Final Corrective Action Plan (CAP)
Chemical Waste Management of the Northwest, Inc. Facility
Arlington, OR

Prepared for
Chemical Waste Management of the Northwest, Inc.
17629 Cedar Springs Lane
Arlington, OR 97812

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GRADIENT

www.gradientcorp.com
One Beacon Street, 17th Floor
Boston, MA 02108
617-395-5000

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Abbreviations

A	Total Area of Each Bakken Oilfield Waste Load
AERMOD	Air Dispersion Model
ARAR	Applicable or Relevant and Appropriate Requirement
CAP	Corrective Action Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWMNW	Chemical Waste Management of the Northwest
EFU	Exclusive Farm Use
EQ	Environmental Quality
ERG	Environmental Restoration Group, Inc.
ERICA	Environmental Risk from Ionizing Contaminants: Assessment and Management
FS	Feasibility Study
GCL	Geosynthetic Clay Liner
GHG	Greenhouse Gas
GIS	Geographic Information System
GSR	Green and Sustainable Remediation
H	Nominal Thickness of Waste Associated with Each Bakken Oilfield Waste Load
HDPE	High-density Polyethylene
HSWA	Hazardous and Solid Waste Amendments
K_h	Horizontal Hydraulic Conductivity
MCM	Mixing Cell Model
MSL	Mean Sea Level
NCP	National Contingency Plan
NORM	Naturally Occurring Radioactive Material
NOV	Notice of Violation
NO_x	Nitrogen Oxide
O&M	Operations and Maintenance
ODEQ	Oregon Department of Environmental Quality
ODOE	Oregon Dept. of Energy
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OWRD	Oregon Water Resource Department
PCB	Polychlorinated Biphenyl
PM_{10}	Particulate Matter Less than 10 Microns in Diameter
POC	Point of Compliance
PPE	Personal Protective Equipment
PRB	Priest Rapids Member of the Wanapum Basalt
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
SO_x	Sulfur Oxide
SWB	Stormwater Basin
TENORM	Technologically Enhanced Naturally Occurring Radioactive Materials
Th-232	Thorium-232
TSDF	Treatment, Storage, and Disposal Facility

U-238	Uranium-238
US ACE	United States Army Corps of Engineers
US BLS	United States Bureau of Labor Statistics
US DOT	United States Department of Transportation
US EPA	United States Environmental Protection Agency
V_{Bakken}	Bakken Oilfield Waste Volume
V_{mx}	Bakken Oilfield Mixed Waste Volume
VOC	Volatile Organic Compound
W	Waste Weight
WM	Waste Management, Inc.
µR	MicroRoentgen

Executive Summary

This Corrective Action Plan (CAP) report for the Chemical Waste Management of the Northwest, Inc. (CWMNW) facility in Arlington, Oregon ("CWMNW facility") has been prepared by Gradient on behalf of CWMNW in response to the February 13, 2020, Notice of Violation (NOV) issued by the Oregon Dept. of Energy (ODOE) to CWMNW (Benner, 2020) and to subsequent correspondence between CWMNW and ODOE.

The scope of the CAP report is intended to address the estimated 1,285 tons of certain oilfield exploration wastes that were disposed of in Landfill L-14 of the CWMNW facility between 2016 and 2019. These wastes originated from liquid management and water recycling services in oil and gas industries located at Bakken oilfield sites (referred to hereafter as "Bakken oilfield waste") and were determined by ODOE to be Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) subject to the disposal prohibition in ORS 469.525 (Oregon State Legislature, 2020a) and OAR 345-050 (ODOE, 2020).

As requested by ODOE (Benner, 2020), this CAP follows "all substantive requirements of the CERCLA process" and includes the following:

- A quantitative evaluation of past, present, and future potential health risk to reasonably anticipated human and ecological receptors resulting from exposure to the subject waste materials.
- An evaluation of remediation alternatives consistent with the nine evaluation criteria in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; National Contingency Plan [NCP]; [40 CFR 300.430(e)(9)]; US EPA, 1987) and including a minimum of two alternatives: exhumation and lawful disposal of all wastes exceeding the definition of "radioactive materials" in OAR 345-050-0006 and *in situ* closure (referred to herein as the "excavate and redispose" and "closure-in-place" alternatives).
- A recommended alternative for final corrective action based on the risk assessment and evaluation of alternatives.

This CAP has been revised in accordance with ODOE's March 24, 2021 Determination Letter (Benner, 2021) and is submitted as the Final CAP.

ES.1 Methodology

Gradient prepared this report in accordance with Oregon environmental cleanup requirements and analogous federal regulations set forth under CERCLA and the NCP. More specifically, the methodology utilized within the CAP consists of the following:

Remedial Action Objectives (RAOs)

Gradient developed RAOs, which are medium-specific goals that guide the remedy evaluation and selection process to specific endpoints that ensure protectiveness. These RAOs were based on relevant United States Environmental Protection Agency (US EPA) and Oregon guidance and regulations, as well as site-specific factors, such as the location, nature, and extent of the Bakken oilfield waste, landfill design features, operational protocols, hydrogeological features, and land and groundwater use in the area.

The CAP RAOs for the CWMNW facility are as follows:

- **Bakken Oilfield Waste:** Control the potential for direct exposure to any Bakken oilfield waste comingled with Resource Conservation and Recovery Act (RCRA) hazardous and non-hazardous waste that could cause adverse human health or ecological effects.
- **Surface Water and Groundwater:** Control the potential for surface water and groundwater to be impacted by any TENORM constituents at levels that would exceed applicable water quality standards or that could cause adverse human health or ecological effects.
- **Air:** Protect potential receptors from exposure to radon daughters at concentrations that may pose a human health risk *via* the inhalation exposure pathway.

Conceptual Remediation Alternatives

Gradient performed a preliminary screening of remediation alternatives to narrow down to those alternatives that may be appropriate to implement to address TENORM buried in an active hazardous waste landfill. The screening process was performed consistent with US EPA and Oregon Dept. of Environmental Quality (ODEQ) guidance (*e.g.*, ODEQ, 2017; US EPA RI FS Guidance, US EPA, 1988) and the NCP (40 CFR 300.430).

Based on preliminary screening, the Closure-in-Place (Remediation Alternative 1) and Excavate and Redispose (Remediation Alternative 2) alternatives were carried forward into the detailed comparative analysis, which is consistent with what ODOE requested (Benner, 2000). The conceptual remediation alternatives are described below.

Remediation Alternative 1: Closure-in-Place

Under this scenario, the Bakken oilfield waste would be left in place in its current location comingled with hazardous wastes from other sources. Features of this alternative that would provide protection to workers and the public would include radiation shielding provided by the decades of additional cover material planned for this landfill prior to final closure (approximately 100 additional feet on average); a dual liner system equipped with leachate collection and leak detection systems to prevent migration of materials into the environment; and a final cover that would prevent or severely limit the potential for precipitation to reach the buried waste. In addition, under this alternative, CWMNW would implement a plan to monitor the presence of radionuclides in groundwater, wastewater treatment plant solid media, Landfill L-14 leachate, and the facility's combined leachate stream as follows.

- Groundwater
  - Radionuclide monitoring in the wells immediately upgradient and downgradient from Landfill L-14 will occur every five years during the landfill's operation. The first radionuclide groundwater sampling event occurred in February 2021.
  - If data from a well downgradient of Landfill L-14 being monitored for non-radionuclides suggest that there may be a potential release from the lined landfill (*i.e.*, failure of the landfill liner), the well is required to enter into Compliance Monitoring, and CWMNW will notify ODOE and include monitoring for radionuclides at the same frequency (triannually) as in the Compliance Monitoring schedule. Radiological monitoring results will be directly reported to ODOE.

    - The groundwater monitoring for radionuclides will continue following landfill closure, during the post-closure period.

- Wastewater Treatment Plant Solid Media
    - Annual radiological sampling and analysis will be performed for the on-site wastewater treatment plant solid media, including flocked solids, spent filters, and carbon filter beds. CWMNW will confirm on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.
- Landfill L-14 Leachate
    - Annual radiological sampling and analysis will be performed for the leachates produced by Landfill L-14 during the operational and post-closure periods for that landfill. The analytical results of this sampling will be reported to ODOE upon receipt. CWMNW will confirm on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.
- Combined Leachate Stream
    - Annual radiological sampling and analysis will be performed for the combined leachate stream from all on-site landfills during the operational and post-closure periods for the CWMNW facility. A sample will be collected from each of the two retention ponds that receive effluent from the wastewater treatment facility. The analytical results of this sampling will be reported to ODOE upon receipt. CWMNW will confirm on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.

Remediation Alternative 2: Excavate and Redispose

Remediation Alternative 2 consists of uncovering, excavating, transporting, and redisposing the Bakken oilfield waste from the CWMNW facility to a Subtitle C landfill permitted to accept TENORM. Under this scenario, approximately 680,000 yd^3 of waste overlying the Bakken oilfield waste would be excavated and relocated to another portion of the facility. Subsequently, approximately 3,244 yd^3 (3,854 tons) waste consisting of the Bakken oilfield waste and waste from other sources that is mixed with Bakken oilfield waste must be excavated and transported to an out-of-state permitted facility.

In this alternative, overburden waste in Landfill L-14 would be managed by workers using heavy equipment to unearth the Bakken oilfield waste. Approximately one-third of the waste is contained in HDPE Macroencapsulation boxes ("Macro boxes") that would need to be breached in place to enable access, then repackaged into new Macro boxes that would temporarily be stored on Landfill L-14. Another approximately one-third of the waste is contained in drums, which would need to be carefully removed to avoid puncturing and placed in lined roll-off containers that would also be temporarily stored on Landfill L-14. The remaining waste generally consists of granular material and would need to be stockpiled and temporarily stored on Landfill L-14 prior to removal for redisposal. The removal of all the Bakken oilfield waste is estimated to take approximately 10 years.

Given the hazardous nature of waste disposed of at the CWMNW facility, all operations at Landfill L-14 would be performed, at a minimum, at Level C safety supplemented by air supply for personnel. However, excavation of the Bakken oilfield waste along with the mixture of hazardous wastes would pose a significant level of risk to workers that would not be entirely mitigated even if properly using personal protective equipment (PPE) or by implementing engineered controls.

ES.2 Results

Gradient performed a detailed assessment of each remediation alternative based on evaluation criteria established in federal and state environmental remediation laws and in consultation with ODOE. These criteria were evaluated using a combination of quantitative and qualitative methods, including the results of the TENORM Dose and Radiological Risk Assessment prepared by RAC (2020a; Attachment C to this CAP). Notably, for all future receptors evaluated (landfill worker, current off-Site resident, future off-Site resident, future on-Site resident, and future intruder) under both remediation alternatives, the cancer morbidity risks are well below US EPA's and ODEQ's target risk ranges and well below the level at which potential health effects may be observed.

Under Alternative 1, RAC (2020a) concluded that the dose for all the receptors was well below the level at which potential health effects may be observed. The highest estimated dose to a present or future landfill worker under Alternative 1 would be so low as to be essentially zero. Even a hypothetical future on-Site resident who builds a house on top of the landfill and drinks water from an adjacent well would not pose an unacceptable human health risk (a maximum estimated dose of 0.12 millirem per year with a corresponding cancer morbidity risk of one in one million); this scenario ignores the fact that groundwater under the facility in the Selah Member would not be suitable for potable use. The risk to a hypothetical intruder who drills a well directly through the landfill was only marginally higher (approximately six in one million probability) and still at the lower end of the US EPA acceptable risk range. For these doses to occur, multiple worst-case assumptions would need to be realized at once, which means that these estimates are most likely unrealistically high. These exposure scenarios were included for the sake of a more complete public understanding of the safety functions provided by the landfill relative to the maximum potential hazard from the TENORM waste. In addition, the future resident and intruder exposure scenarios are also highly unlikely because as part of the closure of the entire facility, once all operations have concluded and the closure of all hazardous waste treatment, storage, and disposal units have been completed and approved, CWMNW must record on the property deed that the land has been used to manage hazardous wastes and that the land use is restricted under 40 CFR 264.110-120 (US EPA, 1993) regulations.

For Alternative 2, the combined analysis from RAC and this CAP found that the risks associated the radioactivity of the wastes under Remediation Alternative 2 would be approximately 35 times higher to the maximally exposed individual (3.5 in 10,000 probability to a landfill excavation worker) than the radiation risks associated with the on-site resident risk in Remediation Alternative 1. In addition to the radiological risk, the excavation of existing buried wastes as part of Remediation Alternative 2 could result in a multitude of difficult to quantify but potentially serious risks associated with the disturbance of the hazardous wastes also present in the landfill, including the rupture of containers and undesired mixing of incompatible wastes. The excavation of comingled waste presents an undue risk for remediation workers due to the potential for exposure to mixtures of wastes with potentially incompatible characteristics that could result in unknown or unintended dangerous chemical reactions.

The results of the comparative analysis of the remediation alternatives demonstrate that Remediation Alternative 1 (Closure-in-Place) is the preferred remediation approach for addressing the Bakken oilfield waste buried in Landfill L-14 at the CWMNW facility, assuming regulatory approval and community acceptance, because it provides the highest degree of overall protectiveness; poses the lowest short-term physical, chemical, and radiological exposure-related risks to workers and the community; and provides long-term effectiveness and protectiveness while also being cost-effective and implementable.

Remediation Alternative 1 would provide a higher level of overall protectiveness than Remediation Alternative 2. In addition, excavating, transporting, and redisposing of the Bakken oilfield waste would create chemical and radiological exposure pathways and additional chemical and radiological risks that are not currently present, and there are significant short-term physical risks associated with its excavation, transport, and redisposal.

The RAC (2020a) Radiological Risk Assessment results demonstrate that in the event of future leachate system failure, potential doses and risks for human health and ecological receptors *via* the groundwater exposure pathway are extremely low and well within the acceptable range set by US EPA, even assuming the confluence of multiple worst-case scenarios. The RAC Radiological Risk Assessment also demonstrated that any Bakken oilfield waste leachate potentially entering groundwater in the future would do so at concentrations that are at least an order of magnitude below the standards for all the individual TENORM constituents under both the federal Safe Drinking Water Act and ODOE's state standards for radioactive material in water under OAR 345-050-0035.

Remediation Alternative 1 is readily implementable. The implementability challenges associated with Remediation Alternative 2, including worker/public safety, disruptions to the community (*e.g.*, truck traffic), and disruption to the landfill operations, are significant. Remediation Alternative 2 would also pose significant implementation challenges associated with the excavation of vast quantities of hazardous waste that would be required to access the Bakken oilfield waste, as well as even finding the Bakken oilfield waste since it is mixed heterogeneously with other hazardous and non-hazardous waste.

Gradient eliminated Remediation Alternative 2 after comparing it to Remediation Alternative 1, based on its lack of overall protectiveness, including its inherent physical, chemical, and radiological human health risks, as well as its challenging implementability, excessive cost, and significant short-term impacts (*e.g.*, estimated 10-year duration to complete remediation leads to more truck traffic; greater impact on the community; air/odor issues). Remediation Alternative 2 does not meet the threshold criteria of Overall Protectiveness. Gradient selected Remediation Alternative 1 as the preferred alternative because it ensures overall and long-term protectiveness while posing low short-term risks to workers and the community and is cost-effective.

Remediation Alternative 1 would not reverse the conditions that led to the original NOV (Benner, 2020). ODOE would need to determine whether the risks inherent with Remediation Alternative 2 would make Alternative 1 an acceptable remedy. Similarly, Gradient anticipates that ODOE will determine whether Remediation Alternative 2 satisfies other potential Applicable or Relevant and Appropriate Requirements (ARARs), as well as the remedy selection criteria of state regulatory approval and community acceptance.

ES.3 Measures Undertaken to Prevent Future Disposal of Radioactive Materials

Common to both remediation alternatives are the following corrective actions that were developed in consultation with ODOE to prevent the potential recurrence of a TENORM disposal event:

- A Waste Screening and Approval Program: Implementation of a waste screening and approval program that identifies potential radioactive waste streams and requires isotopic testing for those categories of wastes. The screening program was prepared and submitted to ODOE by CWMNW, and ODOE concurrence was received.
- A Portal Monitoring System: Installation of a portal monitoring system as part of the Radiological Monitoring Plan at the facility entrance to screen all inbound wastes into the facility for ionizing radiation.

1 Introduction

This Corrective Action Plan (CAP) report for the Chemical Waste Management of the Northwest (CWMNW) facility in Arlington, Oregon ("CWMNW facility") has been prepared by Gradient on behalf of CWMNW in response to the February 13, 2020, Notice of Violation (NOV) issued by the Oregon Dept. of Energy (ODOE) to CWMNW (Benner, 2020) and to subsequent correspondence between CWMNW and ODOE (see Attachment A).

The scope of the CAP report is intended to address the estimated 1,285 tons of certain oilfield exploration wastes that were disposed of in Landfill L-14 of the CWMNW facility between 2016 and 2019.[1] These wastes originated from liquid management and water recycling services in oil and gas industries located at Bakken oilfield sites (referred to hereafter as "Bakken oilfield waste") and were determined by ODOE to be Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) subject to the disposal prohibition in ORS 469.525 and OAR 345-050.

As specifically requested by ODOE (Benner, 2020), this CAP follows "all substantive requirements of the CERCLA process" and includes the following:

- A quantitative evaluation of past, present, and future potential health risk to reasonably anticipated human and ecological receptors resulting from exposure to the subject waste materials.
- An evaluation of remediation alternatives consistent with the nine evaluation criteria in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; National Contingency Plan [NCP]; [40 CFR 300.430(e)(9)]) and including a minimum of two alternatives: exhumation and lawful disposal of all wastes exceeding the definition of "radioactive materials" in OAR 345-050-0006 and *in situ* closure (referred to herein as the "excavate and redispose" and "closure-in-place" alternatives).
- A recommended alternative for final corrective action based on the risk assessment and evaluation of alternatives.

Gradient prepared this report in accordance with Oregon environmental cleanup requirements,[2] and analogous federal regulations set forth under CERCLA and the NCP. In compliance with ODOE's request for the CAP to follow the same general approach used for the Blue Ridge Landfill in Kentucky, Gradient found it imperative to incorporate the specific characteristics of the CWMNW facility in performing the analysis. The CWMNW facility is a Resource Conservation and Recovery Act (RCRA), Treatment, Storage, and Disposal Facility (TSDF) permitted to treat, store, and land dispose a wide range of both hazardous and non-hazardous wastes, whereas the Blue Ridge Landfill is permitted as a Subtitle D landfill primarily designed for the disposal of municipal solid waste. Landfill L-14 of the CWMNW facility is double-lined with secondary and tertiary leak detection systems, and the overall environmental setting is significantly different. Finally, there are some differences in the characteristics of the TENORM wastes that were disposed of at each facility. These site-specific factors are accounted for in the CAP for the CWMNW facility.

[1] Separate from this CAP, CWMNW is working with ODOE to develop appropriate "technological and/or administrative provisions to minimize the potential of future recurrence" as required by ODOE in their NOV (Benner, 2020).

[2] Generally, ORS 465.200 *et seq*. and OAR 340-122-0010 *et seq.*; more specifically, OAR 340-122-0085, which pertains to a feasibility study (FS).

Professional environmental firms have conducted environmental investigations and dose and risk assessments to characterize potential human health impacts associated with the Bakken oilfield waste. K2 Environmental LLC and Environmental Restoration Group, Inc. (ERG) performed a direct gamma survey at the CWMNW facility in June 2020 (see Attachment B). RAC performed a Radiological Dose and Risk Assessment for the Bakken oilfield waste (see Attachment C). Both the findings of the previous environmental investigations and the RAC dose and risk assessment are summarized briefly herein because they are relevant to the evaluation of the remediation alternatives considered in the CAP.

The following sections of the report provide a discussion of relevant facility background and regulatory requirements (Section 2), the Remedial Action Objectives (RAOs; Section 3), the development of the remediation alternatives (Section 4), the corrective action evaluation criteria (Section 5), the evaluation of the alternatives using a combination of qualitative and quantitative methods based on those criteria (Section 6), and a comparative analysis of the remediation alternatives (Section 7) and the Radiological Monitoring Plan (Section 8) to monitor incoming waste streams for TENORM. Attachments A-G provide supporting information.

2 Background

2.1 CWMNW Facility Overview

The CWMNW facility is a permitted Subtitle C Treatment Storage and Disposal Facility (TSDF) located on Cedar Springs Lane in Gilliam County, approximately seven miles southwest of Arlington, Oregon (CH2M Hill, 2008) (Figure 2.1). The facility property consists of approximately 1,288 acres, with about 270 acres permitted for hazardous waste operations (ODEQ, 2016). Based on an aerial photograph (from approximately 2019), Gradient estimates that the total developed area of the CWMNW facility comprises approximately 700 acres. The developed portions of the CWMNW facility that are not directly used for TSDF operations (approximately 430 acres) are used for administration buildings, a laboratory, vehicle and equipment maintenance facilities, staging areas, water and propane tanks, a weather station, and roads (ODEQ, 2006). The CWMNW facility is buffered by over 11,000 acres of undeveloped property owned by Waste Management, Inc. (WM).

Between May 2016 and September 2019, an estimated 1,285 tons of waste from the Bakken oilfield in North Dakota (referred to herein as "Bakken oilfield waste") was disposed of in Landfill L-14 of the CWMNW facility. ODOE determined that these wastes qualified as TENORM subject to the disposal prohibition in ORS 469.525 and OAR 345-050. Due to this disposal, ODOE issued an NOV to CWMNW on February 13, 2020 (Benner, 2020).

The CWMNW facility provides waste management services to customers throughout the United States and Canada. The CWMNW facility also offers services nationally through WM's rail transportation network. The CWMNW facility began limited operations in the early 1970s as Chem Nuclear as a disposal facility that would accept both chemical and radioactive wastes; nonetheless, radioactive waste was not disposed of at the facility in the past (Personal communication with CWMNW Environmental Protection Manager, James L. Denson Jr.). In 1971, the Oregon State Engineer noted that the geological setting was favorable for that proposed use, that the possibility of geological hazards such as "volcanic activity, earthquakes, floods, and landslides" was remote, and that geological hazards did not present a "material risk to the waste disposal structures" (Bartholomew, 1971). In the late 1970s and early 1980s, Oregon enacted rules governing radiation, changing the direction of the permitting effort for Chem Nuclear (Personal communication with CWMNW Environmental Protection Manager, James L. Denson Jr.). The CWMNW facility first obtained a RCRA Hazardous Waste Permit for the storage, treatment, and disposal of hazardous waste in 1988. The permit was reissued in 2006 by the Oregon Department of Environmental Quality (ODEQ). CWMNW is currently in the process of renewing the facility's permit.

The CWMNW facility lies on a rolling plateau ranging in elevation from about 990 to 1,030 feet above mean sea level (MSL). The facility includes 11 landfill units, as well as manmade evaporation ponds, storage units, treatment units, and several stormwater management ponds. There are no natural surface water bodies on the CWMNW facility; however, some precipitation from the areas surrounding the CWMNW facility eventually ponds to the south in Alkali Canyon, where it eventually evaporates (CH2M Hill, 2008).

Land use within Gilliam County is largely grassland/shrubland and agricultural, with the exception of the developed areas in the cities of Arlington, Condon, and Lonerock (Figures 2.1 and 2.2). The CWMNW facility is zoned as General Industrial (M-G), and the surrounding property is zoned as Exclusive Farm Use

(EFU) (Gilliam County, Oregon, 2017, 2020). The nearest residence is approximately two miles southwest of the facility, and the nearest schools and churches are located in Arlington, about 7 miles northeast of the facility (Figure 2.2). The layout of the facility, including Landfill L-14, is presented in Figure 2.3.

The CWMNW facility is a professionally managed, highly engineered TSDF. Landfill L-14 is a double-lined Subtitle C permitted disposal unit that has engineered redundant systems for leachate collection and leak detection. From a groundwater monitoring perspective, the facility is divided up into three separate waste management areas that each have a network of groundwater monitoring wells. These wells are sampled on a regular basis to evaluate groundwater quality in the Selah Member water-bearing zone, which underlies the CWMNW facility (see Sections 2.2.1 and 2.2.2). These monitoring wells provide an effective means of detection in the event of a release of constituents from the waste management areas (ODEQ, 2014a). In the vicinity of Landfill L-14, groundwater is currently monitored at four monitoring wells immediately downgradient of the landfill (Figure 2.3). Groundwater sampling is performed on a semi-annual basis for volatile organic compounds (VOCs) and on an annual basis for polychlorinated biphenyls (PCBs) in the Point of Compliance (POC) wells (ODEQ, 2014a).

The sections below provide details on the permitted wastes, liner and leachate collection system for Landfill L-14, methods used for stormwater control, and post-closure requirements.

2.1.1 Hazardous Waste Permit

The Hazardous Waste Permit allows the CWMNW facility to accept the types of wastes presented in the list below (ODEQ, 2006). This list includes the types of waste that the permit allows to be disposed of at this facility, and thus represents what could potentially be present in Landfill L-14. However, the CWMNW facility has not necessarily accepted all of these waste types in the past, nor has each of these waste types necessarily been disposed of in Landfill L-14.

- The universe of hazardous and non-hazardous wastes including but not limited to:
  - containerized and bulk liquid corrosive wastes,
  - containerized and bulk liquid ignitable and organic wastes,
  - containerized and bulk liquid reactive wastes,
  - all containerized liquid and bulk wastes not included in those listed above, including pesticide wastes plus every combination,
  - bulk or containerized solid wastes including lab packs such as filter cakes and spill and site cleanup residue,
  - bulk and containerized semi-solid or sludge wastes,
  - bulk and containerized PCB wastes greater than or equal to 50 ppm, and
  - containerized compressed gases, with limitations
- Recoverable organic wastes limited to petroleum hydrocarbon wastes from the petroleum refining, transportation, and pipeline sectors.
- The universe of inorganic wastes including but not limited to corrosive wastes, toxicity characteristic wastes, primary and secondary metals wastes (non-reactive), electroplating wastes (non-reactive) soils, sludge, debris, inorganic pigments, aqueous wastes (non-reactive), asbestos and asbestos-containing material (RCRA regulated wastes), commercial chemical products, off-specification species, process residues, and spill residues.

- The universe of reactive wastes including but not limited to water reactive solid wastes, commercial chemical products, off-specification species, process residues, and spill residues.
- The universe of non-recoverable organic hazardous wastes including but not limited to soils, sludges, debris, toxicity characteristics wastes, organic acids and bases, wood products wastes, pesticide wastes, petroleum/refining wastes, aqueous wastes (non-reactive), commercial chemical products, off-specification species, process residues, and spill residues.
- The universe of state-only hazardous waste containing a three percent or greater concentration of any substance or mixture of substances listed in 40 CFR 261.33(e) (US EPA, 2017); state-only hazardous waste containing a ten percent or greater concentration of any substance or mixture of substances listed in 40 CFR 261.33(f); spill cleanup residue, soil, water, or other debris containing any amount of state-only hazardous wastes.
- Demilitarized munitions containing blister agents and nerve agents approved for disposal designated with state-only hazardous waste numbers P998 and P999, respectively; residues from the demilitarization, treatment, and testing of blister and nerve agents designated state-only hazardous waste numbers F998 and F999, respectively.
- PCB-containing materials regulated under OAR 340-110 (ODEQ, 2020a); solid wastes defined by ORS 459.005 (Oregon State Legislature, 2020b) and/or OAR 340-93-0030 (ODEQ, 2020b), including cleanup materials contaminated by hazardous substances, commercial solid waste, construction and demolition waste, industrial solid waste, leachate, sludge, wood waste, and asbestos and asbestos-containing material; and pesticide wastes managed under OAR 340-109-0010.

2.1.2 Landfill L-14 Liner and Leachate Collection System

Landfill L-14 occupies an area of approximately 32 acres[3] and is divided into five cells with primary and secondary liners and leachate collection/detection systems. Cells 1 to 4 have been constructed and contain the Bakken oilfield waste, and are therefore most relevant to the CAP.[4] All cells have an upper (primary) liner and a lower (secondary leak detection) liner; each liner system includes a leachate collection system conveying leachate to their respective sumps, and a tertiary leak detection sump beneath the secondary leachate detection sump. The sumps are placed in the lowest portion of each cell and are the areas with the highest likelihood of a potential release, and therefore provide the earliest possible detection of a release. Leachate is generally pumped from the primary leachate removal sump to a vacuum truck and used for dust control on the landfill surface, where it evaporates (ODEQ, 2014b). If leachate removal is required and dust control is not needed due to rain or snow conditions, the leachate is transported to the wastewater treatment plant located at the CWMNW facility for treatment, and the treated liquid is then pumped into one of two lined ponds (RAC, 2020b).

