 Site Conditions Summary

The Beatty, Nevada, facility is ideally suited for disposal of the encapsulated mercuric sulfide based on the arid site setting, with low average annual rainfall and high evaporation, relatively flat topography, deep groundwater, and low population. The encapsulated mercuric sulfide will be placed into a monofill within the existing footprint of the facility. The Subtitle C landfills at this facility produce only small quantities of leachate, and the hydraulic performance of the containment systems for the active landfills is very high (>99%). In addition, groundwater monitoring wells and monitoring protocols are already in place.

10. PROPOSED WASTE TREATMENT PROCESS COMPARED TO BDAT CRITERIA

The current BDAT criterion for elemental mercury is retort and reuse; however, since the U.S. domestic market for the product no longer exists and export criteria for treatment of mercury waste are becoming more stringent, the existing BDAT standard is no longer appropriate. Therefore, instead of long-term storage, stabilization and secure disposal of the mercury waste appears to be an ideal solution for managing the growing stockpile of domestic mercury effectively, for protection of human health and the environment.

⁶¹ US Ecology, 2019

Stabilization and secure disposal are proven and effective methods for containment of hazardous waste.

The BDAT criteria for mercury waste use TCLP with threshold values of 0.20 mg/L for residues from retort and 0.025 mg/L for other waste. The leachability of mercury in LLDPE-encapsulated mercuric sulfide was tested using LEAF 1313 at a range of pH (7.0 to 12.0 SU), and the resulting leachate concentrations are less than the BDAT criteria (<0.20 mg/L), as summarized in Table 1. This pH testing range encompasses the soil pH range of 8.3 to 9.4 SU measured at the Beatty, Nevada, facility (Table 2). Laboratory reports are provided in Appendix B.

Polyethylene materials are widely used as liquid and chemical barriers in many applications, including for containment of hazardous and radioactive wastes. The LLDPE polymer used for encapsulation of the mercuric sulfide and the HDPE drums used for containment of the LLDPE-encapsulated mercuric sulfide are both expected to have very good chemical resistance and durability under the anticipated service conditions (i.e., buried in a non-reactive monofill at an arid site). The HDPE drums used for containment are manufactured and designed to meet Department of Transportation specifications for transport of materials. They have sufficient structural strength for material handling, maintain their physical properties at a range of temperatures, and are UV and chemically resistant. A specifications sheet for an example of this type of drum is provided in Appendix A.

10.1 Long-Term Effectiveness of Treatment

The long-term effectiveness of treatment considered the potential effects of pH and temperatures on mercuric sulfide and the site-specific disposal conditions that are expected to exist at the US Ecology Beatty, Nevada, facility:

- pH – soil pH ranges from 8.3 to 9.4 SU (Table 2). This range of pH is alkaline, but fairly neutral, and not anticipated to degrade the HDPE drum or the LLDPE-encapsulated mercuric sulfide. Similarly, rainwater that encounters and reacts with this soil will not create highly acidic or highly basic conditions (e.g., less than 2 SU or greater than 12 SU) that could degrade the LLDPE and HDPE materials. Mercuric sulfide is stable from pH range of 0 to 12 SU, depending on redox conditions⁶². In the unlikely event that the LLDPE encapsulation and HDPE containment fail and the mercuric sulfide comes in contact with the site soil, the

⁶² <https://pubs.usgs.gov/pp/0713/report.pdf> (page 28) for eH-pH diagram.

LEAF 1313 / 7470 testing results (Table 1) demonstrate that the leachability of mercury is below current 40 CFR 268 concentration limits of 0.20 mg/L.

- Temperatures - Temperatures in the mercuric sulfide monofill are expected to be relatively constant below shallow depths that are affected by surface temperature. Unlike municipal landfills, the monofill will not have putrescent waste that generates heat as it degrades. Freeze/thaw cycles are also not anticipated to degrade the LLDPE or HDPE, since the materials will be buried at shallow depths (up to 20 feet bgs), only limited amounts of precipitation will migrate deep into the monofill, and groundwater is deep (> 300 feet bgs).

10.2 Discussion of Demonstrated Available Technology

The proposed mercury waste treatment process is consistent with EPA's criteria for determining BDAT. The technology is protective of human health and the environment, is commercially available and demonstrated to be successful at full scale, is highly effective, and provides substantial treatment of the waste.