Each Landfill L-14 cell liner system is constructed of the following layers, described from the top to the bottom: a primary liner system that includes an 18-inch operations layer,[5] a geotextile leachate collection layer, and a 60-mil high-density polyethylene (HDPE) membrane liner. Cells 1 through 3 have a compacted clay liner under the primary HDPE membrane in the secondary liner. Cell 4 is constructed with a geosynthetic clay liner (GCL) *versus* the clay liner used in Cells 1-3. Underlying the GCL or clay liner in each cell is a geotextile leachate collection layer and a 60-mil HDPE secondary membrane which acts as a

[3] Based on the area of the five cells shown on Figure 2.3.
[4] Cell 5 is permitted but has not yet been constructed.
[5] The operations layer is composed of granular material, such as sand or soil, and protects the liner from physical damage from the waste placed in the cell.

leak detection layer. The liner, base materials, and leachate collection systems for Landfill L-14 Cells 1-3 and Landfill L-14 Cell 4,[6] are summarized in Tables 2.1 and 2.2, respectively.

Table 2.1 Landfill L-14 Cells 1-3 Liner Design

Landfill Units	Liner System Design (top to bottom)	Sideslope Design (top to bottom)	Leachate Collection Sumps	Final Cover Design
L-14 Cells 1-3	**Upper (Primary) Liner** ▪ 18" Operations Layer ▪ Geotextile filter ▪ 60-mil HDPE liner ▪ Geosynthetic Clay Liner (GCL) **Lower (Secondary) Leachate Collection System** ▪ Geocomposite (drainage layer) ▪ 60-mil HDPE liner ▪ Geonet ▪ 60 mil Geomembrane ▪ Minimum 3-ft soil/bentonite liner (permeability $1x10^{-7}$ cm/sec or less)	**Upper Primary Liner** ▪ 12-inches granular drainage layer ▪ Protective membrane (option to be removed or left in-place) ▪ Geocomposite drainage layer ▪ 60-mil HDPE liner ▪ Geocomposite drainage layer **Lower (Secondary) Leachate Collection System** ▪ 60-mil HDPE liner ▪ Minimum 3-ft soil/bentonite liner (permeability $1x10^{-7}$ cm/sec or less)	Three primary and Three secondary leachate collection sumps systems are associated with Landfill L-14 cells 1-3. One sump system is located within each cell	See facility's Landfill Final Cover Design Plans document

Note:
HDPE = High-density Polyethylene.
Table recreated from ODEQ (2014b).

Table 2.2 Landfill L-14 Cells 4 and 5 Liner Design

Landfill Units	Liner System Design (top to bottom)	Sideslope Design (top to bottom)	Leachate Collection Sumps	Final Cover Design
L-14 Cells 4 and 5	**Upper (Primary) Liner** ▪ 18" Operations Layer ▪ Geotextile filter ▪ 60-mil HDPE liner ▪ Geosynthetic Clay Liner (GCL) **Lower (Secondary) Leachate Collection System** ▪ Geocomposite (drainage layer) ▪ 60-mil HDPE liner ▪ Geonet ▪ 60 mil Geomembrane ▪ Geosynthetic Clay Liner (GCL)	**Upper Primary Liner** ▪ 12-inches granular drainage layer ▪ Protective membrane (option to be removed or left in-place) ▪ Geocomposite drainage layer ▪ 60-mil HDPE liner ▪ Geocomposite drainage layer **Lower (Secondary) Leachate Collection System** ▪ 60-mil HDPE liner ▪ Minimum 3-ft soil/bentonite liner (permeability $1x10^{-7}$ cm/sec or less)	Landfill L-14 Cell 4 has a primary and secondary leachate collection sump system	See facility's Landfill Final Cover Design Plans document

Notes:
HDPE = High-density Polyethylene.
Table recreated from ODEQ (2014b).

[6] Landfill Cell 5 is approved to have the same liner design features as Cell 4.

2.1.3 Stormwater Control

The facility uses several stormwater management ponds, so that stormwater runoff is maintained at the CWMNW facility. As discussed in Section 2.2.4, due to the semiarid conditions and high evapotranspiration rates in the region, there is limited stormwater runoff potential at the CWMNW facility. Based on the 2018 Surface Water Management Plan (Golder and Associates, 2018), six retention ponds or ditches are planned for the CWMNW facility. These retention ponds are designed as unlined ponds for management of surface water that has not contacted hazardous material. The facility has a stormwater retention pond located north of Landfill L-14 (noted as stormwater basin SWB-2) and retention ditches located at the west edge of Landfill L-14 (SWB-4), just west of L-1 (SWB-3), south of L-6 (SWB-1), and near the south edge of the facility (SWB-5 and SWB-6)[7] (Golder and Associates, 2018). As shown on Figure 2.3, the stormwater management system in 2020, consistent with the 2018 Surface Water Management Plan, included Pond 5 in the southwest portion of the facility, Pond 6 in the southeast portion of the facility, and four retention ditches (RSI, 2020).

2.1.4 Closure and Post-closure Requirements

The closure and post-closure requirements for the facility are discussed in the "Closure/Post-Closure Plan" (ODEQ, 2016). The post-closure plan will remain in effect for at least 30 years after the date of closure; based on the available space in Landfill L-14 and current waste inflow rate, the closure date is estimated to be decades away. Closure timeframes are highly dependent on several factors, the primary of which is the actual waste volume accepted. As part of the closure of Landfill L-14, the landfill will receive an engineered evapotranspiration final cover system. The final cover system for Landfill L-14 (ASW *et al*., 2014a) would consist of three feet of native soil placed over the interim cover and compacted to 90 to 95 percent of the soil's maximum dry density. The final cover system will be vegetated to minimize erosion. Additionally, drainage structures and erosion control measures will be incorporated into the final grading plan as needed (ASW *et al*., 2014a).

Post closure activities that will be performed annually or semi-annually at the facility for at least 30 years include:

- Inspection of closed units "per 40 CFR 264.113 requirements," and following a rainstorm with an intensity of 1 inch over 24 hours. The inspection will include checking the security fencing, checking the landfill cap for erosion and maintaining it, and checking the vegetative cover and re-vegetation as needed.
- Groundwater monitoring for at least 30 years (annual or semi-annual depending on the well).
- Monitoring and maintenance of the leachate collection system, with treatment of leachate as needed.

As part of the closure of the entire facility, once all operations have concluded and the closure of all hazardous waste treatment, storage, and disposal units have been completed and approved, CWMNW must record on the property deed that the land has been used to manage hazardous wastes, that the land use is restricted under 40 CFR 264.110-120 regulations, and that the survey plat and record of the type, location, and quantity of hazardous wastes disposed of within each cell have been filed with the local zoning authority (ODEQ, 2016).

[7] It appears that stormwater basins SWB-5 and SWB-6 were replaced in 2020 by Pond 5 and Pond 6, respectively.

2.2 Physical Setting

The CWMNW facility is located within the south-central portion of the Columbia physiographic province (Deschutes-Umatilla Plateau). The physical setting of the Arlington area is defined by several governing factors, which include (1) a semiarid climate (less than 11 inches of precipitation per year), (2) the presence of thick sequences of basalt bedrock, (3) structural tectonic forces, and (4) multiple flood events occurring between 13,000 and 15,000 years ago (RAC, 2020c).

The majority of the CWMNW facility is located on a plateau, with the southern edge of the facility located in Alkali Canyon. The waste management activities, including operations in Landfill L-14, occur on the plateau above the canyon (RAC, 2020c).

2.2.1 Geology

The following geological units are located below Landfill L-14, from shallowest to deepest (RAC, 2020c):

- Sedimentary deposits of the Dalles Group (Alkali Canyon Formation),
- Selah Member and associated sedimentary deposits of the Ellensburg Formation,
- Priest Rapids Member of the Wanapum Basalt (PRB), and
- Frenchman Springs Member of the Wanapum Basalt.

The geological units are described in more detail below. Figure 2.4 presents a conceptual model and geological cross-section of the area below Landfill L-14 (RAC, 2020c).

The Alkali Canyon Formation outcrops at the surface and overlies the Selah Member. Landfill L-14 penetrates the Alkali Canyon Formation, and its base is in the Selah Member. The Alkali Canyon Formation is unsaturated at the CWMNW facility (Dames and Moore, 1987; RUST, 1998a,b; all as cited in RAC, 2020c).

The Selah Member is a heterogeneous siltstone with varying degrees of clay and sand content. The Selah Member ranges in thickness from 35 to 49 meters (115 to 160 feet) beneath the upland plateau where the active area of the CWMNW facility is located. The upper portion of the Selah Member is unsaturated, with groundwater present in the lowest 6.1 to 21.3 meters (20 to 70 feet) (CH2M Hill, 2008). The depth to groundwater in the Selah Member is approximately 160 feet below the upland plateau, which translates to approximately 80 feet below the base of Landfill L-14 (CH2M Hill, 2008). South of the facility, the Selah Member is largely absent in Alkali Canyon, where it was eroded away by floods of glacial origin that inundated the Columbia Plateau during the Pleistocene epoch (over 10,000 years ago; RAC, 2020c).

The PRB consists of two flows at the CWMNW facility, a younger Lolo flow and the older Rosalia flow. The two flows have the typical characteristics of a basalt flow consisting of dense to columnar-jointed flow interior between a brecciated flow bottom and weathered flow top. The Lolo and Rosalia flows are separated by a partially lithified sedimentary interbed composed of silt and clay (CH2M Hill, 2008; RAC, 2020c). The Frenchman Springs Basalt underlies the PRB and has been used for CWMNW facility water supply wells.

Tectonic activities folded and faulted the older geological units of the Selah Member and PRB after they were deposited. An east-west trending anticline fold is present along the northern portion of the CWMNW facility based on geological borehole data and surface geophysical surveys (see Figure 2.4). The fold dips to the north of the CWMNW facility and towards Alkali Canyon to the south.

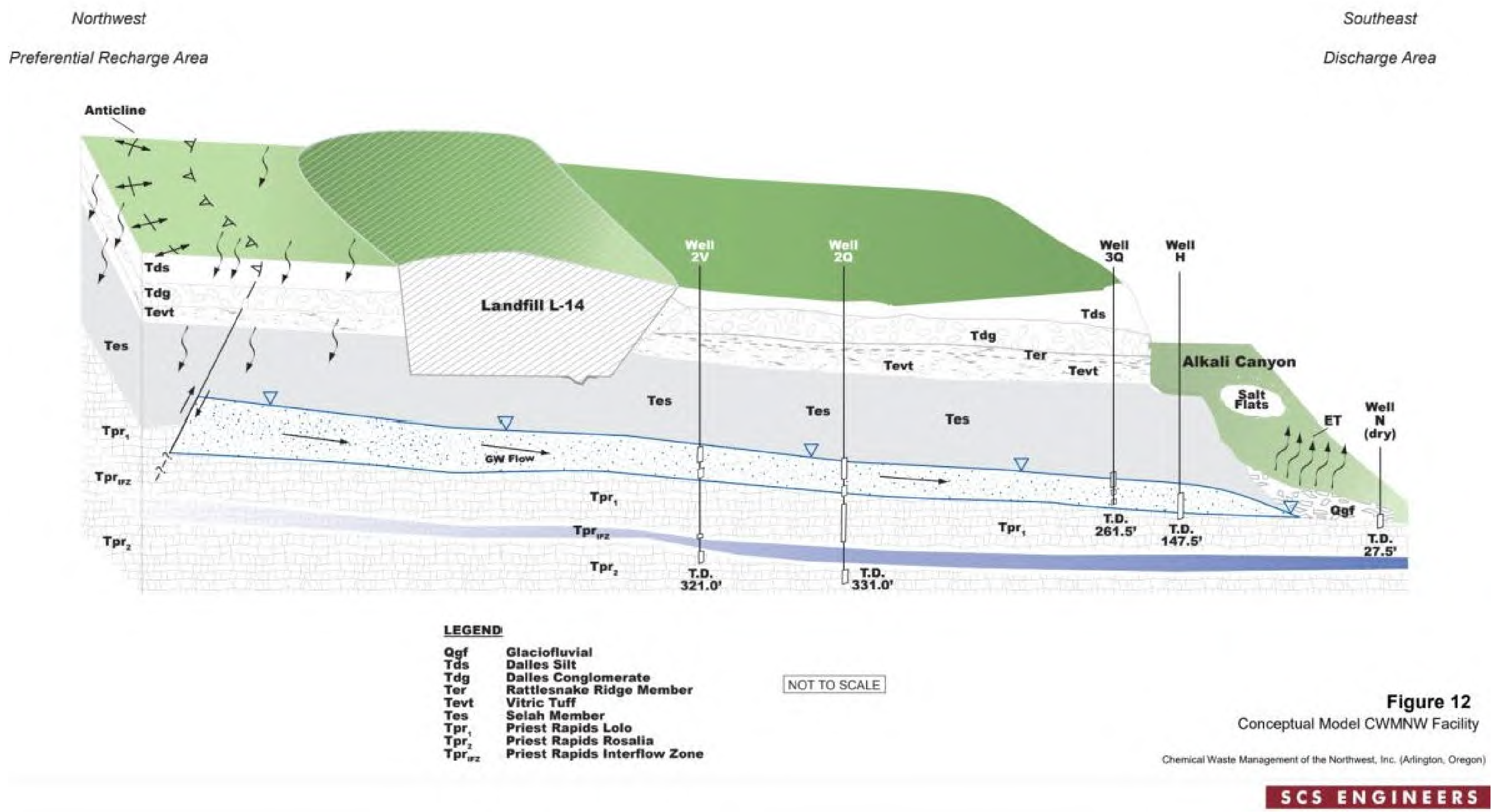

Figure 2.4 Conceptual Model and Geological Cross-section of the CWMNW facility. Source: RAC (2020c).

2.2.2 Hydrogeology

The Selah Member contains the uppermost groundwater-saturated zone beneath the facility. Recharge to the Selah Member occurs along the northern portion of the CWMNW facility near the structural geological features and through the unsaturated zone. Recharge to groundwater is primarily from precipitation and has been previously estimated to be approximately 0.1 feet/year (RUST, 1998b, as cited in RAC, 2020c). Groundwater flow within the saturated portion of the Selah Member is very low flow (on the order of feet per year) and generally toward the southeast and towards Alkali Canyon, consistent with the structural dip of the underlying PRB. Groundwater flow and constituent transport is discussed in the Dose and Risk Assessment report (RAC, 2020a) presented as Attachment C to this CAP. In general, the Selah Member in the area under Landfill L-14 is a confined groundwater system. In the northwestern area, a clay-rich horizon likely acts as a confining to semi-confining layer, below which is a zone of lower clay content (and potentially higher hydraulic conductivity).

The horizontal hydraulic conductivity (K_h) in the Selah Member ranges from 1×10^{-6} to 1×10^{-4} cm/s based on pumping test data, packer testing, and core sample testing (Dames and Moore, 1987 and RUST, 1998a, both as cited in RAC, 2020c; CH2M Hill, 2008). Horizontal hydraulic conductivity values estimated for test intervals crossing the Selah Member/PRB contact and the vertical hydraulic conductivity of the Selah Member have been estimated to range from 5×10^{-9} cm/s to about 5×10^{-6} cm/s with a geometric mean of about 5×10^{-8} cm/s[8] (CH2M Hill 2008). Using the historical average hydraulic gradient of approximately 0.015 to 0.035 m/m and the estimated hydraulic conductivity of the Selah Member, the estimated rate of lateral groundwater flow ranges from 0.23 to 2.1 m/year (0.77 to 6.9 feet/year) (RAC, 2020c).

Radiocarbon dating suggests that the age of the shallow groundwater in the Selah Member ranges from 1,000 to 4,000 years, while groundwater is much older in the PRB (estimated to range from 9,600 to 12,900 years old) and in the deeper Frenchman Springs Basalt used for water supply at the facility (estimated 14,000 to 16,000 years old) (CH2M Hill, 2008). The age differences indicate that there is limited hydraulic connection, if any, between the shallow Selah Member water-bearing zone and the deeper basalt aquifers (RAC, 2020c).

2.2.2.1 Groundwater Well Search

Based on a search of the Oregon Water Resource Department (OWRD) water well database, three water supply wells were identified within two miles of the facility: two are domestic supply wells (GILL 121, 1 mile east of the CWMNW facility, and GILL 294, 1.5 miles southwest of the CWMNW facility), and one is used for watering livestock (GILL 50093, about 1.2 miles south of the CWMNW facility) (Figure 2.5). GILL 121 was drilled in 1956 and is 321 feet deep; GILL 294 was drilled in 1995 and is 65 feet deep; and GILL 50093 was drilled in 2000 and is 505 feet deep (OWRD, 2020). None of these wells are hydraulically connected to the Selah Member groundwater (Personal communication with Christopher Augustine, SCE Engineers [facility hydrogeologist]). Five wells within two miles of the CWMNW facility were listed as industrial wells, and one well was listed as unknown use (Figure 2.5) (OWRD, 2020).

2.2.3 Surface Water

There are no permanent surface water bodies present on the CWMNW facility, and there is no nexus to permanent surface water bodies from the facility. The permanent surface water bodies located in the

[8] For comparison, the horizontal hydraulic conductivity of materials used for engineered landfill liner materials to prevent releases of leachate from a landfill to the environment is typically less than 1×10^{-6} cm/s.

vicinity of the facility include the Columbia River, approximately 7 miles north of the CWMNW facility; the John Day River, approximately 7.5 miles west of the CWMNW facility; Rock Creek, approximately 3.5 miles southwest of the CWMNW facility; and Cedar Springs, approximately 1.5 miles west of the CWMNW facility (Figure 2.6). These permanent water bodies are not hydraulically connected to the surface water at Landfill L-14 or at the CWMNW facility. Surface water movement at the facility is generally described as "[e]phemeral streams drain the upland plateau where the site is located. During winter and early spring, shallow seasonal ponds occasionally form in Alkali Canyon, south of the site" (CH2M Hill, 2008). Surface water at Landfill L-14, consisting of stormwater, is contained and drained to evaporative retention ponds that do not discharge off of the CWMNW facility.

2.2.4 Climate

The climate in the vicinity of the CWMNW facility is characterized by cold winters and hot, dry summers. The climate in the Arlington area is semiarid, with a mean annual precipitation of 9.25 inches/year, most of which occurs between November and March (US Dept. of Commerce, 2020). The mean annual snowfall is 5.8 inches/year (US Dept. of Commerce, 2020). Recharge from precipitation is very low because of high evapotranspiration rates on the order of approximately 67 inches/year (ASW *et al*., 2014b). During the winter and spring, the evapotranspiration rate is lower, especially when thaws of snow and ice coincide with precipitation, which results in localized ponding and potentially increased infiltration. Natural infiltration rates at the CWMNW facility have been estimated to be on the order of 0.1 foot per year (RUST, 1998a, as cited in RAC, 2020c). This represents approximately 10% of the annual precipitation (CH2M Hill, 2008).

Winter rainfall typically occurs for several days in succession and is associated with low pressure frontal systems. Summer rainfall events are infrequent and are generally associated with thunderstorms. Most rainfall events are short in duration and low in intensity (CH2M Hill, 2008). The 25-year, 24-hour rainfall event and the 100-year, 24-hour rainfall event are approximately 1.5-2.0 and 2.0-2.5 inches, respectively (MGS Engineering Consultants, Inc. and Oregon Climate Service, 2007).

2.2.5 Topography

The majority of the CWMNW facility is located on the Deschutes-Umatilla Plateau, with the southern edge of the CWMNW facility located in Alkali Canyon (Figure 2.7). The rolling plateau ranges in elevation from about 990 to 1,030 feet above mean sea level (MSL). Alkali Canyon trends east then north toward the Columbia River. The portion of Alkali Canyon immediately south of the CWMNW facility has internal drainage and contains shallow ponds seasonally during periods of higher precipitation (CH2M Hill, 2008).

The uplands are separated by deep to moderately deep drainages, such as the John Day and Columbia Rivers, or by long anticlinal ridges such as the Columbia Hills. The east-west trending anticlinal ridges have been mostly stripped of their sedimentary cover, and the intervening synclines have been filled with reworked sediments. In the past geological history, lower elevations were subjected to extensive scouring and sedimentation from periodic floods, associated with glacial outwash, which created a regionally extensive lake (Lake Lewis) (CH2M Hill, 2008).

2.3 Overview of Bakken Oilfield Waste Disposal

In September 2019, ODOE became aware that wastes from the Bakken oilfield in North Dakota were being sent to the CWMNW facility in Arlington, Oregon. ODOE had indicated that one North Dakota company which provides brine water supply and recycling services to the oil and gas industry, began shipping wastes to the CWMNW facility in 2016. Between 2016 and 2019, CWMNW accepted an estimated 1,285 tons of waste from the transporter that contained TENORM, the majority of which was determined by ODOE to be subject to the disposal prohibition in ORS 469.525 and OAR 345-050-0006 (Benner, 2020). Approximately 80 % of the total waste consisted of filter socks (Benner, 2020). The Bakken oilfield waste was placed into various locations in Cells 1 through 4 of Landfill L-14. Figure 2.8 presents a plan view of the estimated locations where the Bakken oilfield waste was placed. Table 2.3 shows the loads of Bakken oilfield waste accepted at the CWMNW facility from 2016 to 2019. See also Attachment D for vertical profiles of the estimated Bakken oilfield waste disposal locations.

CWMNW determined that the waste from the generator had been disposed of in Cells 1 through 4 in Landfill L-14. The two primary Naturally Occurring Radioactive Material (NORM) radionuclide decay series for the wastes disposed in Landfill L-14 are uranium-238 (U-238) and thorium-232 (Th-232), shown in Figure 2.9.

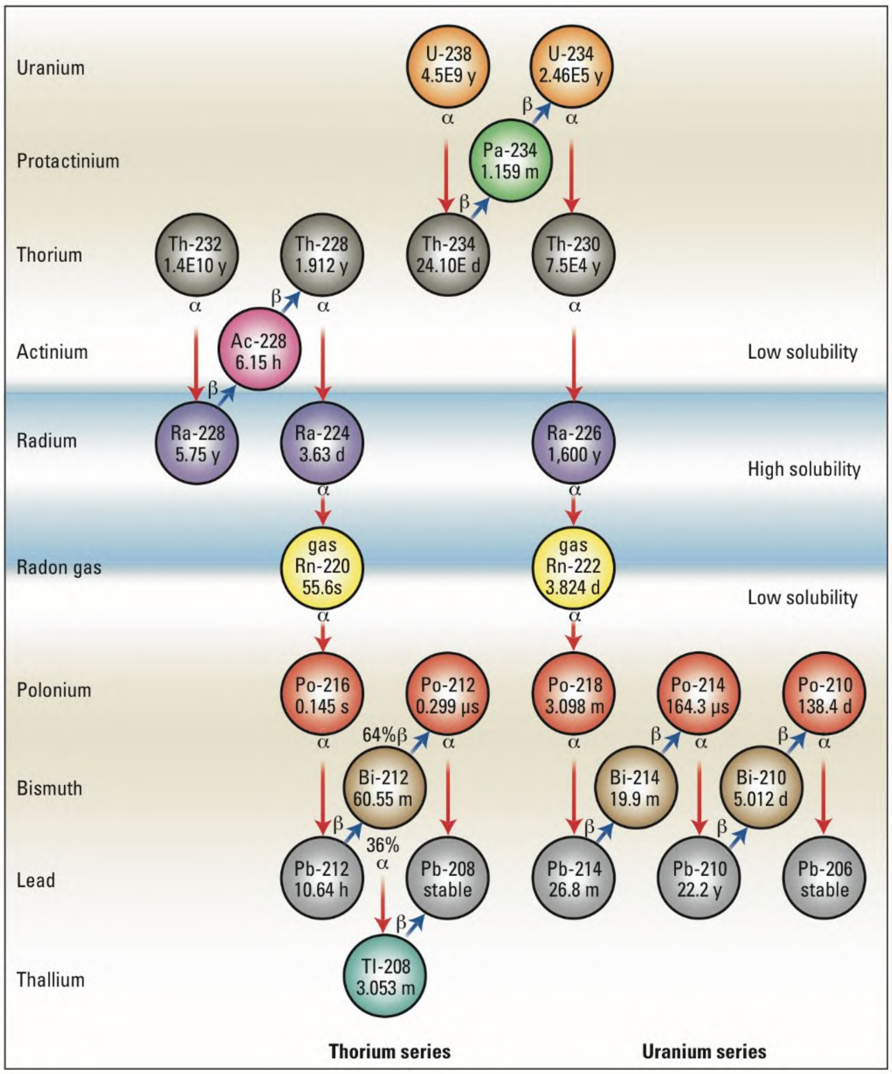

Figure 2.9 Natural Thorium and Uranium Decay Chains. d = Day; h = Hour; m = Minute; s = Second; y = Year. Figure includes elements that have half-lives longer than five minutes. Source: Nelson *et al.* (2015).

2.4 Summary of Landfill L-14 Radiological Investigation

ERG, in collaboration with K2 Environmental LLC, conducted a radiological investigation for the CWMNW facility from June 15 to 19, 2020 (ERG and K2 Environmental LLC, 2020; Attachment B to this CAP). The purpose of this investigation was to determine the external gamma radiological conditions at the Site[9] and to compare these conditions to on-Site reference materials and off-Site background areas. Reference materials were on-Site materials, free of waste, and used for cover and excavation. Background areas were off-Site locations representative of natural undisturbed geology. The investigation consisted of gamma radiation surveys using an Unmanned Aerial Vehicle (*i.e.*, a drone) equipped with radiation detection and GPS equipment to measure gamma count rates across the Site and at the reference material and background areas. Additionally, exposure rate measurements were taken at the reference material and background locations using a high-pressure ionization chamber.

All background measurements were within the expected variability of natural background and agreed with published estimated exposure rates for the area. The average background exposure rate (based on the average exposure rate from the perimeter and two off-Site locations) was 9.66 microRoentgen per hour (μR/hour). The landfill survey indicates an average gross exposure rate of approximately 8.2 μR/hour) with a maximum of 16.3 μR/hour in the excavation layback area. The landfill average is lower than all off-Site background location measurements and the published natural radiation background for this region, and approximately equal to the borrow area reference location average measurement.

The net response of the gamma survey was calculated by subtracting the average background response from each gamma survey record. This resulted in a maximum net (*i.e.*, above-background) exposure rate of approximately 6.7 μR/hour inside the boundary of the excavation layback area (no waste in place) and a maximum net exposure rate of 3.2 μR/hour inside the constructed waste boundary. Small areas of activity greater than 1.5 times the background conditions were identified in the excavation-only area north of the lined portion of the landfill. CWMNW has reviewed these locations and confirmed that no waste has been placed in this area; therefore, the most likely reason for these elevated readings is the presence of a natural clay formation containing slightly higher levels of naturally occurring radionuclides.

The results of the radiological investigation demonstrate that the external gamma conditions within the landfill boundary are characteristic of the waste-free reference material found on-Site used for cover and fill. All external gamma measurements observed within the waste boundary were below the levels observed at the reference material and background areas. The consistency between measurements indicates no observable gamma radiological impacts from waste disposals at these measurement locations. The complete Radiological Investigation Report is presented as Attachment B to this CAP.

2.5 Summary of Receptors and Dose/Risk Assessment

RAC (2020a; Attachment C to this CAP) conducted a radiation dose assessment to assess doses and risks to on-Site workers and nearby community members. The receptors evaluated in the human health risk assessment included on-Site[10] workers (waste handler, landfill worker, excavation worker, and supervisor), current and future off-Site residents, future on-Site residents, and a "future intruder" for the closure-in-place alternative, who is assumed to be an on-Site resident that digs a water well and uses the excavated material for a home foundation (Table 2.4). It should be noted that the future on-Site resident and intruder scenarios were included at the request of ODOE but would not be allowed by virtue of the institutional controls that

[9] The "Site" refers to the CWMNW facility at 17629 Cedar Springs LN, Arlington, Oregon, 97812.

[10] RAC uses the terms "On-Site" and "Off-Site" in the specific context of the receptors and exposure pathways that were evaluated in their dose and risk assessment. Please refer to Attachment C (RAC, 2020a) for further details.

are required as part of the facility permit.[11] Exposure pathways evaluated included inhalation of particulates, incidental ingestion of soil, inhalation of outdoor radon gas, external radiation, and ingestion of groundwater, although not all pathways apply to all receptors.

RAC (2020a) concluded that the dose for all the receptors, including the most highly exposed individual (the excavation worker during excavation of TENORM) was well below the level at which potential health effects may be observed.

Table 2.4 Receptors Evaluated in the Risk Assessment

Scenario	Receptor	Exposure Pathways
During waste disposal	Waste Handler	Inhalation of particulates, ingestion of soil, external
	Current Off-Site Resident	Inhalation of particulates
Leaving the waste in place	Landfill Worker	Inhalation of outdoor radon
	Current Off-Site Resident	Inhalation of outdoor radon
	Future Off-Site Resident	Inhalation of outdoor radon, ingestion of groundwater
	Future On-Site Resident	Inhalation of outdoor radon, ingestion of groundwater
	Future Intruder	Inhalation of indoor and outdoor radon, ingestion of groundwater, external
Excavation and removal	Excavation Worker	Inhalation of particulates, ingestion of soil, external
	Supervisor	Inhalation of particulates, ingestion of soil, external
	Current Off-Site Resident	Inhalation of particulates

RAC conducted additional analyses in support of the CAP to evaluate the long-term and short-term human health risks associated with the two remediation alternatives that the CAP evaluates (RAC, 2020a). Sections 6.3 and 6.5 and Attachment B provide summaries of these additional dose and risk calculations. RAC also conducted an assessment of radiological risk to ecological receptors, including terrestrial biota, using the Environmental Risk from Ionizing Contaminants: Assessment and Management (ERICA) tool. Based on this assessment, all dose rates were substantially less than the screening values, and thus no deleterious ecological effects from radiation are likely to occur should the Bakken oilfield waste remain in place (RAC, 2020a).

2.6 Regulatory Requirements

2.6.1 Landfill Regulatory Requirements

There are several state and federal regulations and acts that regulate hazardous waste management and disposal facilities in Oregon. These regulations include ORS 466 (Hazardous Waste and Hazardous Materials; Oregon State Legislature, 2019), OAR 340-100 through OAR 340-120 (various topics on Hazardous Waste Management), the Solid Waste Disposal Act as amended by RCRA, the Federal

[11] The landfill permit states: "As part of the closure, CWMNW must record on the property deed that the land has been used to manage hazardous wastes, that the land use is restricted under 40 CFR 264.110-120 regulations, and that the survey plat and record of the type, location, and quantity of hazardous wastes disposed of within each cell have been filed with the local zoning authority" (ODEQ, 2016).

Hazardous and Solid Waste Amendments (HSWA), and other regulations promulgated at Title 40 of the Code of Federal Regulations. The CWMNW Arlington Part B facility permit (ODEQ, 2006) is intended to ensure that all operations at the facility are in compliance with these solid waste and hazardous waste regulatory requirements but does not regulate radioactive materials. Section 2.1 presents a discussion of the CWMNW facility landfill permit requirements that are relevant to this CAP analysis. Please note that there are many other state and federal landfill requirements that are not specifically discussed herein because they are not directly relevant to the CAP.

2.6.2 NORM/TENORM-related Requirements

Subject to certain exemptions and thresholds, Oregon Revised Statutes (ORS 469.525) prohibits any waste disposal facility for any radioactive waste to be established, operated, or licensed within the state of Oregon except for under certain conditions. Additionally, OAR 345-050 requires that a person cannot hold or place discarded or unwanted radioactive material for more than seven days at any geographical site in Oregon. Since virtually all natural and man-made materials contain some radioactivity, OAR 345-050 establishes exemption criteria to identify those materials that are exempt from the provisions of OAR 469.525 and may be disposed of within the state. The rule establishes three tables that list the exempt concentrations, exempt quantities, and conditions for exemption of naturally occurring elements.

2.6.3 State Remediation Requirements

ODEQ has established environmental cleanup requirements pursuant to ORS 465.200 *et seq*. (Oregon State Legislature, 2020c) and OAR 340-122-0010 *et seq.* (ODEQ, 2020c). Most relevant to this CAP are OAR 340-122-0085, pertaining to feasibility studies (FS), and the accompanying ODEQ guidance on conducting FS (ODEQ, 2017). An FS is performed when a baseline human health risk assessment identifies that there are risks exceeding acceptable risk levels.[12] Based on these regulations and guidance, an FS is used to evaluate a range of remediation alternatives based on certain specific criteria:

- Overall protectiveness, as demonstrated by a "residual risk assessment."[13]
- Feasibility, as determined based on five remedy selection factors:
  - Effectiveness in achieving protection;
  - Long-term reliability to maintain the required level of protection;
  - Implementability, which evaluates how difficult it may be to implement the alternative;
  - Implementability risk caused by performing the remediation alternative, including impacts to the community, workers, and the environment;[14] and
  - Cost reasonableness, including the overall cost magnitude and the cost-effectiveness (the degree to which costs are proportionate to the benefits to human health and the environment) of each alternative.

[12] 10^{-5} for multiple carcinogens; 10^{-6} for individual carcinogens, Hazard Index of 1 for non-carcinogens as specified in OAR 340-122-0115.
[13] Based on OAR 340-122-0084(4), this includes both a quantitative risk assessment and a qualitative evaluation of the adequacy and reliability of institutional and engineering controls.
[14] ODEQ has also issued a Green Remediation Policy to "promote, support and implement more sustainable practices that lessen the overall environmental impacts of investigation and remediation projects" (ODEQ, 2011).

- The extent of "hot spot"[15] treatment or excavation.

The range of alternatives evaluated in the FS includes the following general response actions: no action, engineering and institutional controls, treatment, and excavation and off-site disposal. As further discussed in Section 4, neither the no action nor treatment general response actions are applicable to the CWMNW facility. The former is not applicable because the CWMNW facility already has extensive institutional and engineering controls in place by virtue of its operation as a RCRA Subtitle C facility (see Section 2.1 for further details). Therefore baseline conditions do not apply. The latter is not applicable because TENORM cannot be treated by *in situ* or *ex situ* remediation technologies. In addition, excavation and off-site disposal may be eliminated from consideration "if it is clearly inappropriate for the contaminated media" (ODEQ, 2017, p. 10).

2.6.4 Federal Remediation Requirements

As specifically requested by ODOE (Benner, 2020), this CAP follows "all substantive requirements of the CERCLA process." Federal regulations under CERCLA and the NCP provide guidance for the selection of remediation alternatives to ensure the protection of human health and the environment. These regulations are generally consistent with the state of Oregon Remediation Requirements.[16] The NCP was designed to standardize the performance of cost-effective, environmentally protective, and human health-protective cleanups and provide a consistent and objective basis for remedy decision-making at a national level. The United States Environmental Protection Agency (US EPA) defined its perspective on "CERCLA-quality" cleanup of hazardous waste in its NCP promulgation notice of 1990 (US EPA, 1990a), indicating that hazardous waste site remediation activity must:

- Be protective of human health and the environment;
- Utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable;
- Be cost-effective;
- Attain Applicable or Relevant and Appropriate Requirements (ARARs); and
- Provide for meaningful public participation.

Particularly relevant to this CAP, CERCLA and the NCP provide a remedy selection framework to "select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste" (40 CFR 300.430[a][1][i]). This framework is based on the following nine criteria that compose the objective rationale for remedy selection (40 CFR 300.430[e][9][iii]):

- All selected remedies must satisfy the **Threshold Criteria:**
    1. Overall protection of human health and the environment; and
    2. Compliance with ARARs.

[15] OAR 340-122-0115 defines hot spots in media other than water as both exceeding the acceptable risk level and meeting at least one other criteria: order-of-magnitude exceedance of risk thresholds, reasonably likely to migrate and create a significant adverse effect on the beneficial use of water, and/or cannot be reliably contained.
[16] Refer to Appendix A of ODEQ (2017) for a comparison of the NCP and Oregon's Environmental Cleanup Law.

- Among the alternatives that satisfy the Threshold Criteria, the preferred remedy is selected based on an evaluation of the **Balancing Criteria:**

   3. Long-term effectiveness and permanence;
   4. Reduction in toxicity, mobility, and volume of waste;
   5. Short-term effectiveness;
   6. Implementability; and
   7. Cost; and

- **Modifying Criteria:**

   8. State support/agency acceptance; and
   9. Community acceptance.

The NCP provides a framework for remedy selection based on these nine criteria, through which the "national goal of the remedy selection process is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste" (40 CFR 300.430[a][1][i]). Remediation alternatives are to be evaluated, compared, and selected on the basis of these nine criteria (40 CFR 300.430[e][9][iii]; 40 CFR 300.430[f]), the purpose of which "is to implement remedies that eliminate, reduce, or control risks to human health of the environment" (40 CFR 300.430[a][1]).

US EPA has additional regulations and guidance that are relevant to radionuclide releases, as described in the following paragraphs.

US EPA established expected cleanup levels for CERCLA sites with radioactive constituents in a memorandum from its Office of Emergency and Remedial Response and its Office of Radiation and Indoor Air (OSWER No. 9200.4-18; US EPA, 1997). This memorandum provides an attachment outlining radiation standards that are likely to be used as ARARs intended to establish cleanup levels or to conduct remedial actions (US EPA, 1997). The guidance indicates that cleanup levels for CERCLA sites that have radioactive constituents must be established as they would for any chemical that poses unacceptable risks to human health and the environment (US EPA, 1997). This means that cancer risks would be estimated using a slope factor approach, and cleanup levels would be expressed in units unique to radiation. US EPA (1997) indicates that cleanup should achieve a level of risk within a carcinogenic risk range of 10^{-4} to 10^{-6} based on reasonable maximum exposure to humans. In simpler terms, the US EPA risk range equates to a 1 in 10,000 to 1 in 1 million extra probability that a reasonably anticipated future person might develop a fatal cancer as a result of exposure to the constituent in question. Generally, US EPA uses 10^{-6} as the "point of departure" for the development of remediation goals[17] (US EPA, 2001).

In addition, an Office of Solid Waste and Emergency Response (OSWER) memorandum from July 2000 added certain response actions for sites with radioactive constituents to better ensure national consistency (US EPA, 2000).

[17] According to US EPA Risk Assessment Guidance for Superfund (US EPA, 2001), "[f]or known or suspected carcinogens acceptable exposure levels are generally concentration levels that represent an excess upper bond lifetime cancer risk to an individual of between 10^{-4} to 10^{-6} using information on the relationship between dose and exposure. The 10^{-6} risk level shall be used as the point of departure for determining remediation goals for alternatives where ARARs [Applicable or Relevant and Appropriate Requirements] are not available or are not sufficiently protective because of the presence of multiple contaminants at a site or multiple pathways of exposure."

The US EPA Clean Air Act regulates TENORM releases, and the US EPA Clean Water Act regulates certain liquid discharges of TENORM. US EPA, however, does not regulate TENORM waste byproducts, such as sludges from water and wastewater (RAC, 2016).

3 Remedial Action Objectives

Remedial Action Objectives (RAOs) are environmental medium-specific goals that guide the remedy evaluation and selection process to specific endpoints that ensure protectiveness.[18] RAOs for Landfill L-14 of the CWMNW facility have been developed based on relevant US EPA and Oregon guidance (*e.g.*, US EPA, 1988, 1989, 1995; ODEQ, 2017) and CWMNW facility-specific factors for the media of concern – Bakken oilfield waste, landfill leachate, surface water[19] and groundwater, and air. In this CAP, Gradient used the RAOs to evaluate the overall protectiveness of the remediation alternatives (see Section 6).

Overall, the RAC dose and risk assessment results show that there are relatively few human health and ecological exposure pathways of concern based on current or reasonably anticipated land and water uses in the vicinity of the CWMNW facility (see Sections 2-5). Table 3.1 describes the CWMNW facility-specific factors relevant to the RAOs. Accordingly, the objectives for the CWMNW facility are as follows.

- **Bakken Oilfield Waste:** Control the potential for direct exposure to any Bakken oilfield waste comingled with RCRA hazardous and non-hazardous waste that could cause adverse human health or ecological effects.
- **Surface Water and Groundwater:** Control the potential for surface water and groundwater to be impacted by any TENORM constituents at levels that would exceed applicable water standards or that could cause adverse human health or ecological effects.
- **Air:** Protect potential receptors from exposure to radon daughters at concentrations that may pose a human health risk *via* the inhalation exposure pathway.

[18] "Remedial action objectives consist of medium-specific or operable unit-specific goals for protecting human health and the environment. The objectives should be as specific as possible but not so specific that the range of [remediation] alternatives that can be developed is unduly limited" (US EPA, 1988).
[19] Surface water was included for comprehensiveness, but, as discussed in Section 2.2.3, there are no permanent surface water bodies present on the Site, and there is no nexus to permanent surface water bodies from the Site.

Table 3.1 CWMNW Facility-specific Factors for Remedial Action Objective Determination

Relevant Factor	Description
Nature of Release	The Bakken oilfield waste consists of wastes from the oil and gas production sector (primarily filter socks) that contain varying amounts of TENORM. These wastes were comingled with RCRA hazardous and non-hazardous waste at Landfill L-14. The Bakken oilfield waste is buried in the landfill and is fully contained within the permitted RCRA Subtitle C facility specifically designed to prevent the release of hazardous substances and other constituents.
Nature and Extent of Contamination	The Bakken oilfield waste contains radiological constituents that have long half-lives. It is mixed with and buried adjacent to a wide spectrum of RCRA hazardous and non-hazardous wastes that have been co-disposed and are contained *in situ* within Landfill L-14. Soluble radiological constituents may leach into precipitation that infiltrates the waste at very low rates, given the semiarid climate, low recharge rate, high evapotranspiration rate, and requirement for an engineered final cover system for Landfill L-14. Radium-226, a common constituent of TENORM, produces radon gas (Rn-222) as it decays.
Hydrogeological Features	Engineered features, including a double geomembrane liner system and a primary leachate extraction system with secondary and tertiary leak detection systems, prevent leachate from migrating outside of the landfill. A final cover system will be installed at landfill closure. The Selah Member aquifer underlying Landfill L-14 has very low hydraulic conductivity and flows South toward Alkali Canyon where it evaporates prior to any discharge to the Alkali Canyon; there is no identified beneficial use of the groundwater in this aquifer in the vicinity of the facility.
Current and Reasonably Anticipated Land Use[a]	The land consists of the 1,288 acres CWMNW facility, surrounded by over 11,000 acres of undeveloped property owned by Waste Management. Surrounding land use is mostly grassland and agricultural, with the nearest residence 1.2 miles southwest of the facility and the town of Arlington about 7 miles to the northeast. As part of facility closure, the land use will be deed restricted under 40 CFR 264.110-120 regulations.
Groundwater Use	There is no potable water at the facility or in its vicinity from the Upper Selah aquifer. The aquifer used for water supply is very deep below the facility. The results of a 2020 well search shows sparse well use within two miles of the facility boundary (Figures 2-5), none of which are hydraulically connected to the upper Selah Member at Landfill L-14.

Notes:

ET = Evapotranspiration; RCRA = Resource Conservation and Recovery Act; TENORM = Technologically Enhanced Naturally Occurring Radioactive Material.

(a) "Remedial action objectives developed during the RI/FS [remedial investigation/feasibility study] should reflect the reasonably anticipated future land use or uses," and "[f]uture land use assumptions allow the baseline risk assessment and the feasibility study to be focused on developing practicable and cost effective remedial alternatives" (US EPA, 1995).

4 Development of Remediation Alternatives

The first part of this section summarizes the preliminary screening of remediation technologies that Gradient performed to identify potentially viable options to address Bakken oilfield wastes disposed of at Landfill L-14 of the CWMNW facility. The screening process was performed consistent with US EPA and ODEQ guidance (*e.g.*, ODEQ, 2017; US EPA RI FS Guidance, US EPA, 1988), and the NCP (40 CFR 300.430). The second part of the section describes the remediation alternatives that Gradient retained for further evaluation in the comparative analysis process (Section 6).

4.1 Preliminary Screening of Remediation Technologies

In general, there are a number of available technologies that may be potentially relevant to addressing hazardous landfill waste and environmental media impacted by hazardous landfill waste. These technologies may be categorized as follows.

Table 4.1 Summary of Potentially Relevant Hazardous Waste Landfill Remediation Technologies

Remediation Technology	Description	Examples
In Situ Treatment Technologies	Remediate contaminants/ media as they exist, in place	Phytoremediation, *in situ* chemical oxidation (ISCO), *in situ* solidification/stabilization (ISS), *in situ* bioremediation, thermal treatment, monitored natural attenuation (MNA)
In Situ Containment Technologies	Prevent the migration of volatile and/or soluble constituents and limit direct contact exposure potential	Landfill caps and liner systems, vertical barrier walls, hydraulic containment
Ex Situ Treatment Technologies	Physical removal of solids, liquids, and/or gas for subsequent *ex situ* treatment	Solids – Excavation followed by redisposal (*e.g.*, in a landfill), incineration, thermal desorption, or chemical stabilization
		Liquids – Groundwater and leachate extraction followed by treatment, such as through air stripping, ion exchange, chemical redox, chemical adsorption, or discharge to POTW
		Gas – Soil gas extraction followed by treatment, such as by flaring or recovery for energy production

Notes:
POTW = Publicly Owned Treatment Works.
Sources: US EPA (2006, 2010); FRTR (c. 2007).

Although the primary focus of this CAP is on TENORM present in Bakken oilfield waste, it should be noted that the CWMNW facility is a Subtitle C landfill that accepts the universe of hazardous waste for pretreatment (if needed) and disposal. The ubiquitous presence of hazardous waste at Landfill L-14 is a concern that limits application of many conventional treatment technologies.

Constituents of TENORM are radionuclides (RAC, 2020a). Thus, in the preliminary screening matrix, Gradient only considered technologies that can be applied to treat radionuclides. Unlike many organic contaminants, such as petroleum hydrocarbons, radionuclides cannot be destroyed or degraded (except through natural decay), and thus, the majority of available remediation technologies described in Table 4.1 are not feasible for the Bakken oilfield waste at the CWMNW facility.

Table 4.2 presents the preliminary remediation technologies screening matrix for each of the media of concern. This matrix summarizes the available remediation technologies, including a description of each technology. Consistent with the NCP (40 CFR 300.430[e][7]), the alternatives listed in Table 4.1 were initially screened on the basis of effectiveness, implementability, and cost for their ability to achieve the RAOs defined in Section 3. NCP (40 CFR 300.430[e][7]) defines these criteria as follows:

- Effectiveness: "This criterion focuses on the degree to which an alternative reduces toxicity, mobility, or volume through treatment, minimizes residual risks and affords long-term protection, complies with ARARs, minimizes short-term impacts, and how quickly it achieves protection. Alternatives providing significantly less effectiveness than other, more promising alternatives may be eliminated. Alternatives that do not provide adequate protection of human health and the environment shall be eliminated from further consideration."
- Implementability: "This criterion focuses on the technical feasibility and availability of the technologies each alternative would employ and the administrative feasibility of implementing the alternative. Alternatives that are technically or administratively infeasible or that would require equipment, specialists, or facilities that are not available within a reasonable period of time may be eliminated from further consideration."
- Cost: "The costs of construction and any long-term costs to operate and maintain the alternatives shall be considered. Costs that are grossly excessive compared to the overall effectiveness of alternatives may be considered as one of several factors used to eliminate alternatives. Alternatives providing effectiveness and implementability similar to that of another alternative by employing a similar method of treatment or engineering control, but at greater cost, may be eliminated."

Based on preliminary screening presented in Table 4.2, both the containment and monitoring (Closure-In-Place) and the excavate and redisposal scenario were carried forward into the detailed comparative analysis of alternatives (see Section 6).

Targeted removal (*e.g.*, by area or depth) and redisposal of the Bakken oilfield waste was eliminated from further consideration in the screening phase. There is no practical way to implement a targeted removal of all of the Bakken oilfield waste because it is buried and mixed with other waste at multiple depths, and it is spread out laterally throughout much of the footprint of Landfill L-14 (see Figure 2.8 and Attachment D). The results of the gamma survey show that there is not an area with elevated external gamma radiological activity associated with the Bakken oilfield waste that could be targeted for excavation. Further, since the results of the dose and risk assessment show that the risks associated with the Bakken oilfield waste remaining in the CWMNW facility are *de minimis* following facility closure, there is no basis to target a lesser fraction of the Bakken oilfield waste as a means for risk reduction. The RAC dose and risk assessment specifically evaluated worst-case exposure assumptions (*e.g.*, the intruder scenario) and found that there were no unacceptable risks associated with any of these exposure scenarios that would warrant targeted removal.

The following sections provide conceptual designs for the two remediation alternatives considered for further evaluation.

4.2 Remediation Alternatives Retained for Consideration

4.2.1 Remediation Alternative 1: Closure-in-Place

This scenario consists of response actions at the CWMNW facility that are consistent with the existing operational and post-closure requirements promulgated by US EPA and ODEQ for hazardous waste landfills. These requirements are outlined in the CWMNW facility operating and closure permit (ODEQ, 2006) and include a dual liner system equipped with leachate collection and leak detection systems, groundwater monitoring, stormwater controls, final cover system installation, and post-closure maintenance and monitoring (see Section 2 for further details). Under this scenario, the Bakken oilfield waste would be left in place in its current location comingled with hazardous wastes from other sources. Normal operation of the landfill continues, and more waste will be disposed of over the Bakken oilfield waste until the permit final grade is achieved. The depth of the Bakken oilfield waste will vary between 18 and 195 feet below the final grade when Landfill L-14 is completely filled to the final permitted grade (Waste Management, Inc., 2020a). Routine groundwater monitoring will continue to evaluate groundwater quality in the upper Selah Member water-bearing zone and to provide an effective means of detection in the event of a release of constituents from the waste management areas. Groundwater is currently monitored at four monitoring wells completed in the upper Selah Member downgradient of Landfill L-14 (see Section 2.1). Groundwater monitoring will continue to be performed on a semi-annual basis for VOCs and on an annual basis for PCBs in the POC wells (ODEQ, 2014a).

Upon the closure of Landfill L-14, construction of an earthen-based evapotranspiration cover (*i.e.*, final cover system) will be conducted to restrict infiltration of rainwater into the landfill and thereby reduce or eliminate leachate production. Post-closure maintenance activities will last for at least 30 years after the landfill closure and include semi-annual and/or annual inspection of the cap and its vegetative cover, security measures, and the leachate collection system. The post-closure activities also include groundwater monitoring for at least 30 years after the landfill closure.

In addition, Remediation Alternative 1 includes the following actions to prevent the further disposal of TENORM waste exceeding state standards in the landfill in the future:

- A Waste Screening and Approval Program: Implementation of a waste screening and approval program that identifies potential radioactive waste streams and requires isotopic testing for those categories of wastes. The screening program was prepared and submitted to ODOE by CWMNW, and ODOE provided concurrence on the program's adequacy.
- A Portal Monitoring System: Installation of a portal monitoring system as part of the Radiological Monitoring Plan (Attachment G) at the facility entrance to screen all inbound wastes into the facility for ionizing radiation.
- Radionuclide Monitoring: Implementation of a plan to monitor the presence of radionuclides in groundwater, wastewater treatment plant solid media, Landfill L-14 leachate, and the facility's combined leachate stream as follows.
  - Groundwater
    - Radionuclide monitoring in the wells immediately upgradient and downgradient from Landfill L-14 will occur every five years during the landfill's operation. The first radionuclide groundwater sampling event ocurred in February 2021.
    - If data from a well downgradient of Landfill L-14 being monitored for non-radionuclides suggest that there may be a potential release from the lined landfill (*i.e.*, failure of the

landfill liner), the well is required to enter into Compliance Monitoring, and CWMNW will notify ODOE and include monitoring for radionuclides at the same frequency (triannually) as in the Compliance Monitoring schedule. Radiological monitoring results will be directly reported to ODOE.

    - The groundwater monitoring for radionuclides will continue following landfill closure, during the post-closure period.

- Wastewater Treatment Plant Solid Media
    - Annual radiological sampling and analysis will be performed for the on-site wastewater treatment plant solid media, including flocked solids, spent filters, and carbon filter beds. CWMNW will confirm on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.

- Landfill L-14 Leachate
    - Annual radiological sampling and analysis will be performed for the leachates produced by Landfill L-14 during the operational and post-closure periods for that landfill. The analytical results of this sampling will be reported to ODOE upon receipt. CWMNW will confirm on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.

- Combined Leachate Stream
    - Annual radiological sampling and analysis will be performed for the combined leachate stream from all on-site landfills during the operational and post-closure periods for the CWMNW facility. A sample will be collected from each of the two retention ponds that receive effluent from the wastewater treatment facility. The analytical results of this sampling will be reported to ODOE upon receipt. CWMNW will confirm on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.

4.2.2 Remediation Alternative 2: Excavate and Redispose

Alternative 2 consists of uncovering, excavating, transporting, and redisposing the Bakken oilfield waste from the CWMNW facility to a Subtitle C landfill permitted to accept TENORM. Under this scenario, approximately 680,000 yd^3 of waste overlying the Bakken oilfield waste would be excavated and relocated to another portion of the facility. Subsequently, approximately 3,244 yd^3 (3,854 tons) waste, consisting of the Bakken oilfield waste and waste from other sources that is mixed with Bakken oilfield waste, must be excavated and transported to an out-of-state permitted facility. A conceptual design for Remediation Alternative 2 and the calculation of the quantities required for the comparative analysis of the remediation alternatives (Section 6) are presented in the remainder of this section.

4.2.2.1 Remediation Alternative 2: Conceptual Design

The following actions will be completed to implement Remediation Alternative 2:

- A Waste Screening and Approval Program: Implementation of a waste screening and approval program that identifies potential radioactive waste streams and requires isotopic testing for those categories of wastes. The screening program was prepared and submitted to ODOE by CWMNW, and the ODOE concurrence was received.

- A Portal Monitoring System: Installation of a portal monitoring system as part of the Radiological Monitoring Plan (Attachment G) at the facility entrance to screen all inbound wastes into the facility or ionizing radiation.
- Excavate and stockpile waste overlying comingled Bakken oilfield waste (overburden waste) to reach target elevations where Bakken oilfield waste is estimated to be present. It is estimated that approximately one-third of the total waste volume in Landfill L-14 is contained in drums, one-third is contained in HDPE Macro boxes, and one-third is disposed of as bulk granular materials. To remove the overburden waste the following actions must be completed:
  - Remove the granular waste material to the top of the Macro boxes and drums, and place removed materials in lined roll-offs;
  - Tear down Macro boxes in place;
  - Remove waste from Macro boxes and place in new Macro boxes, cover, seal, and relocate to a storage area on the landfill;
  - Remove secure drums and place in lined roll-offs;
  - Remove granular waste materials underneath and around the Macro boxes and place in lined roll-offs; and,
  - Repeat the steps above as needed until the target elevation is reached.
- Excavate and explore target lifts to locate and remove Bakken oilfield waste comingled with RCRA waste from other sources. This step includes the following actions:
  - Visually identify Bakken oilfield waste by the presence of filter socks or other means approved by ODOE;
  - Identify Bakken oilfield waste and comingled waste and move to a staging area;
  - Remove other waste materials and place in lined roll-offs; and,
  - Load comingled Bakken oilfield waste into 20-yard roll-off boxes (12-ton capacity) for out-of-state disposal.
- Transport comingled Bakken oilfield waste to a Subtitle C landfill permitted to receive TENORM waste. The US Ecology Subtitle C landfill located in Grandview, Idaho, was identified as a potential Subtitle C landfill that is permitted to accept TENORM, and thus was selected as the final destination of the Bakken oilfield waste in this analysis. The one-way hauling distance between the CWMNW facility and US Ecology facility is approximately 350 miles.
- Given the hazardous nature of waste disposed of at the CWMNW facility, all operations at Landfill-14 must be performed in, at a minimum, Level C safety gear supplemented by supplied air for personnel.
- Excavation of the waste is expected to occur in two separate excavation events based on the location and depth of the Bakken oilfield wastes (further discussed below). Each excavation event will remove and stockpile wastes in the areas of the landfill not part of the current excavation. Following each excavation, all displaced Macro boxes, drums, and granular materials will be replaced back in the excavation area. Once both excavations have been completed, Landfill L-14 would continue its normal operation to the final permit grade in accordance to the facility's operating and closure permit (ODEQ, 2006).

4.2.2.2 Remediation Alternative 2 Quantities

This section of the report presents the approach and results of Gradient's estimation of the following key quantities that are required for evaluation of Remediation Alternative 2:

- Volume of waste received from the Bakken oilfield and placed in Landfill L-14;
- Volume of waste in Landfill L-14 that is mixed with Bakken oilfield waste; and
- Volume of overburden waste that overlies the Bakken oilfield waste or would need to be removed for providing excavation slope stability to reach the waste mixed with Bakken oilfield waste *via* excavation.

The location and depth of the Bakken oilfield waste loads within the landfill are provided in Attachment D and summarized in Table 4.3. The Bakken oilfield waste locations and the landfill's topographic surface surveyed on February 20, 2020 (Waste Management, Inc., 2020b) are presented in Figure 2.8. The topographic map is provided on a 25-foot by 25-foot horizontal grid on which the approximate position of each Bakken oilfield waste load is shown at a grid node on the map. Gradient assumed that the waste received in each load was evenly distributed across the four grid blocks adjacent to the given grid node with a total area, A, of 2,500 square feet.