Does not propose greater total risk to human health and environment. The LLDPE-encapsulated mercuric sulfide will not create dust or allow volatilization of mercury, and in fact, reduces the potential for these risk pathways by encapsulation and burial within the monofill. Leachability of the material is similarly restricted due to the containment within the HDPE drums, low potential for reactions with soil or groundwater in the monofill, and low potential for long-term generation of leachate in the arid environment, especially after the monofill is closed with a final cover system. Future potential risk is also mitigated by encapsulation and burial in the monofill.

Commercially available. The process for conversion of elemental mercury into mercuric sulfide was first observed in the early 1900's. Encapsulation is also not a new technology and has been used in similar technology/applications since the beginning of RCRA to decrease leachability, thereby, essentially eliminating the migration of toxics. LLDPE and HDPE are commercially available materials that have been used in numerous landfills and building material applications such as landfill liners, water pipes, remediation systems, etc.

Substantial treatment and best technology: The leachability of LLDPE-encapsulated mercuric sulfide has been evaluated using LEAF 1313 methodology, and the results are below what is currently achievable for other mercury waste streams and below the 0.20 mg/L threshold for residues from retort.

Containment and stabilization: Reaction of distilled, elemental mercury to mercuric sulfide creates a more stable form of mercury, and the reaction is best completed prior to encapsulation.⁶³ Encapsulation of the fully converted mercuric sulfide with LLDPE further stabilizes mercury, such that leachability is well below thresholds based on TCLP testing (Table 7). The encapsulation (LLDPE), containment (HDPE drum), and placement in the monofill (double-liner system) provides containment redundancy with multiple layers of protection.

Economic factors were not considered in the selection of this technology. Numerous attempts and methodologies were pilot tested to evaluate mercury treatment. This mercuric sulfide reaction combined with encapsulation has consistently passed leachate tests.

11. LONG-TERM MONITORING

The mercuric sulfide monofill monitoring requirements will be conducted in accordance with the RCRA Hazardous Waste Management Permit. Monitoring will include the existing groundwater monitoring system, new groundwater monitoring wells surrounding the cell, and LCRS/LDS sumps. The monofill groundwater monitoring wells and leachate sump collection systems will be included in the existing quarterly data collection and reporting events.

11.1 Mercuric Sulfide Monofill Cap and Closure

Once filled, the monofill will require a final closure system. The details of the closure system will be determined in the RCRA permitting process administered by the NDEP. Monitoring of the closed monofill will be conducted in accordance with the closure requirements of the RCRA Permit.

In conjunction with the NDEP, US Ecology prepared an Alternate Final Cover (AFC) design for Trench 12 that relies on the arid climate and high rate of evapotranspiration to limit migration of precipitation through the cover. US Ecology demonstrated the low rate of infiltration and high rate of evapotranspiration of the AFC design using a lysimeter and soil moisture probes placed in an optimized cover soil. With the approval of the NDEP, this AFC design will be used to close the monofill.

⁶³ Rodriguez, et al, 2012.

12. CONCLUSIONS/RECOMMENDATIONS

The proposed treatment that is the basis of this DET application described herein provides a high level of protection for human health and the environment. Conversion of elemental mercury into mercuric sulfide creates a very stable form of mercury. The process for stabilization of mercury as mercuric sulfide prior to encapsulation has proven to be a successful containment strategy. Prior studies conducted by EPA and other entities attempting to convert and stabilize mercury in one step (i.e., sulfur concrete) were less successful.

The stages of treatment/stabilization and containment (Figure 2 and 5) proposed are:

- Encapsulation of mercuric sulfide with LLDPE;
- Confirmation that LLDPE-encapsulated mercuric sulfide leachate testing results are below the threshold of 0.20 mg/L for leachate using LEAF 1313;
- Placement of LLDPE-encapsulated mercuric sulfide into sealed HDPE drums; and
- Placement of encapsulated mercuric sulfide into a monofill at the Beatty Nevada, facility.

The mercuric sulfide monofill design is ideally suited to limit potential reactions from other materials with the mercury or compete for the sulfide (e.g., nonreactive environment). The arid climate produces very limited precipitation and generation of leachate. There is a very low chance for introduction of other chemistries from organic material in the soil or rainwater, or another landfill waste. The Beatty Nevada, site is an existing Subtitle C permitted facility. The landfill is lined, has a dedicated monitoring system of groundwater monitoring wells, and data reporting procedures are already in place.

Initial laboratory testing results of the LLDPE-encapsulated mercuric sulfide are below the 0.2-mg/L threshold following LEAF 1313 (Appendix B). Additional LEAF 1313 testing will be used in the future to test new batches. Groundwater monitoring and comparison of results to GWPS will be used to demonstrate compliance with permit requirements, including federal and state screening levels that are protective of human health and environment.

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