To estimate the volume of the Bakken oilfield waste inside the landfill, the waste weight, W, received was converted to volume (V_{Bakken}). It was assumed that the density of the *in situ* waste in the landfill is 2,970 lbs/yd^3 (RUST Environment & Infrastructure, 1998; WM, Personal Communication, May 06, 2020). The nominal thickness of the waste associated with each Bakken oilfield waste load, H, was determined by dividing the estimated volume by the area:

$$H = V_{Bakken}/A$$

The Bakken oilfield waste is mixed with waste from other sources and buried in the landfill. It was assumed that the waste from other sources placed within the same lift as Bakken oilfield waste one H above and one H below the Bakken oilfield waste layer is mixed with the Bakken oilfield waste; thus, the actual thickness of the Bakken oilfield mixed waste (V_{mx}) is 3H. Consequently, the total volume of Bakken oilfield mixed waste is three times the volume of the shipped Bakken oilfield waste:

$$V_{mx} = 3 \times V_{Bakken}$$

The estimated Bakken oilfield and mixed waste volumes are presented in Table 4.3.

To estimate the total excavation volume Gradient developed a conceptual excavation approach to remove all Bakken oilfield waste from the landfill. The excavation extent is presented in Figure 4.1. The extent of the envisioned excavation is required to allow for safe working distances from excavation equipment, haul trucks, stockpiles of hazardous overburden waste, Macro box operations of hazardous debris, storage of Macro boxes inside the landfill, and other ancillary uses during the excavation.

Two target elevations (*i.e.*, 1,025 feet MSL[20] for western portion of Landfill L-14 and 946 feet MSL for eastern portion of Landfill L-14) are identified based on the Bakken oilfield waste locations and depths provided in Attachment B. The selected target elevations ensure that the all Bakken oilfield waste loads in

[20] MSL = Mean Sea Level. All elevations are based on North American Vertical Datum of 1988 (NAVD-88).

either portion of the landfill are removed. Figures 4.1 and 4.2 show the excavation plan and cross-sectional view of the excavated areas, respectively. Part of Cell 3 between elevation 1,025 feet MSL in Cells 1 and 2 and elevation 946 feet MSL in Cells 3 and 4 would be sloped between these two elevations for slope stability (see Figure 4.1).

Gradient developed two topographic surfaces in the geographic information system (GIS) software: one for the existing landfill condition on February 20, 2020, as shown in Figure 2.8, and one for the landfill surface after implementation of the excavation plans as shown in Figure 4.1. The excavation volume was estimated using GIS software by calculating the volume contained between the two topographic surfaces. The estimated volumes are presented in Table 4.4. The provided volumes in Table 4.4 are the volumes of waste in the landfill before excavation (in-place volumes).

Table 4.4 Volume of Landfill L-14 to be Excavated Under Remediation Alternative 2

Landfill Cell	Excavation Area (acre)	Excavation Volume In-place (yd^3)
1	3.40	163,712
2	2.64	102,637
3	3.22	142,890
4	4.59	177,043
Total	**13.85**	**586,282**

The volume of the bulk waste and the waste currently contained in the Macro boxes will increase after excavation. Therefore, the volumes of these portions were increased by a factor of 1.25 (fluff factor) to account for the increase of the waste volume after excavation. The fluff factor was not applied to the portion (*i.e.*, one-third of total excavation) of waste which is contained in drums. The total excavation volume includes both the volume of Bakken oilfield mixed waste and the volume of the overburden waste that must be displaced. To separate these two volumes, the Bakken oilfield mixed waste volume, V_{mx}, which was independently estimated as described above, was subtracted from total excavation volume. Table 4.5 presents a summary of the calculated volumes based on the approach described herein. To provide a relative measure for the magnitude of excavation under Remediation Alternative 2, the total excavation volume is also stated as a percentage of the total design capacity of Landfill L-14.

Table 4.5 Waste Volume Summary Under Remediation Alternative 2

Bakken Oilfield Waste Volume (V_{Bakken})	Bakken Oilfield Mixed Waste (V_{mx}, In-place)	Excavation Volume[a]			Percentage of Landfill Capacity to be Excavated[b]
		Total Excavation	Bakken Oilfield Mixed Waste (V_{mx}, Excavated)	Waste to be Displaced ($V_{Displace}$)	
yd^3	yd^3	yd^3	yd^3	yd^3	%
865	2,595	683,996	3,244	680,752	9.31%

Notes:

(a) Excavation volumes are reported after accounting for 25% volume increase after excavation. The volume increase is not applied to the portion of the overlying waste which is disposed in drums.

(b) Percentage of landfill capacity is calculated based on in-place volumes (fluff factor not applied).

Gradient performed a sensitivity analysis to understand the impact of two uncertain parameters that were assumed for the calculations above; one was the area of the Bakken oilfield mixed waste deposit within the landfill, and the other was the thickness of the Bakken oilfield mixed waste layer. The results are as follows:

- Mixed Waste Area: As described above, Gradient assumed that each load of the Bakken oilfield waste are distributed over a 2,500 square feet area within the landfill (see Figure 2.8). The volume of the Bakken oilfield waste was estimated based on the weight of the Bakken oilfield waste and the density of the waste in the landfill, and thus is independent of the footprint area. Similarly, the volume of the mixed waste is independent of the area. Additionally, the volume of the overburden waste that should be displaced to reach to the Bakken oilfield waste was estimated for an excavation plan developed based on the depth of the Bakken oilfield waste and landfill topography. Therefore the estimated volumes are independent of the area at which the individual Bakken oilfield waste is distributed.

- Mixed Waste Thickness: In our calculations Gradient assumed that the waste placed immediately above and below the Bakken oilfield waste is mixed with it and that the thickness of the mixed waste layer is three times the thickness of the Bakken oilfield waste. To investigate the impact of this assumption on the volume of overburden waste be displaced, we changed the ratio of the mixed waste to Bakken oilfield waste thickness between 1 to 7 (in lieu of 3 assumed for the presented volume calculation). A 700% increase in the mixed waste thickness reduced the volume of waste from other sources to be displaced less than 1%; that indicates that this volume is relatively insensitive to the mixed waste thickness. The mixed waste volume is directly proportional to its thickness and thus changes with the same factor that the thickness changes.

A summary of the sensitivity analysis results is reported in the table below.

Table 4.6 Summary of the Sensitivity Analysis Results

Volume\Sensitivity Parameter	Mixed Waste Area	Mixed Waste Thickness
Bakken Oilfield Waste (V_{Bakken})	Independent	Independent
Bakken Oilfield Mixed Waste (V_{mx})	Independent	Directly Proportional
Overburden Waste to be Displaced ($V_{Displace}$)	Independent	Insensitive

5 Corrective Action Evaluation Criteria

The purpose of this section is to identify and describe the criteria that will provide the basis for the comparative analysis of remediation alternatives in subsequent sections. Based on ODOE's February 13, 2020, NOV and discussions with ODOE, Gradient is relying on the NCP/CERCLA criteria for remedy selection,[21] taking into consideration ODEQ's feasibility study criteria.[22] Refer to Section 2.6.3 and 2.6.4 of the CAP for further discussion of state and federal remediation requirements, respectively.

In accordance with federal and Oregon state regulations and guidance (*e.g.*, OAR 340-122-0085; US EPA, 1988, 1989; 40 CFR 300.430 [*i.e.*, the NCP]), Gradient used the following criteria to evaluate the remediation alternatives developed for the CWMNW facility (as described in Section 4).

- **Overall Protection of Human Health and the Environment:** This criterion is used to evaluate whether and how the remediation alternative as a whole achieves and maintains the protection of human health and the environment. In particular, Gradient used this criterion to evaluate the ability of the alternative to achieve the RAOs developed for the CWMNW facility.
- **Compliance with Other Applicable Requirements:** This criterion is used to evaluate whether the alternative complies with other applicable requirements. While included as a criterion within the scope of this CAP, Gradient assumed that ODOE will evaluate the remediation alternatives in the context of state regulations and identify the need for compliance with additional requirements, if any.
- **Long-term Effectiveness and Permanence:** This criterion includes an evaluation of the magnitude of human health risk from untreated contaminated materials or treatment residuals remaining after remedial action has been concluded (which is known as residual risk), and the adequacy and reliability of controls to manage that residual risk.
- **Reduction of Toxicity, Mobility, and Volume Through Treatment:** This criterion refers to the evaluation of whether treatment processes can be used to address the source material, the amount of hazardous material treated (including the principal threat that can be addressed), and the degree of expected reduction in the toxicity, mobility, and volume of source material.
- **Short-term Effectiveness:** This criterion includes an evaluation of the effects of the remediation alternative during the construction and implementation phase, until remedial objectives are met. This criterion includes an evaluation of the protection of the community and workers during the remedial action and the short-term environmental impacts of implementing the remedial action.
- **Implementability:** This criterion is used to evaluate the technical feasibility of the remediation alternative, including construction and operation, reliability, monitoring, and the ease of undertaking remedial action in the context of any logistical constraints at the CWMNW facility. It also considers the administrative feasibility of activities needed to coordinate with other third

[21] Overall protection of human health and the environment; compliance with Applicable or Relevant and Appropriate Requirements (ARARs); long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; cost; regulatory approval; and community acceptance.

[22] Protectiveness, hot spot evaluation, effectiveness, long-term reliability, implementability, implementability risk, and reasonableness of cost.

parties (*e.g.*, regulatory agencies), such as for obtaining permits, and the availability of services and materials necessary for the alternative, such as disposal facilities and qualified contractors.

- **Cost:**[23] This criterion includes an evaluation of direct and indirect capital costs, including the costs of treatment and disposal; the annual costs of operating, maintaining, and monitoring the alternative; and the net present value of these costs.
- **Regulatory Approval and Community Acceptance:** These criteria are used to evaluate the expected level of approval from the regulatory agency overseeing the corrective action and acceptance from community stakeholders, respectively.

These criteria correspond to the nine NCP remedy selection criteria that are used in the "Comparative Analysis" process to evaluate and compare remediation alternatives to ensure the rational selection of a remedy (40 CFR 300.430[f]). They are consistent with the ODEQ criteria used to select remediation alternatives; please refer to Appendix A of ODEQ (2017) for a comparison of the NCP and Oregon's Environmental Cleanup Law. In addition, Gradient has included an analysis of whether the Bakken oilfield waste constitutes a "hot spot" as defined by ODEQ.

[23] According to US EPA guidance: "Cost is a critical factor in the process of identifying a preferred remedy. In fact, CERCLA and the NCP require that every remedy selected must be cost-effective" (US EPA, 1996, p. 5). Remediation alternatives may be "screened out" if they provide equivalent effectiveness and implementability as another less costly alternative (40 CFR 300.430[e][7][iii]; US EPA, 1996, p. 4).

6 Evaluation of Remediation Alternatives

This section provides a detailed assessment of the remediation alternatives defined in Section 4 using the evaluation criteria discussed in Section 5. Each alternative was individually evaluated for each criterion using a combination of qualitative and quantitative methods. The alternatives were then comparatively ranked against one another (Section 7).

6.1 Overall Protectiveness

The overall protectiveness criterion is used to evaluate whether and how the remediation alternative as a whole achieves and maintains the protection of human health and the environment. In particular, this criterion was used to evaluate the ability of each alternative to achieve the Remedial Action Objectives (RAOs) developed for the CWMNW facility.

As summarized in Table 6.1, Remediation Alternative 1 provides the greatest degree of overall protectiveness and is able to achieve all of the RAOs. Remediation Alternative 2 poses significantly higher risks associated with excavating and redisposing overlying hazardous waste within the CWMNW facility, as well as with excavating, hauling, and redisposing the Bakken oilfield waste at a permitted out-of-state facility.

Table 6.1 Overall Protectiveness of the Remediation Alternatives

Remedial Action Objective	Remediation Alternative 1: Closure-in-Place	Remediation Alternative 2: Excavate and Redispose
Control the potential for direct exposure to any Bakken oilfield waste comingled with RCRA hazardous and non-hazardous waste	No direct exposure risk would be present. The Bakken oilfield waste will be buried by significant amounts of overburden waste (final depth range between approximately 18 to 195 feet with an average depth of 108 feet) and a final cover system approved in the landfill's permit, and therefore will not pose a direct exposure risk, even in the unlikely event that a future person were to build a house on top of the landfill and install a well through the waste materials despite land use controls preventing such action. Based on the landfill gamma survey (see Section 2.4 and Attachment B), nearly all (99.99%) of the gamma measurements fall within the range of the reference measurements (soils used for cover) and background measurements.	Excavating Landfill L-14 at the CWMNW facility to remove Bakken oilfield waste will create significant short-term direct exposures to human health and the environment by exposing various types of hazardous waste, as well as the Bakken oilfield waste, during excavation, transport, and redisposal.

Remedial Action Objective	Remediation Alternative 1: Closure-in-Place	Remediation Alternative 2: Excavate and Redispose
Control the potential for surface water and groundwater to become impacted by any TENORM constituents at levels that could cause adverse human health or ecological effects	The existing leachate collection and redundant leak detection systems (see Section 2.1.2) controls leachate release, and existing stormwater control (see Section 2.1.3) prevents the release of Bakken oilfield waste constituents to the environment. There are no permanent hydrologically connected surface water bodies within an approximately 7-mile distance of the CWMNW facility (see Section 2.2.3). The monitoring program (see Section 4.2.1) ensures that conditions remain protective (*i.e.*, that there is not leachate breakthrough). The RAC (2020a) Radiological Dose and Risk Assessment results demonstrate that in the event of future leachate system failure, potential doses and risks for human health and ecological receptors *via* the groundwater exposure pathway are extremely low and well within the acceptable range set by US EPA, even assuming the confluence of multiple worst-case scenarios (future resident drawing water from the edge of the landfill despite land use controls, water is actually potable and in sufficient quantity for consumption contrary to real conditions, TENORM assumed to be the maximum sampled concentration for all wastes instead of a weighted average, TENORM assumed to be concentrated in one location instead of spread throughout landfill, cap and liner degrade faster than designed). The RA also demonstrated that any Bakken oilfield waste leachates potentially entering groundwater in the future would do so at concentrations that are at least an order of magnitude below the standards for all the individual TENORM constituents under both the federal Safe Drinking Water Act and ODOE's state standards for radioactive material in water under OAR 345-050-0035, Table 3.	Removal of the Bakken oilfield waste would decrease potential contaminant flux to leachate, including from potentially soluble TENORM-related constituents, and would therefore reduce potential releases to groundwater. However, the groundwater exposure pathway is not a concern for human health or ecological receptors under either remediation alternative, even assuming hypothetical future potable water use drawn from Landfill L-14 (see Section 2.5 and Attachment C). Further, relocating the Bakken oilfield waste to a different hazardous waste landfill would not eliminate potential leaching concerns at that facility; therefore, there may not be any net environmental benefit from excavating and redisposing the waste.

Remedial Action Objective	Remediation Alternative 1: Closure-in-Place	Remediation Alternative 2: Excavate and Redispose
Protect potential receptors from exposure to radon daughters at concentrations that may pose a human health risk *via* the inhalation exposure pathway	The RAC (2020a) Radiological Dose and Risk Assessment results demonstrate that the potential doses and risks for human health receptors *via* the radon inhalation exposure pathway are extremely low and well within the acceptable range set by US EPA. This includes both current and future landfill workers and future on-site and off-site residents.	Removal of the Bakken oilfield waste would decrease radon flux at the CWMNW facility, including from TENORM-related constituents and therefore would reduce the potential for exposure *via* the inhalation pathway. However, since the RAC (2020a) Radiological Risk Assessment results demonstrate that potential doses and risks for human health receptors *via* the radon inhalation exposure pathway are extremely low if the Bakken oilfield waste remained in place, there would be negligible risk reduction associated with its removal. Further, relocating the Bakken oilfield waste to a different hazardous waste landfill would not eliminate potential radon generation at that facility; therefore, there may not be any net environmental benefit from excavating and redisposing the waste.

Notes:
ODOE = Oregon Dept. of Energy; RAC = Risk Assessment Corporation; TENORM = Technologically Enhanced Naturally Occurring Radioactive Material; US EPA = US Environmental Protection Agency.

6.2 Compliance with Other Applicable Requirements

This criterion is used to evaluate whether a remediation alternative complies with other applicable requirements. While Gradient includes this as a criterion within the scope of this CAP, the CWMNW facility is a highly regulated entity subject to stringent state and federal requirements as part of its operating and closure permit (see Section 2.6). For purposes of this report, Gradient has assumed that the Oregon State regulators will evaluate the remediation alternatives in the context of Oregon State regulations and highlight the need for compliance with additional requirements, if any, associated with the recommended remediation alternative.

Based on the analysis provided in the RAC Radiological Risk Assessment, both Remediation Alternative 1 and Remediation Alternative 2 would meet relevant radiological standards for drinking water, radon gas exposure, and radiation exposure to off-site and potential future on-site residents under a hypothetical unrestricted land use scenario. Both scenarios would also achieve the US EPA target risk range of 10^{-4} to 10^{-6}, although Alternative 2 would result in a relatively higher risk to an on-site excavation worker than any receptors under Remediation Alternative 1. Conversely, there are significantly lower human health risks associated with Remediation Alternative 1. Remediation Alternative 1 would not reverse the conditions that led to the original NOV (Benner, 2020). ODOE would need to determine whether the risks inherent with Remediation Alternative 2 would make Alternative 1 an acceptable remedy.

Compliance with legal and regulatory requirements associated with the safe management of hazardous (non-radioactive) wastes, including Occupational Safety and Health Administration (OSHA) requirements, during an excavation alternative, was not evaluated in detail in this CAP.

6.3 Long-term Effectiveness and Performance

This criterion includes an evaluation of the magnitude of human health risk from untreated contaminated materials or treatment residuals remaining after remedial action has been concluded (known as residual risk), and the adequacy and reliability of controls to manage that residual risk.[24] At the CWMNW facility, Gradient evaluated long-term effectiveness and permanence using the results of the Radiological Risk Assessment prepared by RAC (2020a; see Attachment C), which specifically evaluated residual risk associated with the buried Bakken oilfield waste at the CWMNW facility (Section 6.3.1). Gradient also evaluated long-term effectiveness and permanence with respect to the adequacy and reliability of controls used to manage the residual risk (Section 6.3.2).

The radiological dose and risk calculations performed for each remediation alternative represent worst-case scenarios, whereby the results are expected to overestimate actual doses and risks. Exposure parameters are generally representative of reasonable maximum exposures. Underlying transport calculations used to determine the air and groundwater concentrations were deliberately high-sided, resulting in higher estimates of risk than would be likely to actually be incurred.

[24] Consistent with OAR 340-122-0084(4), this includes both a quantitative risk assessment and a qualitative evaluation of the adequacy and reliability of institutional and engineering controls.

6.3.1 Long-term Effectiveness of Remediation Alternative 1

RAC (2020a; see Attachment C) evaluated the following receptor exposure pathways that are relevant to Remediation Alternative 1 (Closure-in-Place and Monitoring).[25]

- *Landfill workers.* These are individuals that currently work within the waste footprint of Landfill L-14 on a regular basis. The only complete exposure pathway is inhalation of outdoor radon, with 30 years of exposure. RAC evaluated the worker for inhalation of outdoor radon generated from the TENORM waste left in place.
- *Current off-Site residents.* These receptors are residents that live in the residence closest to the Arlington Landfill, approximately 10,700 feet southwest of Landfill L-14. RAC evaluated the off-Site resident for inhalation of outdoor radon, again assuming 30 years of exposure.
- *Future off-Site residents.* RAC evaluated a hypothetical future off-Site resident who is assumed to live at the same location as the current off-Site resident. For groundwater ingestion, the well is assumed to be located 100 meters from the TENORM disposals in Landfill L-14. A distance of 100 meters was selected to be consistent with the ODOE Order (Benner, 2000). The evaluation is performed until maximum concentrations and doses are reached. RAC evaluated the future off-Site resident for inhalation of outdoor radon and ingestion of groundwater based on both the weighted average and maximum modeled concentrations.
- *Future on-Site residents.* RAC evaluated a hypothetical future on-Site resident who uses a well that is located at the immediate downgradient edge of the TENORM waste. RAC evaluated the future on-Site resident for inhalation of outdoor radon and ingestion of groundwater based on the weighted average and maximum concentrations. Doses and concentrations were modeled out to time of peak, which occurred at greater than 100,000 years into the future.
- *Future intruder.* As a sensitivity analysis, RAC also evaluated a future intruder, a person similar to the future on-Site resident but who excavates into the TENORM waste and then uses the excavated materials as the foundation for a home. For the future intruder, RAC evaluated inhalation of indoor and outdoor radon, external radiation, and ingestion of groundwater based on the maximum modeled concentration.

RAC (2020a) evaluated the potential exposure to long-term radon emissions from the TENORM waste using US Nuclear Regulatory Commission models and methods for assessing uranium mill tailings. RAC evaluated a worst-case hypothetical scenario in the diffusion model to calculate radon emissions from the waste. RAC assumed that Ra-226 (the parent radionuclide of Rn-222) was uniformly distributed throughout the thickness of compacted TENORM waste. RAC assumed that the radon emanation coefficient for the waste was similar to that of uranium mill tailings. This assumption represents a worst-case scenario, given that radon emanation from the filter socks is substantially lower than radon emanation from uranium mill tailings (RAC, 2020a). RAC evaluated risks using both a weighted average and a maximum source term. The maximum source term assumed that all of the Bakken oilfield waste was present at the highest measured concentration from all waste loads. The average source term was a weighted average based on the mass of each waste type relative to the total mass disposed in the landfill and the average radionuclide concentration for each waste type. Waste types included filter socks, filters, pipe scale, and "other" (RAC, 2020a).

[25] There is not a corresponding section focused on the long-term effectiveness of Alternative 2 because it would be contingent upon the landfill-specific conditions, long-term closure requirements, and environmental conditions at the receiving facility where the Bakken oilfield waste would be redisposed.

RAC used the US EPA air dispersion model (AERMOD) to calculate dispersion factors. Dispersion factors were calculated assuming typical daytime atmospheric conditions and average local wind speed. The RAC (2020a) Radiological Dose and Risk Assessment report includes a detailed discussion of the dispersion model, including the parameters used in this analysis (see Attachment C).

RAC evaluated the potential future migration of radionuclides from the Bakken oilfield source to a receptor groundwater well using a simplified conceptual model that tends to overestimate concentrations. RAC modeled two groundwater scenarios, assuming that the receptor well is located either at the downgradient edge of the source, or 100 meters from the downgradient edge. To ensure that doses and risks were not underestimated, RAC eliminated the impact of the leachate collection system, redundant leak detection systems, and the facility's liner system from the analysis. RAC used the saturated Mixing Cell Model (MCM) to model the fate and transport of dissolved constituents in groundwater. This model was selected because it accounts for the differences in transport characteristics of radioactive progeny. The RAC (2020a) Radiological Dose and Risk Assessment report presents a detailed discussion of the groundwater fate and transport models, including the parameters used in this analysis (see Attachment C).

Table 6.2 provides a summary of the worst-case lifetime (*i.e.*, 30-year) cancer morbidity risk estimates for Remediation Alternative 1.[26] Cancer morbidity risk calculations for Remediation Alternative 1 assume that after the TENORM waste disposal, the landfill workers and current off-Site residents may inhale outdoor radon; and the future off-Site and on-Site residents may inhale outdoor radon and ingest contaminated drinking water. Inhalation of outdoor radon by the most exposed worker (landfill worker) is overstated in the model as in reality it is mitigated by the use of required personal protective equipment (PPE). Further, there are no potable sources of water in the upper Selah Member. Cancer risks are expressed as a unitless probability (*e.g.*, 1 in 1 million, or 1×10^{-6}) of an individual developing cancer over a lifetime as a result of exposures related to the Bakken oilfield wastes. US EPA calls this the "excess lifetime cancer risk" because it refers to the probability of cancer above and beyond the background rate of cancer in the general population, which is approximately 40 out of 100 for men and 39 out of 100 for women (American Cancer Society, 2020). US EPA has established a target cancer risk range of 1×10^{-6} to 1×10^{-4} (US EPA, 1990b, 1991). ODEQ has an acceptable risk level of 1×10^{-6} for individual carcinogens and 1×10^{-5} for exposure to multiple carcinogens (ODEQ, 2020c).

The cancer morbidity risks are presented in Table 6.2 using the worst-case scenarios. For all receptors evaluated (landfill worker, current off-Site resident, future off-Site resident, future on-Site resident, and future intruder) the cancer morbidity risks are well below US EPA's and ODEQ's target cancer risk ranges and well below the level at which potential health effects may be observed (Table 6.2). Table 6.3 translates risk values from scientific notation (10^{-6}) to real numbers (1 in 1 million). Risks associated with the Bakken oilfield wastes disposed in Landfill L-14 in Table 6.2 are very low in comparison with the risks from common daily activities. The detailed results and calculations for radiation doses and risks can be found in Attachment C.

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[26] RAC also evaluated cancer mortality risk (the risk of dying from cancer) for all receptors, but those values are not discussed here, as they are lower than the cancer morbidity risk (the risk of developing cancer).

Table 6.2 Lifetime Cancer Morbidity Risk Estimates[a] for Remediation Alternative 1: Closure-in-Place and Monitoring

Receptor	Maximum Source Term Cancer Morbidity Risk	Average Source Term Cancer Morbidity Risk	US EPA Target Risk Range	ODEQ Target Risk Range
Landfill Worker	2.0E-16	1.2E-16	1E-06 to 1E-04	1E-06 to 1E-05
Current Off-Site Resident	5.9E-19	3.7E-19	1E-06 to 1E-04	1E-06 to 1E-05
Future Off-Site Resident	7.9E-07	2.9E-08	1E-06 to 1E-04	1E-06 to 1E-05
Future On-Site Resident	1.0E-06	3.8E-08	1E-06 to 1E-04	1E-06 to 1E-05
Future Intruder	6.3E-06	--[b]	1E-06 to 1E-04	1E-06 to 1E-05

Notes:
ODEQ = Oregon Department of Environmental Quality; US EPA = United States Environmental Protection Agency.
(a) Lifetime risks of developing cancer for the average US population assuming 30 years of exposure (RAC, 2020a).
(b) The intruder risk was evaluated using the maximum source term only.
(c) All values are below US EPA and ODEQ target cancer risk range.

Table 6.3 General Description of Risk Levels

Risk (Scientific Notation)	Alternate Scientific Notation	Probability
1×10^{-6}	1E-06	1 in 1 million (1,000,000)
1×10^{-7}	1E-07	1 in 10 million (10,000,000)
1×10^{-9}	1E-09	1 in 1 billion (1,000,000,000)
1×10^{-12}	1E-12	1 in 1 trillion (1,000,000,000,000)
1×10^{-15}	1E-15	1 in 1 quadrillion (1,000,000,000,000,000)
1×10^{-18}	1E-18	1 in 1 quintillion (1,000,000,000,000,000,000)

6.3.2 Adequacy and Reliability of Engineering Controls

Gradient also evaluated long-term effectiveness and permanence with respect to the adequacy and reliability of controls to manage the residual risk. The Bakken oilfield waste is buried within the landfill, where it will be covered by an average of approximately 100 feet of other types of waste. As noted above, the landfill has multiple engineered environmental controls, as required by the conditions of its operating and closure permit (ORD 089 452 353; ODEQ, 2006) and consistent with Oregon and federal hazardous waste regulations. As detailed in Section 2, these environmental controls consist of the following:

- A dual liner system that prevents the migration of leachate constituents from the landfill into native groundwater beneath the landfill. The primary liner is a multi-component composite liner system underlain by compacted clay (cells 1-3) or GCL (Cell 4), and the secondary leak detection liner system consists of second geomembrane underlain by compacted clay (Cells 1-3) or GCL (Cell 4) (see Section 2.1.2);
- A leachate collection system that drains, extracts, and collects leachate, which reduces vertically downward hydraulic gradients and further minimizes the potential for leachate migration beyond the landfill boundary. Leachate is generally pumped from the primary leachate removal sump applied for dust control on the landfill surface or to the waste water treatment plant where it is treated and sent to the evaporation ponds (see Section 2.1.2);
- A secondary leak detection system beneath the primary leachate collection system that provides the earliest possible capture and detection of a potential release from the primary system eliminating impacts to groundwater. The tertiary leak detection system is constructed beneath the

area with the highest likelihood of a potential release underneath the secondary leachate detection sump (see Section 2.1.2);

- Stormwater management infrastructure that minimize infiltration into the landfill waste by diverting stormwater run-on away from the waste footprint (see Section 2.1.3); and,
- A post-closure engineered final cover system that will further eliminate infiltration of stormwater into the landfill waste mass (see Section 2.1.4).

Routine groundwater monitoring is performed to ensure early detection of any leachate influences on groundwater through the redundant liner and leachate detection systems. Groundwater is currently monitored at four monitoring wells immediately downgradient of Landfill L-14, completed in the shallow Selah Member to evaluate groundwater quality in the Selah Member water-bearing zone, to provide an effective means of detection in the event of a release of constituents from the waste management areas (ODEQ, 2014a; see Section 2.1 for details).

Long-term, post-closure requirements include the following:

- Inspection of the closed landfill units in compliance with the CWMNW facility hazardous waste permit requirements (ODEQ, 2006; see Section 2.1.4 for details). The inspection will include checking the security fencing; checking the landfill cap for erosion and maintaining it; checking the vegetative cover and re-vegetation as needed; and,
- Groundwater monitoring for 30 years (annual or semi-annual depending on the well). This requirement will include monitoring and maintenance of the leachate collection system, with treatment of leachate as needed.

Under Remediation Alternative 1, these environmental controls would remain in place as described in Section 4.2.1. Additional corrective actions that will be implemented as part of Remediation Alternative 1 include a groundwater Radionuclide Sampling Plan to be performed along with routine groundwater monitoring during the remaining landfill operational period and within the 30-year post-closure monitoring period, radiological monitoring of solid media from the wastewater treatment plant, radiological monitoring of Landfill L-14 leachate, and radiological monitoring of the combined leachate stream (see Section 4.2.1 for details). A Waste Screening and Approval Program has been implemented to radiologically characterize and approve incoming waste streams that have been categorized as having the potential to contain TENORM, and a portal monitoring system has been installed to screen all incoming waste for radioactivity.

The RAC (2020a) Radiological Risk Assessment results demonstrate that in the event of future leachate system failure (*i.e.*, beyond the 30-year post closure period), potential doses and risks for human health and ecological receptors *via* the groundwater exposure pathway are extremely low and well within the acceptable range set by US EPA, even assuming the confluence of multiple worst-case scenarios (future resident drawing water from the edge of the landfill despite land use controls, water is actually potable and in sufficient quantity for consumption contrary to real conditions, TENORM assumed to be the maximum sampled concentration for all wastes instead of a weighted average, TENORM assumed to be concentrated in one location instead of spread throughout landfill, cap and liner degrade faster than designed).

The Radiological Risk Assessment also demonstrated that any Bakken oilfield waste leachates potentially entering groundwater in the future would do so at concentrations that are at least an order of magnitude below the standards for all the individual TENORM constituents under both the federal Safe Drinking Water Act and ODOE's state standards for radioactive material in water under OAR 345-050-0035, Table 3.

6.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

This criterion refers to the evaluation of whether treatment processes can be used to address the source material; the amount of hazardous material treated, including the principal threat that can be addressed; and the degree of expected reduction in the toxicity, mobility, and volume of source material.

Both of the remediation alternatives reduce the potential environmental mobility of the Bakken oilfield waste by containing it through a combined liner/cap/leachate collection system. Remediation Alternative 1 achieves this at the CWMNW facility, while Remediation Alternative 2 would do so at a different landfill facility. Reduction of toxicity of the Bakken oilfield waste is not relevant, because radionuclides cannot be destroyed or degraded (other than by natural decay); further, radiological measurements completed during the July 2020 survey demonstrate that the external gamma conditions within the Landfill L-14 boundary are characteristic of the waste-free reference material used for cover and fill. All external gamma measurements observed within the waste boundary were below the levels observed at the reference material and background areas. The consistency between measurements indicates no observable gamma radiological impacts from waste disposals at these measurement locations (see Attachment B). Reduction of volume is also not relevant, because there is no practical way to reduce the volume of the Bakken oilfield waste. However, excavation of the Bakken oilfield waste under Remediation Alternative 2 would increase its overall volume. This is a common phenomena (referred to as a "fluff factor") during earthworking since *in situ* materials are more compacted than *ex situ* materials.

Remediation Alternative 2 requires excavation and displacement of an estimated 600,000 yd^3 of overlying hazardous waste of different types with various types of hazards[27] (see Section 4.2.2 for details). Excavating, hauling within the CWMNW facility, and redisposing of these wastes requires employing heavy earthwork equipment over multiple years. Consequently, the toxicity and mobility of the unearthed hazardous wastes, unrelated to Bakken oilfield waste, is expected to significantly increase under Remediation Alternative 2. The excavation of existing buried wastes could result in the rupture of containers, and undesired mixing of incompatible wastes. The excavation of comingled waste presents an undue risk for workers due to the potential for exposure to mixtures of wastes with potentially incompatible characteristics that could result in unknown or unintended chemical reactions. These risks include both non-carcinogenic and carcinogenic health effects (see Section 6.5.2 for further details).

6.4.1 "Hot Spot" Analysis

OAR 340-122-0115 defines hot spots in media (other than water) as both exceeding the acceptable risk level[28] and meeting at least one other criteria: order-of-magnitude exceedance of risk thresholds; reasonably likely to migrate and create a significant adverse effect on the beneficial use of water; and/or cannot be reliably contained. The Bakken oilfield waste does not meet this definition because all of the receptors and exposure pathways evaluated in the RAC dose and risk assessment meet the acceptable risk level (see Section 2.5). For all four receptors evaluated (landfill worker, current off-Site resident, future off-Site resident, and future on-Site resident), the cancer morbidity risks are well below US EPA's target cancer risk range and well below the level at which potential health effects may be observed (Table 6.2).

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[27] See Section 2.1.1 for the list of types of waste that the landfill permit allows to be disposed of at this facility, and thus may be present in Landfill L-14.

[28] 10^{-5} for multiple carcinogens; 10^{-6} for individual carcinogens; Hazard Index of 1 for non-carcinogens as specified in OAR 340-122-0115.

6.5 Short-term Effectiveness

This criterion includes an evaluation of the effects of the remediation alternative during the construction and implementation phases, until remedial objectives are met; the protection of the community and workers during the remedial action; and the short-term environmental impacts of implementing the remedial action.[29] Gradient evaluated short-term effectiveness using two different methods: remedy risk analysis and Green and Sustainable Remediation (GSR) analysis.

Gradient and RAC quantified and compared the physical and radiological risks, respectively, posed by executing each remediation alternative. In addition, RAC evaluated radiological risks to workers and the community by comparing a calculated dose to health-protective benchmarks. Gradient used actuarial techniques to evaluate the physical risks to workers by estimating the number of injuries and fatalities sustained by workers involved with remediation activities for each remediation alternative. Gradient also used actuarial techniques to evaluate the physical risks to the community by estimating the number of injuries and fatalities sustained by individuals in the surrounding community from haul truck accidents. Additionally, Gradient qualitatively evaluated short-term chemical risks posed to workers during the implementation of the remediation alternatives.

In the GSR analysis, Gradient calculated the environmental impacts associated with the "life cycle" of each remediation alternative on the basis of the following metrics: air emissions (greenhouse gases [GHGs], sulfur oxides [SO_x], nitrogen oxides [NO_x], particulate matter less than 10 microns in diameter [PM_{10}]), energy consumption, and resource consumption.

The following sub-sections describe the methodology and results of these analyses (see Attachment E for further details).

6.5.1 Short-term Radiological Risks

Remediation Alternative 2 includes excavation of the Bakken oilfield waste disposed in Landfill L-14 and redisposing the waste at an out-of-state Subtitle C disposal facility permitted to accept the waste. RAC (2020a) evaluated risks during excavation for the following receptors and exposure pathways that are relevant to Remediation Alternative 2 (Excavation and Redisposal). RAC used the unrealistic worst-case assumption that the excavation workers and the supervisor were not wearing PPE or using supplied air.

- *Excavation workers.* These are workers that are involved in the hypothetical excavation process, but they are not landfill employees. The excavation worker is assumed to attend all of the waste removals. RAC evaluated the excavation workers for inhalation of particulates, ingestion of soil, and external radiation exposure. This individual sits in an enclosed cab of heavy equipment.
- *Supervisor.* This individual monitors the hypothetical excavation process and is assumed to be present for all of the removals. RAC evaluated the supervisor for inhalation of particulates, ingestion of soil, and external radiation exposure. This individual is on the ground, ensuring removal operations are conducted properly and safely.

[29] Similarly, Oregon State regulations require the consideration of implementability risk caused by performing the remediation alternative, including impacts to the community, workers, and the environment. In addition, ODEQ has a Green Remediation Policy to "promote, support and implement more sustainable practices that lessen the overall environmental impacts of investigation and remediation projects" (ODEQ, 2011).

- *Current off-Site residents.* These receptors are residents that live in homes closest to the Arlington Landfill, approximately 10,700 feet (3,260 meters) southwest of Landfill L-14. RAC evaluated the off-Site resident for inhalation of particulates.

Table 6.4 presents the cancer morbidity risk estimates during the excavation period for Remediation Alternative 2; RAC did not perform cancer risk calculations for this period in Remediation Alternative 1 because it does not involve excavation. The calculated cancer morbidity risk estimates for Remediation Alternative 2, while within US EPA and ODEQ target cancer risk ranges for all on-Site and off-Site receptors, were approximately 35 times higher than Remediation Alternative 1 for the excavation worker under Remediation Alternative 2 compared to a hypothetical future on-site resident under Remediation Alternative 1.

Table 6.4 Cancer Morbidity Risk Estimates for Remediation Alternative 2 During Excavation

Receptor	Maximum Source Term Cancer Morbidity Risk	Average Source Term Cancer Morbidity Risk	US EPA Target Risk Range	ODEQ Target Risk Range
Excavation Worker	3.5E-05	2.2E-05	1E-06 to 1E-04	1E-06 to 1E-05
Supervisor	3.5E-05	2.2E-05	1E-06 to 1E-04	1E-06 to 1E-05
Current Off-Site Resident	2.5E-13	1.6E-13	1E-06 to 1E-04	1E-06 to 1E-05

Notes:
ODEQ = Oregon Department of Environmental Quality; US EPA = United States Environmental Protection Agency.

6.5.2 Short-term Chemical Exposure to Workers

As discussed in Section 2, under the CWMNW RCRA Hazardous Waste Permit, the CWMNW facility can accept a wide range of solid and liquid hazardous, non-hazardous, toxic, corrosive, and reactive wastes (ODEQ, 2006). This list (provided in Section 2.1.1) includes the range of wastes that could potentially be present in Landfill L-14. These waste streams are profiled and then, as needed, treated or stabilized. Approximately one-third of the wastes are packaged in additional containment (*i.e.*, Macroencapsulation ["Macro"] boxes or drums) prior to *in situ* placement within the Subtitle C double-lined landfill.

Two remediation alternatives are being considered under the CAP: excavation, transportation, and out-of-state redisposal of the Bakken oilfield waste (which would be comingled with other waste present in Landfill L-14) at a secure Subtitle C landfill permitted to accept TENORM, or leaving the Bakken oilfield waste where it is currently buried in Landfill L-14 to eliminate any direct exposure to this waste. This section discusses the risks from worker exposure to hazardous chemicals under the excavation and removal alternative.[30] In this alternative, nearly 600,000 yd^3 of overburden waste in Landfill L-14 would be managed by workers using heavy equipment to unearth the Bakken oilfield waste. Approximately one-third of the waste is contained in Macro boxes that would need to be breached in place to enable access, then repackaged into new Macro boxes that would temporarily be stored on Landfill L-14. Another approximately one-third of the waste is contained in drums, which would need to be carefully removed to avoid puncturing and placed in lined roll-off containers that would also be temporarily stored on Landfill L-14. The remaining waste generally consists of granular material and would need to be stockpiled and temporarily stored on Landfill L-14 prior to removal for redisposal. The removal of all the Bakken oilfield waste is estimated to take approximately 10 years.

[30] There are *de minimis* risks associated with the closure-in-place alternative because the CWMNW facility is specifically designed and operated to mitigate such risks using a variety of engineering and institutional controls. Refer to Section 2.1 for further details.

Waste materials would be handled with heavy equipment such as trackhoes, loaders, or excavators; thus, the equipment operator and the supervisor on the ground helping to direct the operation have the greatest potential to receive chemical exposures from the waste materials brought to the surface. The specific chemicals and mixtures that are present in any section of Landfill L-14 are not known with specificity and could potentially include one or more chemicals from the categories listed in Section 2.1.1.

6.5.2.1 Worker Exposures and Risks

Workers have the potential to be exposed to hazardous chemicals in the excavated wastes *via* incidental ingestion, dermal contact, and inhalation (of volatile compounds, fugitive dust, or released gases). Excavation of a wide range of chemical substances can pose a high hazard condition to workers, and the worker hazard is expected to be greater for the excavation of the waste than when the waste was originally buried. During original burial of each waste stream, its chemical characteristics are known and it is appropriately stabilized, containerized, and segregated from other specific wastes on each lift to exclude potential reactions. However, the excavation of existing buried wastes could result in the rupture of containers and undesired mixing of incompatible wastes. The excavation of comingled waste presents an undue risk for workers due to the potential for exposure to mixtures of wastes with potentially incompatible characteristics that could result in unknown or unintended chemical reactions.

In addition to the possibility of causing unknown or unintended chemical reactions, excavation of unknown mixtures of wastes in containers also has a similar risk potential if containers are ruptured and create spills and exposure concerns such as releases of volatile vapors that could present an acute hazard for workers. Since the generated vapors have the possibility of being heavier than air, it cannot be assumed that any vapors would be dispersed into ambient air simply because the work is conducted outdoors. Examples of potential adverse chemical reactions producing toxic gases include generation of hydrogen cyanide gas from mixing of sodium cyanide with waste that causes a pH change, or chlorine gas from mixing sodium hypochlorite with waste that causes a pH change.

The permitted waste types (Section 2.1.1) may include those with a RCRA characteristic of reactivity. Treated reactive wastes have the potential to create several types of reactions when mixed with other unknown wastes; potential reactions include creation of toxic gases or generation of heat. Reactive wastes clearly would pose an unacceptable risk to workers due to the potential of fire, explosion, or release of toxic gases.

The permitted wastes also include those listed as "acute hazardous waste," defined as chemicals that have been "found to be fatal to humans in low doses…or capable of causing or significantly contributing to an increase in serious irreversible, or incapacitating reversible, illness" (US EPA, 2020). Worker exposure to materials classified as acute hazardous waste would pose a risk of serious illness.

The effects of chemical exposure depend on the chemical, its concentration, the exposure route, and the duration of exposure, but acute hazards associated with inhalation can result in adverse effects such as behavioral changes; breathing difficulties; changes in complexion or skin color; coordination difficulties; coughing; dizziness; drooling; diarrhea; fatigue and/or weakness; irritability; irritation of eyes, nose, respiratory tract, skin, or throat; headache; light-headedness; nausea; sneezing; sweating; tearing; or tightness in the chest (NIOSH *et al*., 1985).

Although workers would be required to wear PPE during the excavation, it should be noted that not all of the risks can be mitigated with the use of PPE (*e.g.*, fire and explosion). Due to the unknown identity and concentrations of the chemicals in the waste materials and that can potentially be released to air, worker respiratory protection would need to include the use of supplied air because air purifying respirators do not provide adequate protection (NIOSH *et al*., 1985). Having workers on supplied air is cumbersome and presents additional risks due to the nature of the work and would also significantly slow worker productivity, especially considering the facility's semiarid climate. Therefore, excavation and subsequent mixture of unknown wastes could result in heat generation causing fire, or the release of toxic gases and volatile organic compounds to the air that would present an acute inhalation hazard to workers.

In summary, excavation of the Bakken oilfield waste along with the mixture of hazardous wastes would pose a significant level of risk to workers that would not be entirely mitigated even if properly using PPE or by implementing engineered controls. Due to the unknown mixture of chemicals, their concentrations, and the possibility of adverse reactions between chemicals or chemicals exposed to air, excavation of these wastes would present an unacceptable, if not extreme, risk to human health. In contrast, the waste is currently entombed in Landfill L-14, where the exposure risk has been effectively minimized or eliminated through a combination of previously implemented institutional and engineering controls, as well as additional institutional and engineering controls that will be implemented upon landfill closure (see Section 2).

While the focus above is on acute risks, worker exposure to chemicals during removal of hazardous waste also has the potential for chronic (long-term) health risks since removal is anticipated to take approximately 10 years. Chronic non-carcinogenic health effects may include effects on the liver, kidney, eyes, skin, blood, respiratory system, central nervous system, or gastrointestinal system. Long-term health effects could also include cancer from exposure to carcinogens (NIOSH *et al*., 1985).

6.5.2.2 Hazardous Waste Incidents

Examples of incidents that have occurred when working with or transferring hazardous wastes are presented below. Although these situations are not identical to the waste removal scenario that is being considered for the CWMNW facility, they are nevertheless representative of incidents that can occur as a result of a reaction between incompatible wastes, a release of toxic gases, or ignition of flammable chemicals.

- In 2016, during cleanup work at Hanford Burial Ground in Washington, a drum that had been removed from the ground began smoking after the contents reacted with oxygen, and workers took cover for 90 minutes until the reaction abated (Culverwell, 2016).
- In 2015, at a low-level nuclear waste landfill in Beatty, Nevada, moisture from heavy rain penetrated a protective earthen cap and came into contact with metallic sodium in corroded steel drums, causing a fire and series of explosions (Rogers, 2016).
- In 2018, there was an explosion causing one death and significant damage to structures at the US Ecology facility in Grandview, Idaho (Blanchard, 2018).
- In 2018, a fire occurred in the emissions control system at the Stericycle facility in Tacoma, Washington (WA Ecology, 2019).
- In 2006, an explosion and fire occurred in Apex, North Carolina, when incompatible chemicals reacted at the Environmental Quality (EQ) TSDF, resulting in the evacuation of 17,000 residents (US CSB, 2008).

Several older incidents (pre-1995) occurred at commercial TSDFs in US EPA Region 10, as a result of mixing incompatible hazardous waste:

- In 1992, at Northwest EnviroServe (a TSDF near Seattle), the mixing of incompatible waste in a stabilization unit resulted in the generation of heat, flames, and toxic fumes (US EPA, 1999).

- In 1990, at the Washington Chemical facility in Spokane, incompatible reactive wastes were mixed and sealed into a 55-gallon drum, which resulted in an explosion that launched the drum across the facility and spewed hazardous waste (US EPA, 1999).

6.5.3 Physical Risks

Gradient performed a physical risk analysis to estimate the impact of Remediation Alternative 2 compared to Remediation Alternative 1. Hence, for both remediation alternatives, the physical risk analysis included only those activities that would be performed in addition to the standard operational and post-closure requirements for the CWMNW facility. Therefore, Gradient assumed that:

- Remediation Alternative 1 posed zero incremental physical safety risk[31]; and
- Physical risks associated with the implementation of the Remediation Alternative 2 work elements (*i.e.*, excavation, transportation, and redisposal of the Bakken oilfield and overlying wastes), as well as additional personnel transport to and from the CWMNW facility, were the bases of the calculated risks for Remediation Alternative 2.

Consistent with these general assumptions, Gradient calculated worker and community safety metrics (*i.e.*, injuries and fatalities) using several published methods (Leigh and Hoskin, 1999, 2000; Hoskin *et al.*, 1994; Cohen *et al.*, 1997; Herman, 2014) that rely on actuarial statistics of worker fatalities and injuries published by the United States Bureau of Labor Statistics (US BLS), vehicle crash statistics published by the United States Department of Transportation (US DOT), and estimates of the amount and type of labor (*e.g.*, construction worker, engineer) and haul truck mileage required to implement each remediation alternative. Gradient provides details and assumptions for these calculations below.

Injury and fatality risks for on-Site[32] workers originate from two sources: general work risks and transportation-related risks. Gradient calculated general work risks from accidents for six labor categories (*i.e.*, construction laborers, site supervisor, construction project managers, construction technicians, field engineers, and project managers) by estimating the hours for each labor category and multiplying it by corresponding fatality and injury rates published by the US BLS (US Dept. of Labor, 2018a,b,c). The labor categories considered herein are more detailed than the labor categories evaluated in Section 6.5.1 for evaluating the radiological risks. This is because assuming fewer labor categories would increase the radiological exposure time of each category and lead to a more conservative radiological risk assessment.

Gradient calculated risks for personnel that travel between their residence and work places using SiteWise™ version 3.1, based on the same input data used for estimation of the emissions caused by personnel transportation. The reported risks for on-Site workers is the sum of the risks originating from these two sources.

Off-Site injury and fatality risks were calculated based on total travel mileage and truck crash data. Only Remediation Alternative 2 involved a significant amount of off-Site truck activities. Gradient assumed that the Bakken oilfield waste would be moved in 20 yard roll-off boxes (12 tons capacity) to a landfill 350 miles away,[33] and then calculated the total travel mileage accordingly. Gradient used truck accident rates from 2017 (the most recent data available), provided by US DOT's "Large Truck Crash Facts" report (US

[31] The corrective actions described in Section 8 would be performed in addition to either remediation alternative and are therefore excluded from this analysis.
[32] Gradient is using the terms "on-Site" and "off-Site" in this section to specifically refer to Landfill L-14 of the CWMNW facility.
[33] The US Ecology Subtitle C landfill located in Grandview, Idaho, is a Subtitle C landfill that is permitted to accept TENORM and thus was selected as the final destination of the Bakken oilfield waste in this analysis.

DOT, 2019), to estimate the total number of fatalities and injuries in crashes involving trucks. This report also states that in 2017, 73.1% of the persons injured and 82.3% of the persons killed in large truck crashes were not truck occupants. These percentages provide the ratio of non-truck occupants (community) to truck occupants injured or killed in truck accidents.

Table 6.5 summarizes physical risks for on-Site workers and off-Site risks caused by truck traffic that were calculated using the methods described above. The results suggest that while there is minimal incremental on-Site work activity, and thus minimal incremental risks to on-Site workers, associated with Remediation Alternative 1, Remediation Alternative 2 would lead to 8.453 non-fatal and 0.090 fatal injuries among on-Site workers. The implementation of Remediation Alternative 2 requires significantly more labor than the implementation of Remediation Alternative 1, which accounts for this difference.

For off-Site risks, only Remediation Alternative 2 requires incremental off-Site truck activities. Gradient's analysis indicates that the implementation of this remediation alternative involves over 225,000 miles of truck travel. This amount of truck activity would lead to an expected 0.078 non-fatal and 0.003 fatal injuries in crashes involving trucks associated with Remediation Alternative 2. More detailed results and calculations for the physical risk analysis can be found in Attachment E.

Table 6.5 Summary of Physical Risks for the Remediation Alternatives

Risk Category	Remediation Alternative 1: Closure-in-Place	Remediation Alternative 2: Excavate and Redispose	Notes
On-Site Workers			
Total worker labor (equivalent worker hours)	0.0	712,024	Estimated (see On-Site Safety Calculation Worksheet in Attachment E)
Weighted average worker injury rate (per 10,000 hours)	0.0	0.119	Estimated (see On-Site Safety Calculation Worksheet in Attachment E)
Weighted average worker fatality rate (per 100,000 hours)	0.0	0.013	Estimated (see On-Site Safety Calculation Worksheet in Attachment E)
Expected worker injuries (number of injury incidents)	0.0	8.453	Sum of risks to on-Site workers (estimated by multiplying required labor hours by worker injury rate data) and risks originating from personnel transport (see Attachment E for details)
Expected worker fatalities (number of fatality incidents)	0.0	0.090	Sum of risks to on-Site workers (estimated by multiplying required labor hours by worker fatality rate data) and risks originating from personnel transport (see Attachment E for details)
Off-Site Community Members			
Total truck travel miles	0.0	225,400	Estimated (see Off-Site Safety Calculation Worksheet in Attachment E)
Truck crash with injury rate (per mile of truck travel)	0.0	3.44E-7	Based on 2017 US DOT statistics (US DOT, 2019)
Expected truck crashes with injuries	0.0	0.078	Based on 2017 US DOT statistics (US DOT, 2019)
Injuries in truck crashes (persons)	0.0	0.112	Calculated based on 2017 US DOT statistics (73.1% of persons injured in truck crashes are not truck occupants; US DOT, 2019)
Truck crash with fatality rate (per mile of truck travel)	0.0	1.42E-08	Based on 2017 US DOT statistics (US DOT, 2019)
Expected truck crashes with fatalities	0.0	0.003	Based on 2017 US DOT statistics (US DOT, 2019)
Fatalities in truck crashes (persons)	0.0	0.004	Calculated based on 2017 US DOT statistics (82.3% of persons killed in truck crashes are not truck occupants; US DOT, 2019)

Note:
US DOT = US Department of Transportation.

6.5.4 GSR

Gradient used SiteWise™ version 3.1 in this analysis to evaluate the sustainability metrics associated with the remediation alternatives for addressing any TENORM at the CWMNW facility. SiteWise™ is a Microsoft Excel-based tool jointly developed by the United States Navy, the United States Army, the United States Army Corps of Engineers (US ACE), and Battelle for estimating the environmental footprint of remediation alternative components (NAVFAC *et al.*, 2013). The following input categories and corresponding footprint databases are integrated into this modeling tool: material usage; transportation of the required materials, equipment, and personnel to and from the landfill; activities at Landfill L-14 (*e.g.*, equipment operation); and management of the waste produced by the activity (NAVFAC *et al.*, 2013). The default values used by the model for calculating footprint parameters are saved in lookup tables and may be overridden by user-specific values as needed.

Gradient performed the GSR analysis on a relative basis to estimate the environmental impact of Remediation Alternative 2 compared to Remediation Alternative 1. Hence, for Remediation Alternative 2, the GSR analysis included only those activities that would be performed in addition to the standard operational and post-closure requirements for Landfill L-14 at the CWMNW facility.[34] As such, Gradient reports all GSR metrics for Remediation Alternative 1 as equal to zero and report the incremental metric values for Remediation Alternative 2.

The methodology and key assumptions for the GSR analysis are as follows.

- Material, water, and electricity usage do not significantly vary between the two remediation alternatives, and, therefore, Gradient eliminated these factors from this analysis. Air emissions (GHGs, SO_x, NO_x, PM_{10}) and energy consumption were the GSR output metrics that vary significantly between the alternatives, and thus Gradient included them in the analysis.
- The key work elements of Remediation Alternative 2 that Gradient analyzed in the GSR analysis include the following: excavate landfill to target elevations discussed in Section 4.2.2, open Macro boxes containing bulk waste, remove buried drums, transport overburden waste to another portion of the landfill, repack overburden bulk waste into Macro boxes, dispose drums, excavate the Bakken oilfield waste and mixed waste with it, and prepare and transport the Bakken oilfield waste 350 miles to a TENORM-licensed solid waste landfill. Gradient calculated GSR metrics for the operation of earthworking equipment, transportation of bulk materials (*i.e.*, overburden and Bakken oilfield wastes), and personnel transportation to and from the CWMNW facility. For personnel transport, Gradient assumed the total number of trips, distance traveled, number of travelers, type of vehicles, fuel used, and number of occupants in order to estimate the footprint. In the case of bulk material transportation, Gradient used the total weight and the round-trip distance traveled by trucks to estimate environmental impacts.

Table 6.6 summarizes the results of the GSR analysis performed using the methods and tools described above. The GSR analysis results show that the environmental footprint of the implementation of Remediation Alternative 2 (Excavate and Redispose) is significantly larger than Remediation Alternative 1 (Closure-in-Place). This gap is mostly due to energy consumption and environmental emissions associated with landfill excavation. The total energy required to implement Remediation Alternative 2 is approximately 171,000 MMBTU[35] greater than that of Remediation Alternative 1. This amount of energy

[34] The corrective actions described in Section 8 would be performed in addition to either remediation alternative and are therefore excluded from this analysis.
[35] MMBTU stands for million British thermal units.

is equivalent to burning approximately 1,250,000 gallons of diesel fuel.[36] More detailed results and calculations for the GSR analysis can be found in Attachment E.

Table 6.6 Summary of GSR Metrics for the Remediation Alternatives

Risk Category	Remediation Alternative 1: Closure-in-Place	Remediation Alternative 2: Excavate and Redispose
GHG emissions (metric ton)	0	11,000
Total energy used (MMBTU)	0	171,000
Total NO_x emissions (metric ton)	0	70
Total SO_x emissions (metric ton)	0	18
Total PM_{10} emissions (metric ton)	0	8

Notes:
All values are rounded; GHG = Greenhouse Gas; GSR = Green and Sustainable Remediation; MMBTU = Million British Thermal Units; NO_x = Nitrogen Oxide; PM_{10} = Particulate Matter Less Than 10 Microns in Diameter; SO_x = Sulfur Oxide.

6.6 Implementability

This criterion is used to evaluate the technical feasibility of the remediation alternatives, including construction and operation, reliability, monitoring, and the ease of undertaking remedial action in the context of any logistical constraints at the CWMNW facility. It also considers the administrative feasibility of activities needed to coordinate with other third parties (*e.g.*, regulatory agencies), such as for obtaining permits, and the availability of services and materials necessary to the remediation alternative, such as disposal facilities and qualified contractors.

Remediation Alternative 1 is clearly implementable. The required technologies are available, and the engineering measures and qualified contractors are in place to perform the work this alternative requires. CWMNW has regulatory approvals, including permits, for the operation, closure, and post-closure monitoring of the landfill. Regulatory approval would, however, be required to leave the buried Bakken oilfield waste in place.

Remediation Alternative 2 has significant implementability challenges, as described below:

- Implementing a significant excavation project with heavy machinery at a hazardous waste landfill where various types of heterogeneous waste are disposed of in various shapes (*i.e.*, bulk granular waste, contained in drums, contained in Macro boxes) is extremely difficult. The operation may mobilize the buried hazardous materials or expose the workers to physical and chemical injury risks (discussed separately in Section 6.5.2 and 6.5.3).
- Health and safety monitoring would be required during remediation activities. All activities should be performed in Level C PPE, at minimum, and with supplied air.
- Transporting the estimated 3,244 yd^3 of Bakken oilfield waste and comingled waste require about 322 truckloads traveling over 225,000 miles. It could require the use of dedicated trucks and/or truck decontamination after each shipment.
- Transporting the buried Bakken oilfield waste and comingled waste to another landfill for redisposal increases the risk of physical injury and fatality due to accidents (both for workers and in the community) and increases radiological exposures for workers and for the public along the haul route (discussed in Section 6.5.3).

[36] One gallon diesel fuel is approximately equivalent to 0.137 MMBTU.

- The need to obtain permit approval to transport and dispose of the Bakken oilfield waste at another landfill facility could be time consuming.
- Considering the volume of overburden that must be displaced and the slow operation rate dictated by safety measures required for operating in this environment, the time to complete Remediation Alternative 2 is estimated at approximately 10 years. Permits and regulatory requirements may change in this period, requiring extra time and effort to comply with the new requirements.
- The availability of adequately trained laborers and specialized equipment to perform the work would be difficult to procure for an extended duration.
- Decontamination of excavation equipment and trucks after hauling each shipment would generate additional waste that would require disposal.

6.7 Cost

This criterion includes an evaluation of direct and indirect capital costs, including the costs of treatment and disposal; the annual costs of operating, maintaining, and monitoring the remediation alternative; and the net present value of these costs.

Gradient prepared a screening-level cost estimate to evaluate the relative cost of the remediation alternatives. Gradient based the cost estimates on conceptual remedy designs for each alternative, including the major activities, transportation needs, and health and safety, engineering, and labor and material requirements. Gradient performed this cost estimate on a relative basis, in that Gradient only took the incremental costs associated with each remediation alternative (compared to standard operation and closure procedure in accordance to the current permits) into consideration. Consequently, the costs reported in this section should only be used for relative comparison between the remediation alternatives.[37]

Two important factors that control the remediation costs are the earthwork equipment output rates (*e.g.*, volume of waste excavated per unit time) and operation cost units. Gradient obtained the earthworking equipment output rates from CWMNW based on contractor rates to perform earthworking activities at the CWMNW facility (see Attachment F). Gradient developed the cost estimate based on industry standard cost estimation guidance (*e.g.*, *Heavy Construction Cost Books* [R.S. Means Co., 2020]; "A Guide to Developing and Documenting Cost Estimates During the Feasibility Study" [US EPA and US ACE, 2000]), Gradient's experience with other projects, the CWMNW facility-specific unit costs realized at the CWMNW facility, and professional judgment. The utilized methodology and assumptions for the cost estimate are described below.

- **Capital Costs:**
  - Both remediation alternatives include costs for implementation of a portal monitoring system.
  - Remediation Alternative 2 capital requirements include the costs of (a) engineering design, (b) excavating the overlying waste that includes a combination of bulk waste, drums, and Macro boxes, (c) placing overlying waste in other sections of the landfill, including repacking waste in new Macro boxes and disposing of bulk waste and drums, (d) excavating Bakken oilfield waste, and hauling the Bakken oilfield waste and any mixed waste to a permitted out-of-state landfill approximately 350 miles away from the CWMNW facility, (e) disposing of the Bakken

[37] The Radiological Monitoring Plan described in Attachment G would be performed in addition to either remediation alternative and are therefore excluded from this analysis.

oilfield waste and mixed waste at the permitted landfill, and (f) health and safety equipment and training, in addition to engineering controls.

- **Future Costs:**
  - CWMNW facility post-closure operations and maintenance (O&M) and standard post-closure monitoring activities are similar for the two alternatives, except that additional radionuclide monitoring is required under Remediation Alternative 1. The radionuclide monitoring costs are estimated for both the period that Landfill L-14 remains operational (30 years estimated based on available head space) and post-closure monitoring period (30 years after closure).
  - Gradient used an industry-standard 7.0% annual discount rate to calculate the net present value of the future costs (US EPA and US ACE, 2000).
  - Gradient did not account for cost escalation because of work timing in its cost estimate.
- **Management and Contingency Costs:**
  - Gradient included costs associated with project and construction management and contingency in the cost estimate, in accordance with standard recommendations for cost estimates of remediation alternatives (US EPA and US ACE, 2000). The upper end of the range for excavation contingency[38] was used given the significant uncertainties and challenges associated with implementing Remediation Alternative 2.

Table 6.7 shows the summary of remediation alternative costs. Detailed cost estimate calculations can be found in Attachment F. Based on this analysis, Excavate and Redispose (Remediation Alternative 2) costs over $200 million dollars more than Closure-in-Place (Remediation Alternative 1).

Table 6.7 Summary of Incremental Remediation Alternative Costs

Remediation Alternative	Capital Cost	Future Cost	Total Cost = Capital Cost + NPV[a] for Future Cost
1. Closure-in-Place	$520,000	$85,000	$605,000
2. Excavate and Redispose	$210,760,000	$0	$210,760,000[b]

Notes:
Costs are incremental above Remediation Alternative 1 and should be used for relative comparison purposes only. All costs are rounded to the nearest $10,000.
(a) NPV stands for net present value, and Gradient calculated the NPV based on a 7% annual discount rate. A sensitivity analysis was performed on the discount rate. Varying the rate between 2% and 10% led to total costs of $582,000 and $701,000 for Remediation Alternative 1, respectively, and thus had no substantive effect on the result of the cost analysis.
(b) Equivalent to approximately $358/yd^3 "all-in."

6.8 Regulatory Approval and Community Acceptance

These criteria are used to evaluate the anticipated level of approval from the regulatory agency and acceptance from community stakeholders, respectively. Both regulatory approval and community acceptance have been evaluated by ODOE during its review of the CAP submittal (see Attachments A).

[38] US EPA and US ACE (2000) suggest a 15% to 55% contingency during the feasibility study for soil excavation remediation technology.

7 Comparative Analysis of Remediation Alternatives

As described below, the results of the comparative analysis of the remediation alternatives demonstrate that Remediation Alternative 1 (Closure-in-Place) is the preferred remediation approach for addressing the Bakken oilfield waste buried in Landfill L-14 at the CWMNW facility, assuming regulatory approval and community acceptance, because it provides the highest degree of overall protectiveness; poses the lowest short-term physical, chemical, and radiological exposure-related risks to workers and the community; and provides long-term effectiveness and protectiveness while also being cost-effective and implementable.

The risks associated with Remediation Alternative 2 are orders of magnitude higher in all categories, while risks associated with Remediation Alternative 1 are either zero or orders of magnitude lower. In addition, as discussed in Section 6.5.2, the excavation of existing buried wastes as part of Remediation Alternative 2 could result in the rupture of containers and undesired mixing of incompatible wastes. The excavation of comingled waste presents an undue risk for remediation workers due to the potential for exposure to mixtures of wastes with potentially incompatible characteristics that could result in unknown or unintended chemical reactions.

Remediation Alternative 1 would provide a higher level of overall protectiveness than Remediation Alternative 2. Excavating, transporting, and redisposing of the Bakken oilfield waste would create chemical and radiological exposure pathways and additional chemical and radiological risks that are not currently present, and there are significant short-term physical risks associated with its excavation, transport, and redisposal.

The RAC Radiological Risk Assessment demonstrates that there are no unacceptable risks associated with Remediation Alternative 1. For all receptors evaluated (landfill worker, current off-Site resident, future off-Site resident, future on-Site resident, and future intruder), the cancer morbidity risks are well below US EPA's and ODEQ's target cancer risk ranges and well below the level at which potential health effects may be observed. The RAC (2020a) Radiological Risk Assessment results demonstrate that in the event of future leachate system failure, potential doses and risks for human health and ecological receptors *via* the groundwater exposure pathway are extremely low and well within the acceptable range set by US EPA, even assuming the confluence of multiple worst-case scenarios. Further, the RAC (2020a) Radiological Risk Assessment results also demonstrate that the potential doses and risks for human health receptors *via* the radon inhalation exposure pathway are extremely low and well within the acceptable range set by US EPA. This includes both current and future landfill workers and future on-site and off-site residents.

Remediation Alternative 1 is readily implementable. The implementability challenges associated with Remediation Alternative 2, including worker/public safety, disruptions to the community (*e.g.*, truck traffic), and disruption to the landfill operations, are significant. Remediation Alternative 2 would also pose significant implementation challenges associated with the excavation of vast quantities of hazardous waste that would be required to access the Bakken oilfield waste, as well as even finding the Bakken oilfield waste since it is mixed heterogeneously with other hazardous and non-hazardous waste.

Gradient eliminated Remediation Alternative 2 after comparing it to Remediation Alternative 1, based on its lack of overall protectiveness, including its inherent physical, chemical, and radiological human health risks, as well as its challenging implementability, excessive cost, significant short-term impacts (*e.g.*, estimated ten-year duration to complete remediation leads to more truck traffic; greater impact on the community; air/odor issues), and the lack of net environmental benefit. Remediation Alternative 2 does not meet the threshold criteria of Overall Protectiveness. Gradient selected Remediation Alternative 1 because it ensures overall and long-term protectiveness while posing low short-term risks to workers and the community and is cost-effective.

Remediation Alternative 1 also includes the following actions to prevent the further disposal of TENORM waste exceeding state standards at the CWMNW facility in the future:

- A Waste Screening and Approval Program: Implementation of a waste screening and approval program that identifies potential radioactive waste streams and requires isotopic testing for those categories of wastes. The screening program was prepared and submitted to ODOE by CWMNW, and ODOE provided concurrence on the program's adequacy.
- A Portal Monitoring System: Installation of a portal monitoring system as part of the Radiological Monitoring Plan (Attachment G) at the facility entrance to screen all inbound wastes into the facility for ionizing radiation.

Remediation Alternative 1 would not reverse the conditions that led to the original NOV (Benner, 2020). However, ODOE issued a determination that Remediation Alternative 1, with amendments specified in its March 24, 2021 letter (Benner, 2021; see Attachment A), is the preferred final remedy.

8 Radiological Monitoring Plan

The CWMNW facility accepts a wide range of hazardous and non-hazardous industrial wastes for treatment and disposal. Some waste streams may include Naturally Occurring Radioactive Material (NORM) and/or TENORM. This section briefly describes the Radiological Monitoring Plan (Perma-Fix Environmental Services, 2020) that will be implemented at the CWMNW facility to ensure that all incoming wastes meet the requirements. The complete Radiological Monitoring Plan is presented as Attachment G to this CAP.

Once CWMNW approves shipment of a waste for disposal, the waste load typically arrives at CWMNW facility *via* truck and/or rail. Rail shipments will be off-loaded to a transport vehicle and driven over private roads into the facility through a single entry point where screening will be completed by radiation detectors. Two action levels are established in the Radiological Monitoring Plan:

Action Level 1: The exposure rate threshold for Action Level 1 is two times the ambient background for monitoring of material in a waste load. Indication of the exceedance will be made by the truck portal monitor with an audible or visual response at the unit and within the receiving department.

Action Level 2: The exposure rate threshold for Action Level 2 is 2,000 µR/hour above the ambient background for monitoring of material in a waste load. This action level is consistent with DOT regulation for radiological exposure rates in the cab of vehicles. If an exposure rate above 2,000 µR/hour is identified in a waste load, the state of Oregon Department of Energy will be notified, and no additional action will be performed without the specific instruction to do so by ODOE.

A flow chart illustrating the incoming waste process and requirements for Action Level exceedances is shown as Figure 8.1.

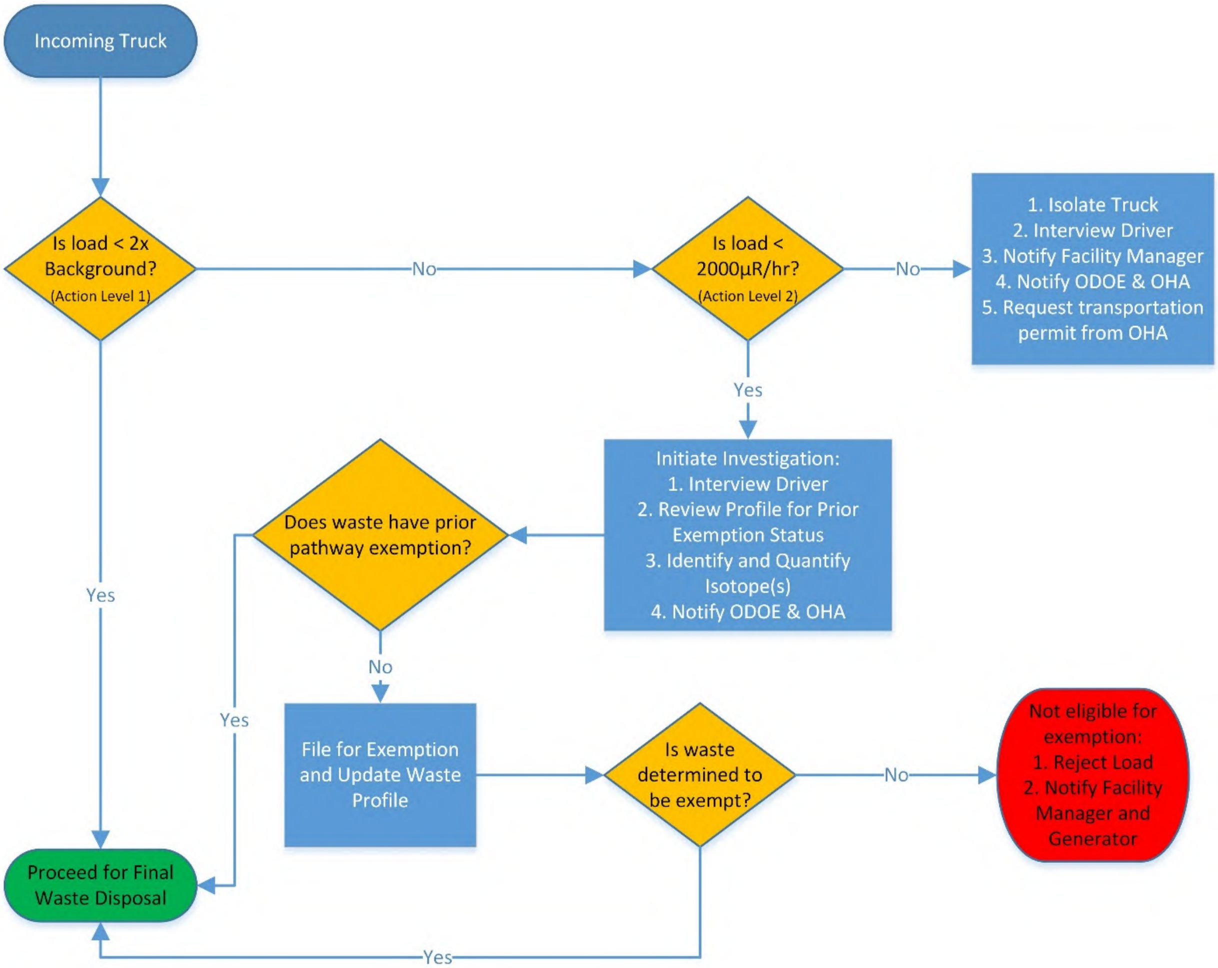


Figure 8.1 Action Level Response Flowchart (Perma-Fix Environmental Services, 2020).

References

American Cancer Society. 2020. "Cancer Facts & Figures 2020." 76p. Accessed on March 17, 2020 at http://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/annual-cancer-facts-and-figures/2020/cancer-facts-and-figures-2020.pdf.

Applied Soil Water Technologies, LLC (ASW); Dwyer Engineering, LLC; Waste Management, Inc. 2014a. "Draft Alternative Final Cover Design Report, Landfills L-12, L-13 and L-14, Chemical Waste Management Arlington Facility, Gilliam County, Oregon." Report to Chemical Waste Management of the Northwest, Inc., Arlington, OR. 120p., August.

Applied Soil Water Technologies, LLC (ASW); Dwyer Engineering, LLC; Waste Management, Inc. 2014b. "Alternative Final Cover Design Report, Landfills L-12, L-13 and L-14, Chemical Waste Management Arlington Facility, Gilliam County, Oregon (Standalone Document No. 17)." Report to Chemical Waste Management of the Northwest, Inc., Arlington, OR. 149p., August.

Bartholomew, WS. [Oregon State Engineer, Water Resources Dept.]. 1971. Letter to K. Spies (Oregon Dept. of Environmental Quality) re: Geological and sub-surface investigations of proposed Arlington disposal site, Gilliam County, Oregon. 2p., April 6.

Benner, J. [Oregon Dept. of Energy (ODOE)]. 2020. Letter to J. Denson (Waste Management, Inc.) re: Notice of Violation issued to Chemical Waste Management of the Northwest, a subsidiary of Waste Management, Inc. for violations of Oregon Administrative Rules (OAR) prohibiting the disposal of radioactive materials. OAR 345-050-0006. 10p., February 13.

Benner, J. [Oregon Dept. of Energy (ODOE)]. 2021. Letter Report to J. Denson (Waste Management) re: Completed review of the Corrective Action Plan submitted by Chemical Waste Management of the Northwest (CWMNW) on September 8, 2020 and all the comments submitted to the ODOE. 76p., March 24.

Blanchard, N. 2018. "US ecology 'fiercely focused' on determining cause of Idaho explosion, officials say." *Idaho Statesman* November 19. Accessed on July 28, 2020 at https://www.idahostatesman.com/news/local/article221871790.html.

CH2M Hill. 2008. "Updated Hydrogeologic Conceptual Site Model Report, Chemical Waste Management of the Northwest, Inc., Arlington, Oregon (Final Report)." Report to Waste Management, Inc. 221p., February.

Cohen, JT; Beck, BD; Rudel, R. 1997. "Life years lost at hazardous waste sites: Remediation worker fatalities vs. cancer deaths to nearby residents." *Risk Anal.* 17(4):419-425.

Culverwell, W. 2016. "Hanford workers take cover after burial ground incident." *Tri-City Herald* August 11. Accessed on July 9, 2020 at https://www.tri-cityherald.com/news/local/hanford/article95169297.html.

Environmental Restoration Group, Inc. (ERG); K2 Environmental LLC. 2020. "Gamma Survey Report." Report to Chemical Waste Management of the Northwest (CWMNW), Arlington, OR. 42p., September.

Environmental Systems Research Institute (ESRI). 2020. "World Imagery: Aerial imagery web mapping service." January 6. Accessed on January 16, 2020 at https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9.

Federal Remediation Technologies Roundtable (FRTR). c. 2007. "Table 3-2: Treatment Technologies Screening Matrix." 1p. Accessed on June 28, 2011 at http://www.frtr.gov/matrix2/section3/table3_2.pdf.

Geosyntec Consultants. 2020. "CWMNW Landfill 3D Model Cross-Sections, Chemical Waste Management of the Northwest, 17629 Cedar Springs Lane, Arlington, OR (Final)." Report to Waste Management, Inc. Submitted to Oregon Dept. of Energy (ODOE). 7p., March.

Gilliam County, Oregon. 2017. "County Zoning and Land Development Ordinance [Articles 1 through 5]." 147p., May 3. Accessed on June 29, 2020 at http://www.co.gilliam.or.us/government/planning_department/2017_comprehensive_plan_and_zoning_ordinance.php.

Gilliam County, Oregon. 2020. "Gilliam County, OR Zoning Map." 1p. Accessed on June 29, 2020 at https://www.arcgis.com/apps/webappviewer/index.html?id=c0fccc37daa4493caa0d30465e8f054d.

Golder Associates. 2017. "Surface Water Management Plan Facility Map, CWMNW Landfill L-14 Cell 4 Design, Arlington, Oregon (Draft)." Report to Chemical Waste Management of the Northwest, Inc., Arlington, OR. 1p., November 30.

Golder Associates. 2018. "Surface Water Management Plan, Chemical Waste Management of the Northwest, Inc., Arlington, Oregon." Report to Chemical Waste Management of the Northwest, Inc., Arlington, OR. 38p., January 19.

Herman, K. 2014. "Actuarial risk analysis to promote National Contingency Plan (NCP)-consistent remediation." *Remediation* 24(3):11-19. doi: 10.1002/rem.21392.

Hoskin, AF; Leigh, JP; Planek, TW. 1994. "Estimated risk of occupational fatalities associated with hazardous waste site remediation." *Risk Anal.* 14(6):1011-1017.

K2 Environmental LLC; ERG. 2020. "CWMNW Gamma Survey Overview." Submitted to Oregon Dept. of Energy (ODOE). 3p., April 30.

Leigh, JP; Hoskin, A. 1999. "Hazards for nearby residents and cleanup workers of waste sites." *J. Occup. Environ. Med.* 41:331-348.

Leigh, JP; Hoskin, AF. 2000. "Remediation of contaminated sediments: A comparative analysis of risks to residents vs. remedial workers." *Soil Sediment Contam.* 9:291-309.

MGS Engineering Consultants, Inc.; Oregon Climate Service. 2007. "Regional Precipitation-Frequency Analysis and Spatial Mapping of 24-Hour Precipitation in Oregon." Report to Oregon Dept. of Transportation (ODOT). 84p., August.

Multi-Resolution Land Characteristics Consortium (MRLC). 2016. "NLCD 2016 Land Cover (CONUS)." Accessed on June 8, 2020 at https://www.mrlc.gov/data/nlcd-2016-land-cover-conus.

National Geographic Society (NGS). 2013. "USA Topo Maps: Web mapping service." Accessed on July 15, 2020 at https://www.arcgis.com/home/item.html?id=99cd5fbd98934028802b4f797c4b1732.

National Institute for Occupational Safety and Health (NIOSH); Occupational Safety and Health Administration (OSHA); US Coast Guard; US EPA. 1985. "Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities." National Institute for Occupational Safety and Health (NIOSH). DHHS (NIOSH) No. 85-115, EPA 930-R-85-102, 199p., October.

Nelson, AW; Eitrheim, ES; Knight, AW; May, D; Mehrhoff, MA; Shannon, R; Litman, R; Burnett, WC; Forbes, TZ; Schultz, MK. 2015. "Understanding the radioactive ingrowth and decay of naturally occurring radioactive materials in the environment: An analysis of produced fluids from the Marcellus Shale." *Environ. Health Perspect.* 123(7):689-396. doi: 10.1289/ehp.1408855.

Oregon Dept. of Energy (ODOE). 2020. "Radioactive Waste Materials." Energy Facility Siting Council. OAR 345-050. Accessed on July 30, 2020 at https://secure.sos.state.or.us/oard/displayDivisionRules.action?selectedDivision=1588.

Oregon Dept. of Environmental Quality (ODEQ). 2006. "Hazardous Waste Permit for the Storage, Treatment, and Disposal of Hazardous Waste, Chemical Waste Management of the Northwest, Inc., 17629 Cedar Springs Lane, Arlington, OR 97812 (Rev. 30)." Permit No. ORD 089 452 353, 112p., August 21. Accessed on June 26, 2020 at https://www.deq.state.or.us/Webdocs/Controls/Output/PdfHandler.ashx?p=521ed693-d0f1-4e47-96c6-a9e0e9660636pdf&s=6321-CWMNW-Permit-Language-Revision-30.pdf.

Oregon Dept. of Environmental Quality (ODEQ). 2011."Green Remediation Policy." Land Quality Division. 2p., November 2.

Oregon Dept. of Environmental Quality (ODEQ). 2014a. "Ground Water Monitoring Plan For Chemical Waste Management of the Northwest, Inc. Arlington Facility - ORD 089 452 353, 17629 Cedar Springs Lane, Arlington, Oregon (Standalone Document No. 7)." 149p., April.

Oregon Dept. of Environmental Quality (ODEQ). 2014b. "Chemical Waste Management of the Northwest, Inc. Landfill Design and Operations Plan (Revision 8) (Standalone Document No. 14)." 46p., October.

Oregon Dept. of Environmental Quality (ODEQ). 2016. "Closure/Post-Closure Plan For Chemical Waste Management of the Northwest, Inc. Arlington Facility - ORD 089 452 353, 17629 Cedar Springs Lane, Arlington, Oregon (Attachment Document No. 5)." 28p., April 14.

Oregon Dept. of Environmental Quality (ODEQ). 2017. "Guidance for Conducting Feasibility Studies." Waste Management and Cleanup Division. 31p., December 1.

Oregon Dept. of Environmental Quality (ODEQ). 2019. "Ground Water Monitoring Plan For Chemical Waste Management of the Northwest, Inc. Arlington Facility - ORD 089 452 353, 17629 Cedar Springs Lane, Arlington, Oregon (Attachment No. 7) (Revised)." 38p., August.

Oregon Dept. of Environmental Quality (ODEQ). 2020a. "Department of Environmental Quality Divisions." OAR 340. Accessed on July 30, 2020 at https://secure.sos.state.or.us/oard/displayChapterRules.action.

Oregon Dept. of Environmental Quality (ODEQ). 2020b. "Solid Waste; General Provisions: Definitions." OAR 340-093-0030. Accessed on July 30, 2020 at https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=256072.

Oregon Dept. of Environmental Quality (ODEQ). 2020c. "Hazardous Substance Remedial Action Rules: Definitions." OAR 340-122-0115. Accessed on July 28, 2020 at https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=71832.

Oregon Dept. of Environmental Quality (ODEQ). 2020d. "Figure 3-1: Map Showing Locations of Waste Management Areas (WMAs) and Selah Member Groundwater Monitoring Network, Chemical Waste Management of the Northwest, Inc. (Arlington, Oregon)." In *Ground Water Monitoring Plan For Chemical Waste Management of the Northwest, Inc. Arlington Facility - ORD 089 452 353, 17629 Cedar Springs Lane, Arlington, Oregon (Attachment No. 7) (Revised).* 1p., March 22.

Oregon Dept. of Transportation (ODOT). 2019. "City boundaries for the state of Oregon." December 4. Accessed on July 12, 2020 at ftp://ftp.odot.state.or.us/tdb/trandata/GIS_data/Boundaries/

Oregon State Legislature. 2019. "Hazardous Waste and Hazardous Materials II: Storage, treatment and disposal of hazardous waste and PCB." ORS 466. Accessed on July 30, 2020 at https://www.oregonlegislature.gov/bills_laws/ors/ors466.html.

Oregon State Legislature. 2020a. "Regulation of Energy Facilities: Radioactive waste disposal facilities prohibited." ORS 469.525. Accessed on July 30, 2020 at https://www.oregonlaws.org/ors/469.525.

Oregon State Legislature. 2020b. "Solid Waste Management: Definitions for ORS 459.005 to 459.437, 459.705 to 459.790 and 459A.005 to 459A.665." ORS 459.005. Accessed on July 30, 2020 at https://www.oregonlaws.org/ors/459.005.

Oregon State Legislature. 2020c. "Hazardous Waste and Hazardous Materials I; Removal or Remedial Action: Definitions for ORS 465.200 to 465.545." ORS 465.200. Accessed on July 30, 2020 at https://www.oregonlaws.org/ors/465.200.

Oregon Water Resources Dept. (OWRD). 2020. "Oregon well search." Accessed on July 6 2020 at https://apps.wrd.state.or.us/apps/gw/well_log/Default.aspx.

Perma-Fix Environmental Services. 2020. "Radiological Monitoring Plan, Chemical Waste Management, Inc., Arlington, Oregon (PF-CWM-RMP, Rev. 0)." Report to Chemical Waste Management, Arlington, OR. Submitted to Oregon Dept. of Environmental Quality (ODEQ). 43p., August.

R.S. Means Co. 2019. *2020 Heavy Construction Costs Book with RSMeans Data (34th Annual Edition).* (Ed.: Hale, Derrick), Gordian, Hingham, MA. 754p.

Risk Assessment Corp. (RAC). 2016. "Dose and Risk Assessment of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) Disposals at the Blue Ridge Landfill (Final)." Report to Advanced Disposal. 172p., October 11.

Risk Assessment Corp. (RAC). 2020a. "Final Report, CWMNW Arlington, OR: Chemical Waste Management of the Northwest, Inc. Landfill Radiological Dose and Risk Assessment for Bakken Oilfield Waste Disposals in Arlington, OR." Report to Waste Management, Inc. Submitted to Oregon Dept. of Environmental Quality (ODEQ). 100p., September 1.

Risk Assessment Corp. (RAC). 2020b. Technical Memorandum, CWMNW Arlington, OR: Analysis of Leachate Management Practices for the Chemical Waste Management of the Northwest Facility in Arlington, OR. Report to Waste Management, Inc. 42p., May 29.

Risk Assessment Corp. (RAC). 2020c. Technical Memorandum, CWMNW Arlington, OR: Overview of Geology and Hydrology at the Chemical Waste Management Site and Approach to Groundwater Pathway Modeling for the Bakken Oilfield Waste Disposals. Report to Waste Management, Inc. Submitted to Oregon Dept. of Energy (ODOE). 18p., April 30.

Rogers Surveying Inc., P.S. (RSI). 2020. "Asbuilt Survey, Chemical Waste Management of the Northwest Storm System Improvements." Report to Chemical Waste Management of the Northwest, Inc. 1p., April 23.

Rogers, K. 2016. "A year after fiery accident at radioactive waste dump in Nevada, the meter is running on a fix." *Las Vegas Rev. J.* October 23. Accessed on July 9, 2020 at https://www.reviewjournal.com/local/local-nevada/a-year-after-fiery-accident-at-radioactive-waste-dump-in-nevada-the-meter-is-running-on-a-fix/

RUST Environment & Infrastructure. 1998. "Hydrogeologic Investigation and Engineering Design Report for Landfill L-14, Arlington, Oregon (Excerpt)." Report to Waste Management, Inc. 6p., February.

US Census Bureau (USCB). 2019. "Roads TIGER/Line shapefiles (United States)." Accessed on July 12, 2020 at https://www2.census.gov/geo/tiger/TGRGDB19/

US Chemical Safety and Hazard Investigation Board (US CSB). 2008. "Case Study: Fire and Community Evacuation in Apex, North Carolina." 2007-01-I-NC, 14p., April 16. Accessed on July 28, 2020 at https://www.csb.gov/assets/1/20/eqfinalreport.pdf?13733.

US Dept. of Commerce. 2020. "Summary of Monthly Normals 1981-2010 (Arlington, OR US USC00350265)" National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data, and Information Service (NESDIS). 4p. Accessed on July 2, 2020 at https://www.ncdc.noaa.gov/cdo-web/datatools/normals.

US Dept. of Labor. 2018a. "Table R100. Incidence rates for nonfatal occupational injuries and illnesses involving days away from work per 10,000 full-time workers by occupation and selected events or exposures leading to injury or illness, private industry, 2018." Bureau of Labor Statistics. Accessed on July 12, 2020 at https://www.bls.gov/iif/soii-data.htm/

US Dept. of Labor. 2018b. "Table R72. Incidence rates for nonfatal occupational injuries and illnesses involving days away from work per 10,000 full-time workers by nature of injury or illness and industry sector, private industry, 2018." Bureau of Labor Statistics. Accessed on July 12, 2020 at https://www.bls.gov/iif/soii-data.htm/

US Dept. of Labor. 2018c. "Hours-based fatal injury rates by industry, occupation, and selected demographic characteristics, 2018." Bureau of Labor Statistics. Accessed on July 1, 2020 at https://www.bls.gov/iif/oshcfoi1.htm#rates.

US Dept. of Transportation (US DOT). 2019. "Large Truck and Bus Crash Facts 2017." Federal Motor Carrier Safety Administration, Analysis Division. FMCSA-RRA-18-018, 118p., May.

US EPA. 1987. "National Priorities List for uncontrolled hazardous waste sites; Final Rule and Proposed Rule concerning federal facility sites (40 CFR 300)." *Fed. Reg.* 52(140):27620-27042. July 22.

US EPA. 1988. "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (Interim final)." Office of Emergency and Remedial Response. OSWER Directive 9335.3-01, EPA-540/G-89-004, 186p., October.

US EPA. 1989. "The Feasibility Study: Development and Screening of Remedial Action Alternatives." Office of Solid Waste and Emergency Response (OSWER). OSWER Directive 9355.3-01FS3, 4p., November. Accessed on June 23, 2016 at https://semspub.epa.gov/work/HQ/174411.pdf.

US EPA. 1990a. "A Guide to Selecting Superfund Remedial Actions." Office of Solid Waste and Emergency Response (OSWER). OSWER Directive 9355.0-27FS, 6p., April.

US EPA. 1990b. "National Oil and Hazardous Substances Pollution Contingency Plan; Final rule." *Fed. Reg.* 55(46):8666-8865. March 8.

US EPA. 1991. "Role of the baseline risk assessment in Superfund remedy selection decisions." Office of Solid Waste and Emergency Response (OSWER). National Technical Information Service (NTIS). OSWER Directive 9355.0-30, NTIS PB91-92139, 10p., April 22.

US EPA. 1993. "Corrective action management unit and temporary units; corrective action provisions under Subtitle C [40 CFR Part 264 RCRA Corrective Action/CAMUs] (Final)." *Fed. Reg.* 58:8658-8685. February 16.

US EPA. 1995. Memorandum to EPA Regional Directors re: Land use in the CERCLA remedy selection process. Office of Solid Waste and Emergency Response (OSWER). OSWER Directive No. 9355.7-04. 11p., May 25.

US EPA. 1996. "The Role of Cost in the Superfund Remedy Selection Process." Office of Solid Waste and Emergency Response (OSWER). EPA 540/F-96/018, PB96-963245, 8p., September.

US EPA. 1997. Memorandum to National Superfund Policy Managers, et al. re: Establishment of cleanup levels for CERCLA sites with radioactive contamination. Office of Solid Waste and Emergency Response (OSWER). OSWER No. 9200.4-18, 20p., August 22.

US EPA. 1999. "Report on Emergency Incidents at Hazardous Waste Combustion Facilities and Other Treatment, Storage, and Disposal Facilities (TSDFs)." Office of Solid Waste and Emergency Response (OSWER), Permits and Programs Division. EPA530-R-99-014, 48p., June.

US EPA. 2000. Memorandum to National Superfund Policy Managers, Regions 1-10, et al. re: Headquarters consultation for radioactively contaminated sites. Office of Solid Waste and Emergency Response (OSWER). OSWER No. 9200.1-33P, 4p., July 26.

US EPA. 2001. "Risk Assessment Guidance for Superfund (RAGS). Volume I: Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments) (Final)." Office of Emergency and Remedial Response. Publication 9285.7-47, 76p., December. http://www.epa.gov/oswer/riskassessment/ragsd/tara.htm.

US EPA. 2006. "In Situ Treatment Technologies for Contaminated Soil: Engineering Forum Issue Paper." Office of Solid Waste and Emergency Response (OSWER). EPA 542/F-06/013, 35p., November.

US EPA. 2010. "Superfund Remedy Report [formerly Treatment Technologies for Site Cleanup: Annual Status Report] (Thirteenth Edition)." Office of Solid Waste and Emergency Response (OSWER). EPA-542-R-10-004, 144p., September. Accessed on October 01, 2010 at http://clu-in.org/asr/

US EPA. 2017. "Discarded commercial chemical products, off-specification species, container residues, and spill residues thereof." 40 CFR 261.33. 22p.

US EPA. 2020. "Defining hazardous waste: Listed, characteristic and mixed radiological wastes." Accessed on July 6, 2020 at https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes.

US EPA; US Army Corps of Engineers (US ACE). 2000. "A Guide to Developing and Documenting Cost Estimates During the Feasibility Study." Office of Emergency and Remedial Response. EPA 540-R-00-002, OSWER 9355.0-75, 82p., July.

US Geological Survey (USGS). 2019. "USGS National Hydrography Dataset (NHD) for the State of Oregon." April 17. Accessed on July 12, 2020 at ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Hydrography/NHD/State/HighResolution/GDB/

US Navy, Naval Facilities Engineering Command (NAVFAC); US Army Corps of Engineers (US ACE); Battelle Memorial Institute. 2013. "SiteWise(TM) Version 3 User Guide." UG-NAVFAC-EXWC-EV-1302, 92p., July.

Washington State Dept. of Ecology (WA Ecology). 2019. "Dangerous fire on Tacoma tideflats leads to $1.9 million fine." October 7. Accessed on July 28, 2020 at https://ecology.wa.gov/About-us/Get-to-know-us/News/2019/Dangerous-fire-on-Tacoma-tideflats-leads-to-$1-9-m.

Waste Management, Inc. 2020a. "Waste locations (Final)." May 8.

Waste Management, Inc. 2020b. "L-14 Fill Grid (Current Survey), Chem Waste Landfill, Arlington, Oregon." OR02-2236-3DM-01, 1p., March.

Tables

Table 2.3 Bakken Oilfield Waste Placed in Landfill L-14

Date Placed	Load/ Receipt	Weight	Estimated Waste Depth from Existing Grade[1]
--	--	(lb)	(ft)
05/02/16	446720	32,100	30.6
05/10/16	446836	43,620	37.6
05/18/16	446973	27,860	48.5
05/18/16	446981	19,020	48.5
05/24/16	447048	21,760	32.0
05/24/16	447063	21,560	33.8
06/27/16	447567	42,200	19.7
08/01/16	448100	40,140	17.7
09/20/16	449003	33,380	31.5
10/24/16	449661	37,320	21.7
11/28/16	450407	44,860	6.8
01/30/17	451339	39,800	32.5
02/27/17	451839	32,300	34.5
03/27/17	452330	36,960	22.3
04/17/17	452734	36,340	15.8
05/15/17	453308	34,180	22.5
06/06/17	453727	40,280	18.0
07/11/17	454308	39,860	17.6
07/24/17	454766	42,380	16.7
08/21/17	455472	42,360	16.5
09/18/17	456152	44,820	16.5
10/09/17	456853	43,960	42.0
11/27/17	458207	42,340	36.6
12/18/17	458784	41,760	41.3
01/16/18	459385	43,440	32.1
02/12/18	459976	37,120	26.9
03/05/18	460416	40,040	23.5
04/02/18	460955	48,180	40.4
04/27/18	461637	41,140	18.5
05/03/18	461767	38,900	34.7
05/25/18	462320	42,560	16.1
06/25/18	462864	42,140	19.5
07/19/18	463439	37,780	9.6
07/24/18	463561	35,280	19.1
08/14/18	463953	42,660	10.9
08/29/18	464319	44,960	10.1
09/10/18	464549	42,120	11.1
09/24/18	464843	47,280	11.6
10/01/18	465009	42,300	10.7
10/19/18	465444	40,160	15.3
11/05/18	465769	38,040	13.0
11/12/18	465882	41,540	14.1
12/10/18	466397	41,480	10.7
01/07/19	466988	44,140	8.6
01/14/19	467191	41,620	17.5
01/18/19	467337	43,080	8.5

Date Placed	Load/ Receipt	Weight	Estimated Waste Depth from Existing Grade[1]
--	--	(lb)	(ft)
03/06/19	468237	39,520	14.0
03/12/19	468343	44,640	14.0
03/18/19	468470	45,520	10.5
04/02/19	468809	43,620	8.7
04/22/19	469235	40,840	23.3
04/29/19	469421	47,640	25.7
05/06/19	469607	45,260	23.1
05/13/19	469770	46,440	26.2
05/20/19	469947	43,620	26.5
05/28/19	470097	44,380	26.5
06/18/19	470644	43,460	26.5
06/24/19	470788	35,880	21.7
07/15/19	471276	41,940	19.0
07/29/19	471601	43,360	18.6
08/05/19	471743	41,780	19.5
09/03/19	472261	40,300	13.1
09/09/19	472369	40,780	12.7
09/16/19	472510	43,220	19.5
	Sum (lb)	**2,569,320**	
	Sum (tons)	**1,284.66**	

Note:

(1) Based on existing landfill grade surveyed on February 20, 2020.

Table 4.2 Preliminary Screening of Remediation Technologies

Medium	General Response Category	Process/Technology	Description	Retained as Viable Option?	Effectiveness	Implementability	Cost
Bakken Oilfield Waste	Current Landfill Operations (containment and monitoring)	Institutional and Engineering Controls	Operational and post-closure monitoring consistent with existing landfill operating and closure permit.	Yes	Effective: Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2020a). Containment (liner and cap) and monitoring are already required by the facility's operating and closure permit.	Readily implementable: No additional actions required in respect to Bakken oilfield waste.	Low incremental cost.
	In Situ Stabilization	*In Situ* Stabilization	*In situ* blending of cement and source material to immobilize source material and minimize the generation of leachate.	No	Highly ineffective: Likely to mobilize or bring to the surface Bakken oilfield waste and hazardous waste, increasing potential worker exposure. Likely to increase the mobility and exposure risk of other hazardous waste materials buried above Bakken oilfield waste. Will comingle stabilized hazardous wastes and rupture waste storage containers, and may cause dangerous chemical reactions (*e.g.* , fire, explosion, off-gassing).	Not Implementable: Drilling through hazardous waste overlying the Bakken oilfield waste is extremely dangerous, if even possible. The overburden is heterogeneous, containing drums and macro boxes. Drilling into the landfill (if possible) poses high risks to the engineered liner and leachate extraction system.	Very high: The base technology unit cost is relatively high, and further considering the Implementability issues and required safety and precautionary measures, the actual cost at a hazardous waste landfill would be very high.
	Excavate and Redispose	Excavation and Off-Site Disposal	Removal and off-Site disposal of Bakken oilfield waste.	Yes	Effective: Reduces contaminant mass flux into landfill leachate. Removes radon source.	Low Implementability: The implementation of this technology involves excavating, loading, and transporting the buried waste to another landfill for redisposal. This operation requires heavy machinery and traffic, both on-Site and off-Site. It will increase the chemical exposure from the waste materials brought to the surface for the workers at the Site and the risk of physical injury and fatality due to accidents (both for workers and in the community), and increases radiological exposures for workers and for the public along the haul route.	Very high: Given the volume of the overburden that needs to be displaced and the required safety measures, the cost would be prohibitive.
Surface Water and Groundwater	Current Landfill Operations (containment and monitoring)	Institutional and Engineering Controls	Operational and post-closure monitoring consistent with existing landfill operating and closure permit.	Yes	Effective: Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2020a). Groundwater monitoring plan is already implemented, and a leak detection system is installed as required by facility's operating and closure permit. The facility is located in a semiarid climate, and the closest permanent surface water body is approximately 7 miles away; surface water is not an exposure pathway.	Readily implementable: Groundwater monitoring plan has been previously developed and implemented. Radionuclides analysis must be added to the monitoring plan.	Low
	Physical Containment	Low-permeability Cap	Containment of source areas *via* a low-permeability cap to limit infiltration of water.	No	Similar or lower effectiveness compared to the containment and monitoring remediation alternative; all permit requirements are in common between the two remediation alternatives, but this alternative does not include radionuclides monitoring in groundwater. Additionally, low infiltration and high ET limit the potential efficacy of a low-permeability cap.	No additional action required; there is currently a dual-liner system in place as part of the facility's operating and closure permit requirements.	Medium
	Monitored Natural Attenuation (MNA)	Sampling and Chemical Analysis	Monitoring dissolved-phase contamination in groundwater to ensure long-term protectiveness.	No	Effective: Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2020a).	Readily implementable: Groundwater monitoring plan has been previously developed and implemented. Radionuclides analysis must be added to the monitoring plan. Adding radionuclides to the groundwater monitoring plan makes this remediation alternative the same as containment and monitoring remediation alternative.	Low

Medium	General Response Category	Process/Technology	Description	Retained as Viable Option?	Effectiveness	Implementability	Cost
Gas (Radon)	Current Landfill Operations (containment and monitoring)	Institutional and Engineering Controls	Operational and post-closure monitoring consistent with existing landfill operating and closure permit.	Yes	Effective: Radiation doses are well below the level at which potential health effects may be observed. Risks are well within acceptable ranges (RAC, 2020a). Bakken oilfield waste will be buried - on average - by approximately 100 feet of waste and HDPE macro boxes, further reducing radon flux.	Readily implementable: No additional actions required in respect to Bakken oilfield waste.	Low
	Physical Containment	Vapor Barrier	Containment of source areas *via* a low-permeability vapor barrier to reduce radon flux.	No	Effective: Reduces radon mass flux.	Limited implementable: Installing a vapor barrier will interfere with existing landfill operations. Construction activity in the landfill poses high risks of exposure to hazardous waste to workers.	Medium
	Monitored Natural Attenuation (MNA)	Sampling and Chemical Analysis	Monitoring for radon levels to ensure long-term protectiveness.	No	Effective: Could ensure long-term protectiveness.	Limited implementable: Elevated local background radiation will likely lead to false positives in sample results.	Medium

Notes:

ET = Evapotranspiration; HDPE = High-density Polyethylene.

Table 4.3 Bakken Oilfield Waste Volume

Load/ Receipt	Weight	Date Placed	Estimated Bottom of Waste Elevation[1]	Estimated Bakken Waste Volume (V_{Bakken})	Estimated Bakken Mixed Waste Volume (V_{mx})
--	lbs	--	ft msl NAVD-88	yd^3	yd^3
446720	32,100	05/02/16	1,026.5	11	32
446836	43,620	05/10/16	1,033.5	15	44
446973	27,860	05/18/16	1,033.5	9	28
446981	19,020	05/18/16	1,033.5	6	19
447048	21,760	05/24/16	1,033.5	7	22
447063	21,560	05/24/16	1,033.5	7	22
447567	42,200	06/27/16	1,040.5	14	43
448100	40,140	08/01/16	1,033.5	14	41
449003	33,380	09/20/16	1,040.5	11	34
449661	37,320	10/24/16	1,040.5	13	38
450407	44,860	11/28/16	1,040.5	15	45
451339	39,800	01/30/17	1,047.5	13	40
451839	32,300	02/27/17	1,047.5	11	33
452330	36,960	03/27/17	1,047.5	12	37
452734	36,340	04/17/17	1,052.5	12	37
453308	34,180	05/15/17	1,059.5	12	35
453727	40,280	06/06/17	1,062.0	14	41
454308	39,860	07/11/17	1,059.5	13	40
454766	42,380	07/24/17	1,060.5	14	43
455472	42,360	08/21/17	1,065.5	14	43
456152	44,820	09/18/17	1,065.5	15	45
456853	43,960	10/09/17	946.0	15	44
458207	42,340	11/27/17	946.0	14	43
458784	41,760	12/18/17	946.0	14	42
459385	43,440	01/16/18	949.5	15	44
459976	37,120	02/12/18	956.5	12	37
460416	40,040	03/05/18	956.5	13	40
460955	48,180	04/02/18	956.5	16	49
461637	41,140	04/27/18	963.5	14	42
461767	38,900	05/03/18	963.5	13	39
462320	42,560	05/25/18	970.5	14	43
462864	42,140	06/25/18	977.5	14	43
463439	37,780	07/19/18	977.5	13	38
463561	35,280	07/24/18	977.5	12	36
463953	42,660	08/14/18	977.5	14	43
464319	44,960	08/29/18	977.5	15	45
464549	42,120	09/10/18	984.5	14	43
464843	47,280	09/24/18	984.5	16	48
465009	42,300	10/01/18	984.5	14	43
465444	40,160	10/19/18	991.5	14	41
465769	38,040	11/05/18	991.5	13	38
465882	41,540	11/12/18	991.5	14	42
466397	41,480	12/10/18	998.5	14	42

Load/ Receipt	Weight	Date Placed	Estimated Bottom of Waste Elevation[1]	Estimated Bakken Waste Volume (V_{Bakken})	Estimated Bakken Mixed Waste Volume (V_{mx})
--	lbs	--	ft msl NAVD-88	yd^3	yd^3
466988	44,140	01/07/19	998.5	15	45
467191	41,620	01/14/19	998.5	14	42
467337	43,080	01/18/19	998.5	15	44
468237	39,520	03/06/19	1,002.0	13	40
468343	44,640	03/12/19	1,002.0	15	45
468470	45,520	03/18/19	1,005.5	15	46
468809	43,620	04/02/19	1,005.5	15	44
469235	40,840	04/22/19	960.0	14	41
469421	47,640	04/29/19	956.5	16	48
469607	45,260	05/06/19	956.5	15	46
469770	46,440	05/13/19	956.5	16	47
469947	43,620	05/20/19	963.5	15	44
470097	44,380	05/28/19	963.5	15	45
470644	43,460	06/18/19	963.5	15	44
470788	35,880	06/24/19	963.5	12	36
471276	41,940	07/15/19	963.5	14	42
471601	43,360	07/29/19	963.5	15	44
471743	41,780	08/05/19	970.5	14	42
472261	40,300	09/03/19	970.5	14	41
472369	40,780	09/09/19	970.5	14	41
472510	43,220	09/16/19	970.5	15	44
Volume in-place				865	2,595
Volume after excavation				1,081	3,244

Notes:

lbs = Pounds; msl NAVD-88 = Mean Sea Level NAVD-88; yd^3 = cubic yards.

(1) Based on existing landfill grade surveyed on February 20, 2020.

Table 7.1 Comparative Analysis of the Remediation Alternatives

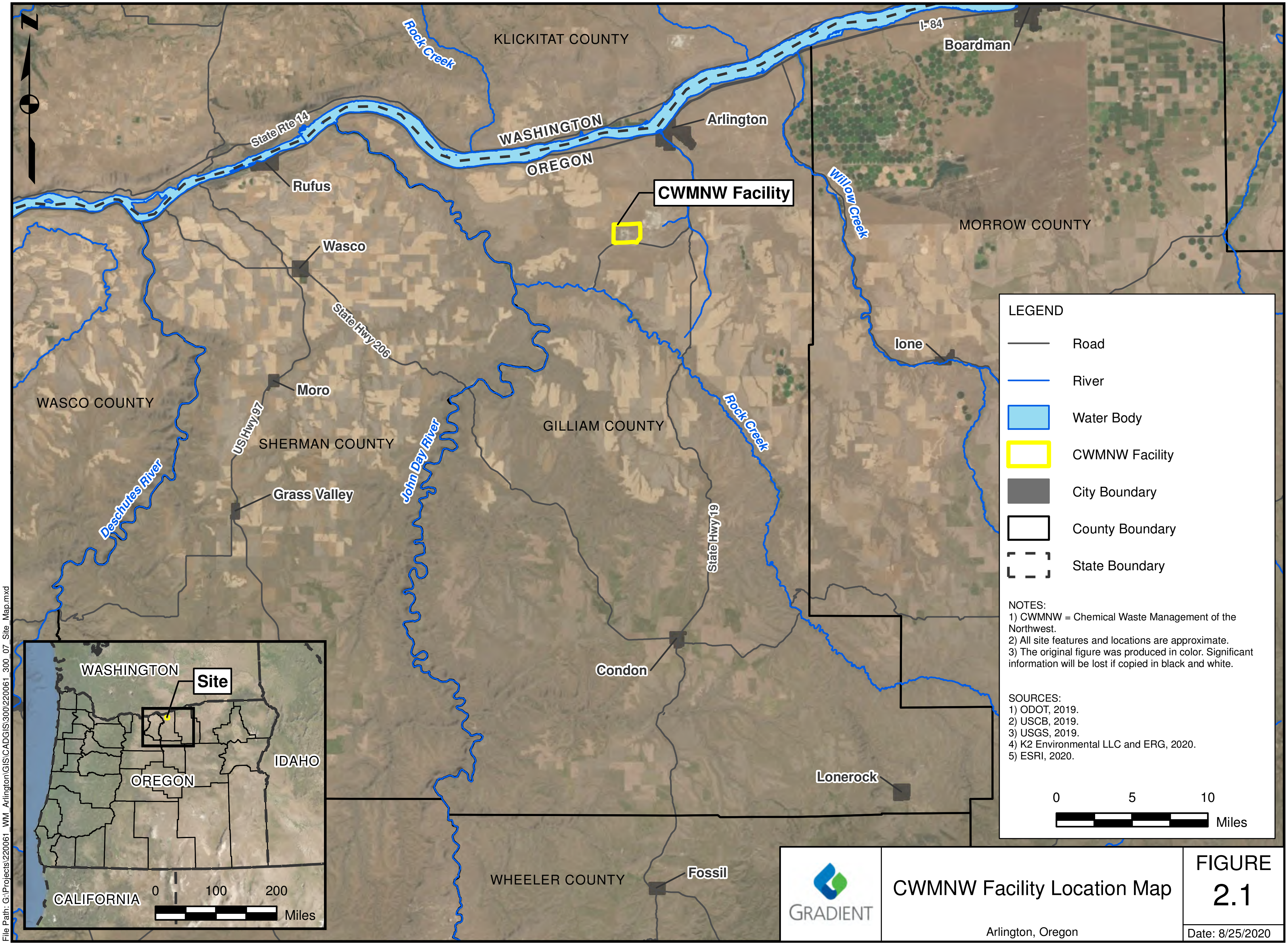
Evaluation Criteria	**Remediation Alternative 1: Closure-in-Place and Monitoring**	**Remediation Alternative 2: Excavate and Redispose Bakken Oilfield Waste**
Overall Protection of Human Health and the Environment	High – There are no unacceptable human health risks from exposure to the Bakken oilfield waste based on current and future exposures (see RAC, 2020a).	Low – There are no unacceptable human health risks from exposure to the Bakken oilfield waste based on current and future exposures (see RAC, 2020a). Excavating, transporting, and redisposing of the Bakken oilfield waste would create additional physical, chemical, and radiological risks.
Long-term Effectiveness and Permanence	Moderate – The existing containment system (liners and leachate collection system) effectively controls leachate release, and the required post-closure cap would minimize leachate generation after closure.	Moderate – At the CWMNW facility, removal of material would decrease contaminant flux to leachate and soil vapors over time, thus enhancing the long-term attenuation and stability of impacts to both media and decreasing long-term risks associated with exposure to Bakken oilfield waste-related constituents. However, relocating the Bakken oilfield waste to a different landfill would pose concerns regarding long-term effectiveness that are similar to those posed by the CWMNW facility.
Reduction of Toxicity, Mobility, and Volume (TMV) Through Treatment	Moderate – Reduces the potential environmental mobility of the Bakken oilfield waste by containing it through a combined liner/cap/leachate extraction system at the CWMNW facility. Volume and toxicity are not reduced, although exposure is mitigated.	Moderate – Reduces the potential environmental mobility of the Bakken oilfield waste by containing it through a combined liner/cap/leachate extraction system at a different landfill. Volume and toxicity are not reduced, although exposure is mitigated. Bakken oilfield waste volume would increase *ex situ via* excavation.
Short-term Effectiveness	High – Minimal incremental remedy risks from implementing this alternative.	Low – There are physical, chemical, and radiological risks to workers and the community from implementing this alternative. There will also be greater short-term impacts, disruptiveness, and inconvenience for the communities associated with heavy truck traffic and noise, emissions, and accident risks. There will be increased environmental impacts (*e.g.*, air impacts, GHG emissions) relative to Remediation Alternative 1.
Implementability	High – The technologies are available, and qualified contractors are in place to perform the work. Regulatory approval is required to leave the buried Bakken oilfield waste in place.	Low – There are significant implementability challenges associated with a major excavation in an active hazardous waste landfill and hauling the Bakken oilfield waste hundreds of miles to a different facility for redisposal.
Cost	Low – Low incremental costs are required for additional radionuclide sampling. Low cost uncertainty.	High – Significant capital costs for excavation, transport, and redisposal of the Bakken oilfield waste. High cost uncertainty.
Conclusion	This alternative was selected because it provides a high degree of overall protectiveness, poses the lowest short-term physical and radiological exposure-related risks to workers and the community, and provides long-term effectiveness and protectiveness while also being cost-effective and implementable.	This alternative was not selected because it is less protective, more costly, and less implementable, and because it poses significantly greater short-term impacts than Remediation Alternative 1.

Notes:

CWMNW = Chemical Waste Management of the Northwest; GHG = Greenhouse Gas.

Subject to regulatory approval and community acceptance.

Figures



GRADIENT

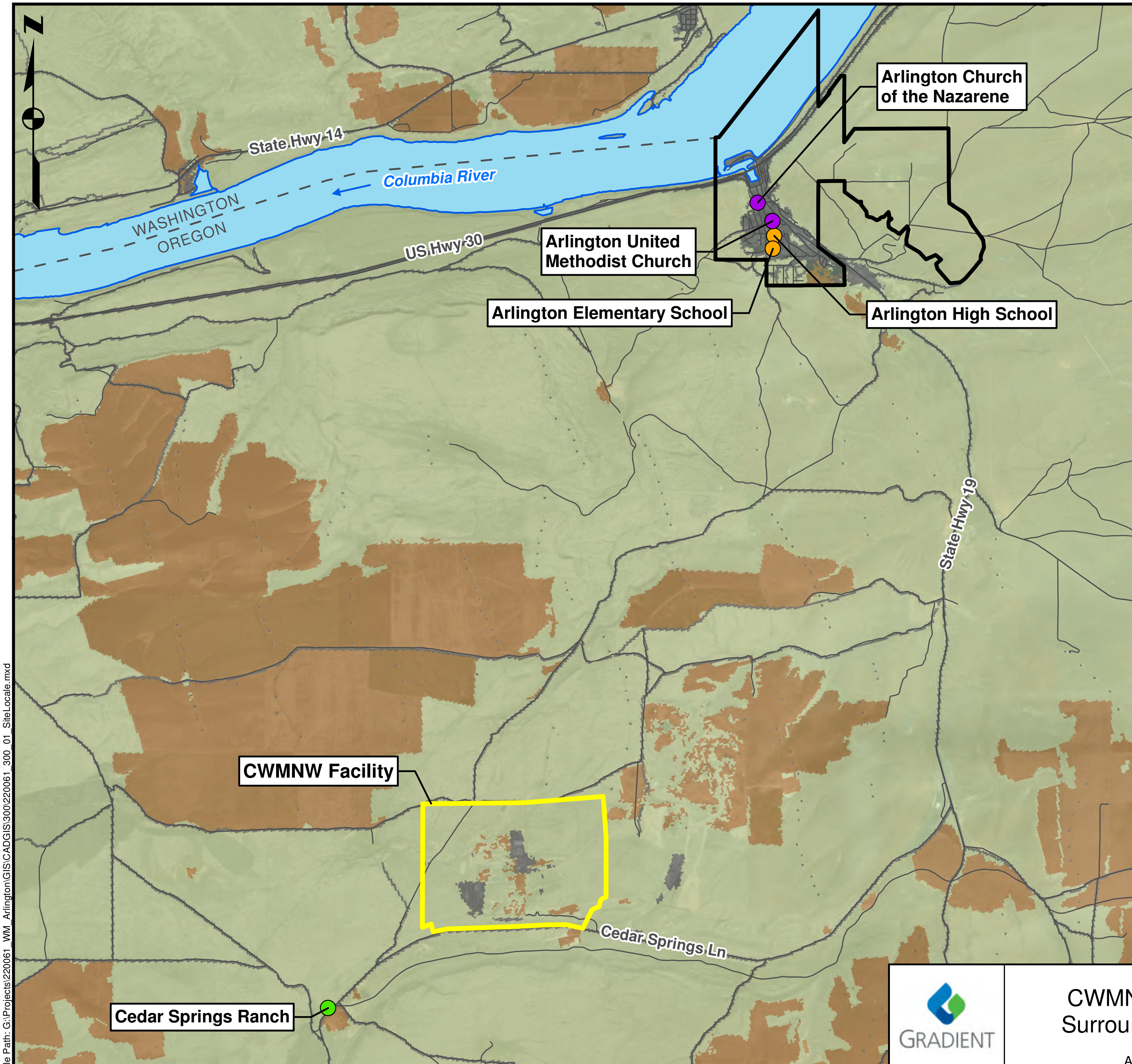
CWMNW Facility Location Map

Arlington, Oregon

FIGURE 2.1

Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_07_Site_Map.mxd



NOTES:
1) CWMNW = Chemical Waste Management of the Northwest.
2) All site features and locations are approximate.
3) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
1) MRLC, 2016.
2) ODOT, 2019.
3) USCB, 2019.
4) USGS, 2019.
5) K2 Environmental LLC and ERG, 2020.
6) ESRI, 2020.

GRADIENT

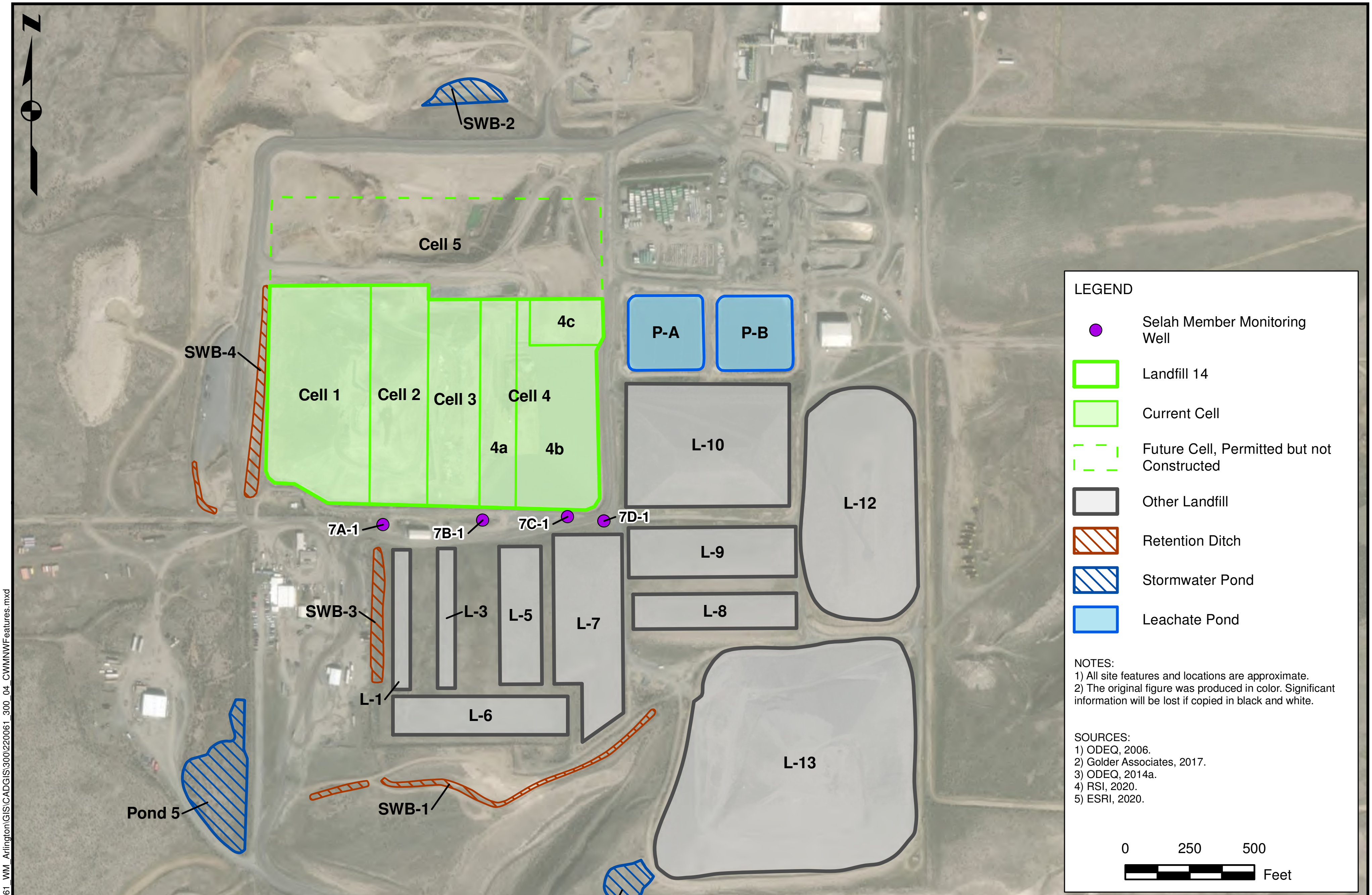
CWMNW Facility and Surrounding Land Use

Arlington, Oregon

FIGURE 2.2

Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_01_SiteLocate.mxd



GRADIENT

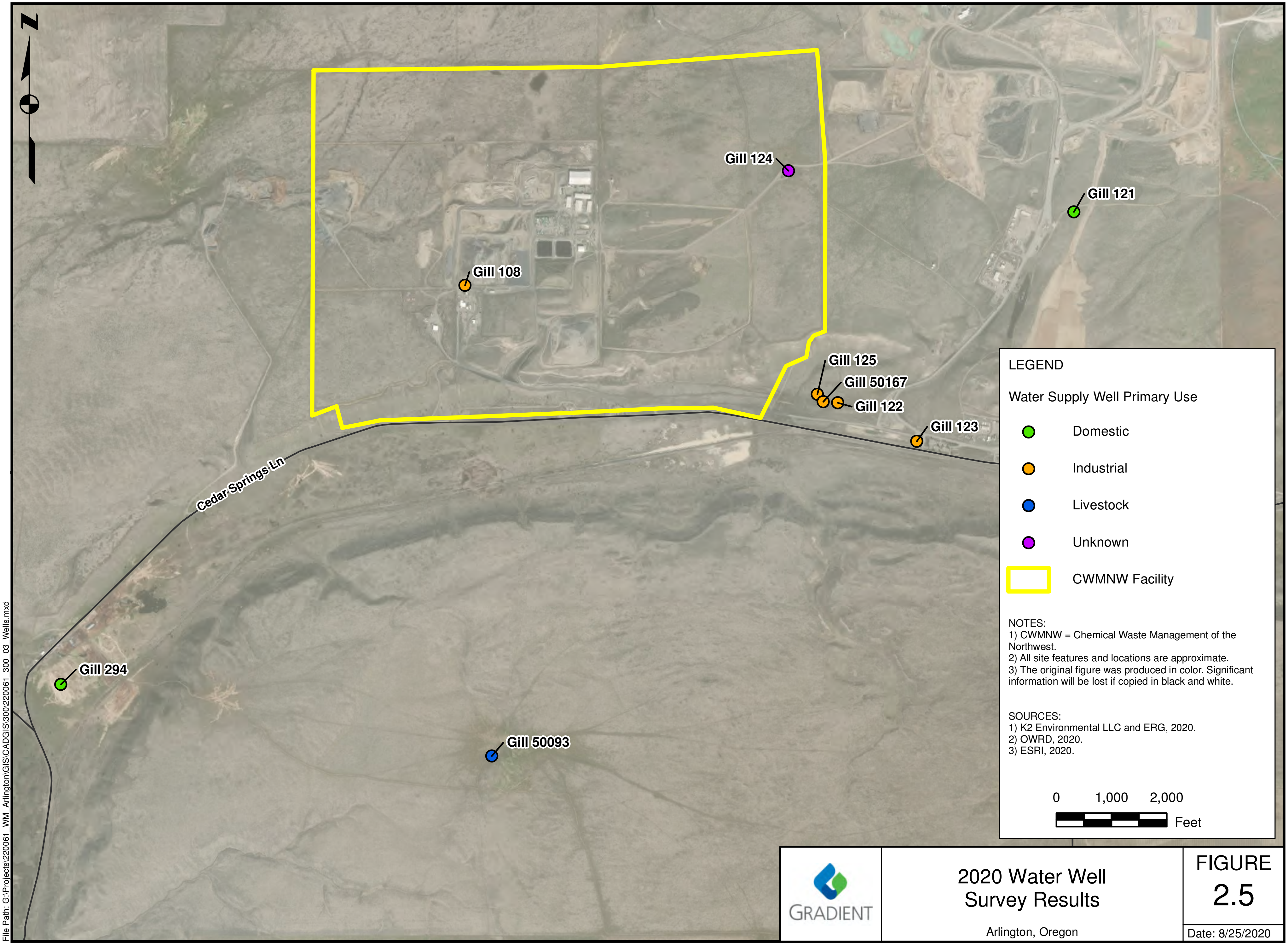
CWMNW Facility
Site Features

Arlington, Oregon

FIGURE 2.3

Date: 8/25/2020

File Path: G:\Projects\220061\CADGIS\300\220061_300_04_CWMNWFeatures.mxd



GRADIENT

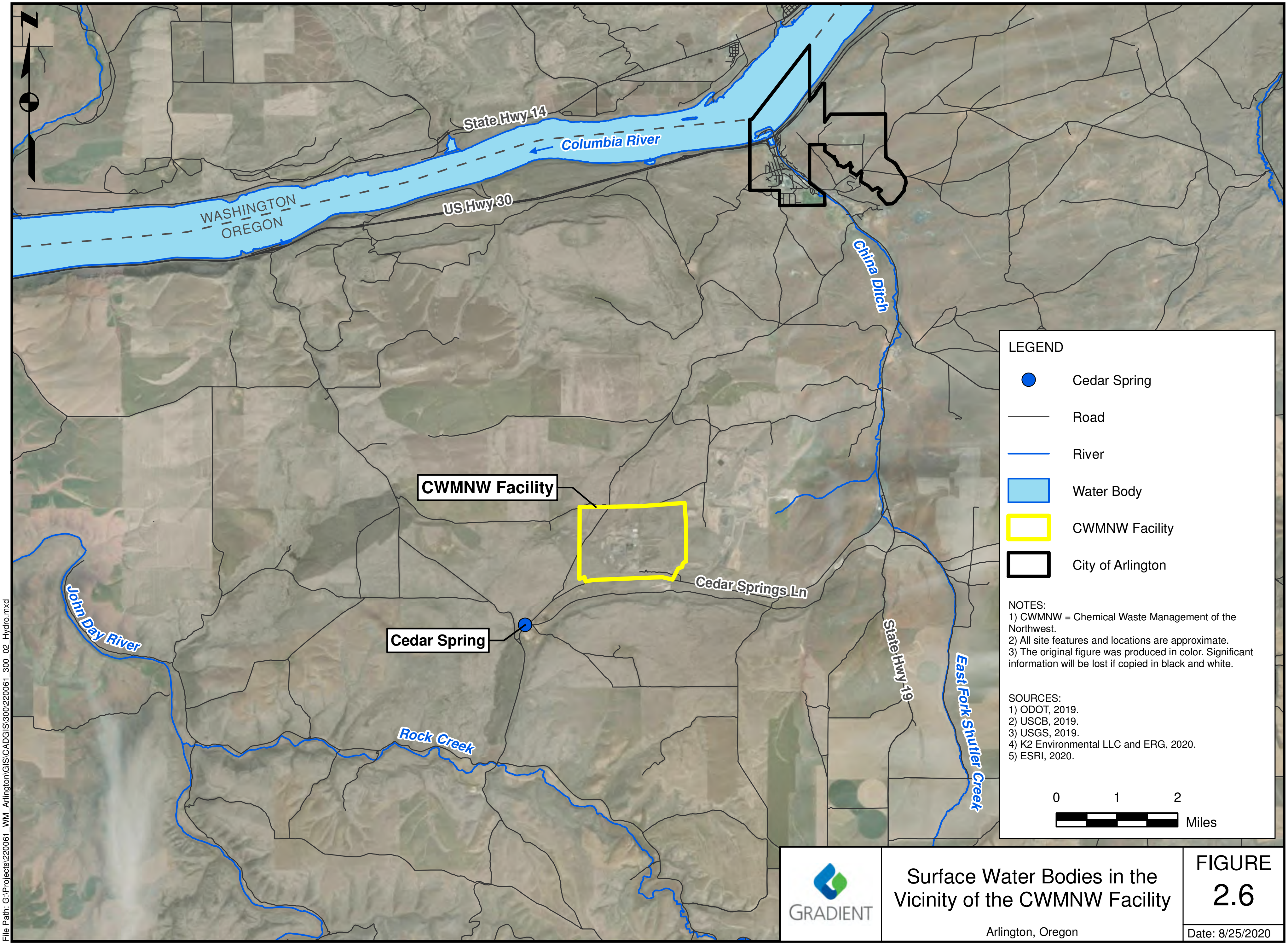
2020 Water Well Survey Results

Arlington, Oregon

FIGURE 2.5

Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_03_Wells.mxd



GRADIENT

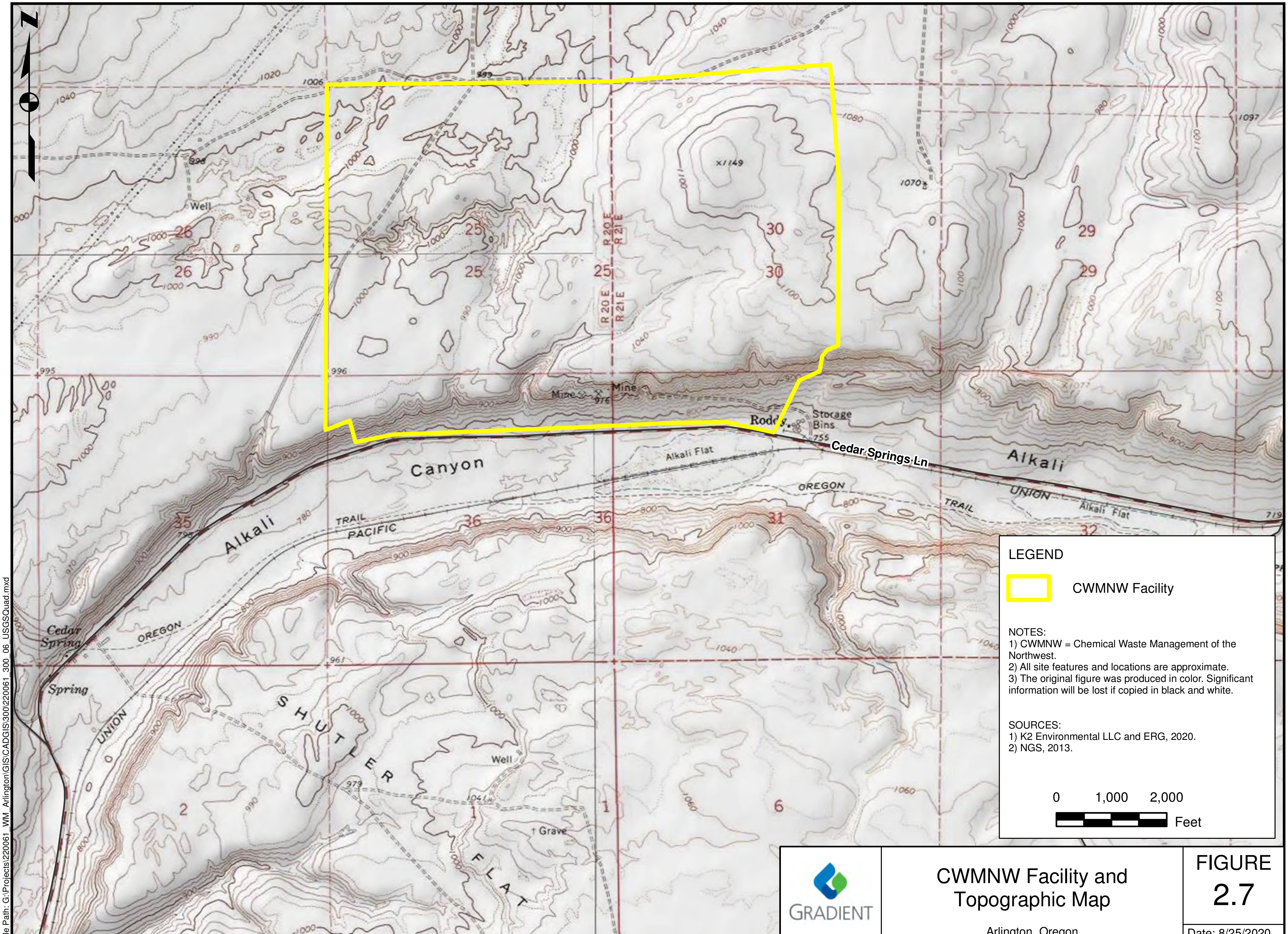
Surface Water Bodies in the Vicinity of the CWMNW Facility

Arlington, Oregon

FIGURE 2.6

Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_02_Hydro.mxd



NOTES:
1) CWMNW = Chemical Waste Management of the Northwest.
2) All site features and locations are approximate.
3) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
1) K2 Environmental LLC and ERG, 2020.
2) NGS, 2013.

GRADIENT

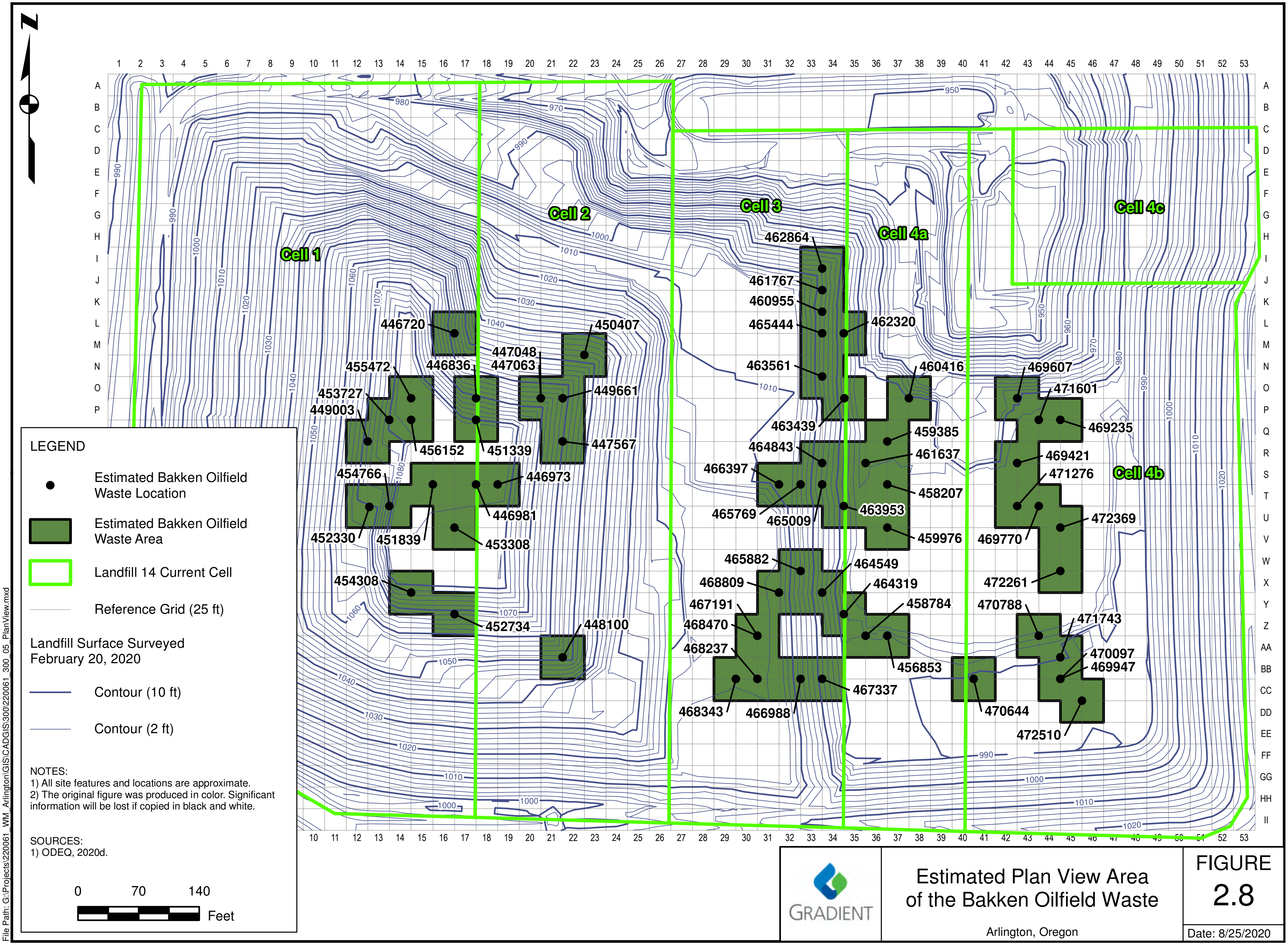
CWMNW Facility and Topographic Map

Arlington, Oregon

FIGURE 2.7

Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_06_USGSQuad.mxd

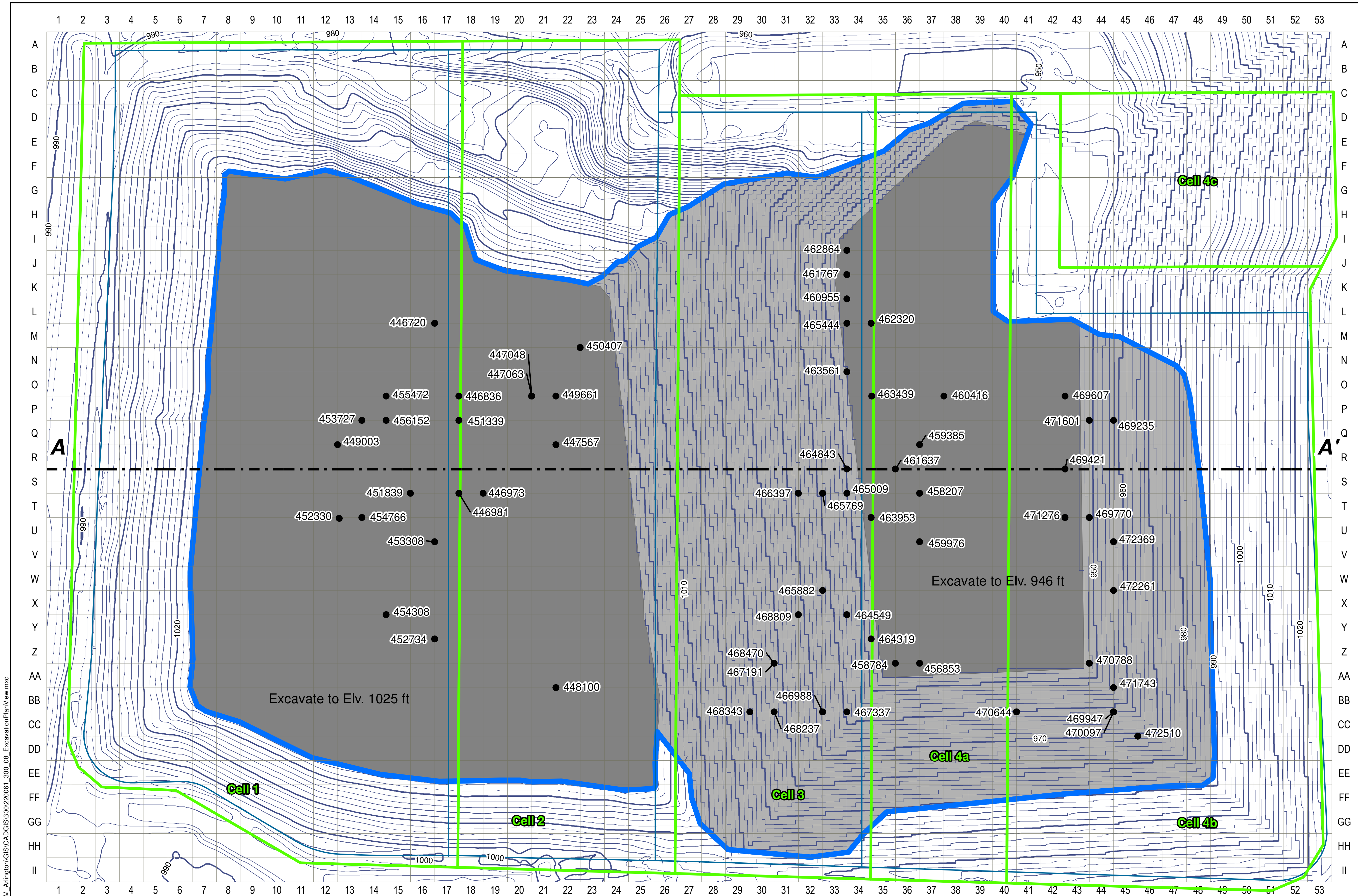


Estimated Plan View Area of the Bakken Oilfield Waste

Arlington, Oregon

FIGURE 2.8

Date: 8/25/2020



LEGEND

- ● Estimated Bakken Oilfield Waste Location
- Landfill 14 Current Cell
- Limit of Waste Excavation
- Cross-section (Figure 4.2)

Post-excavation Contour (ft MSL NAVD-88)

- Contour (2 ft)
- Contour (10 ft)

NOTES:
1) MSL = Mean Sea Level.
2) NAVD-88 = North American Vertical Datum of 1988.
3) The approximate location of each Bakken oilfield waste load within the landfill was shown on a grid node within a 25-ft by 25-ft grid provided by Waste Management. We assumed that the waste received in each load was evenly distributed across the four grid blocks adjacent to the given grid node.
4) The depth of each load was provided by Waste Management and calculated based on the difference between the placed waste grade level and the landfill grade level as of February 20, 2020.
5) All site features and locations are approximate.
6) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
1) Waste Management, Inc., 2020b.

0 50 100
Feet

GRADIENT

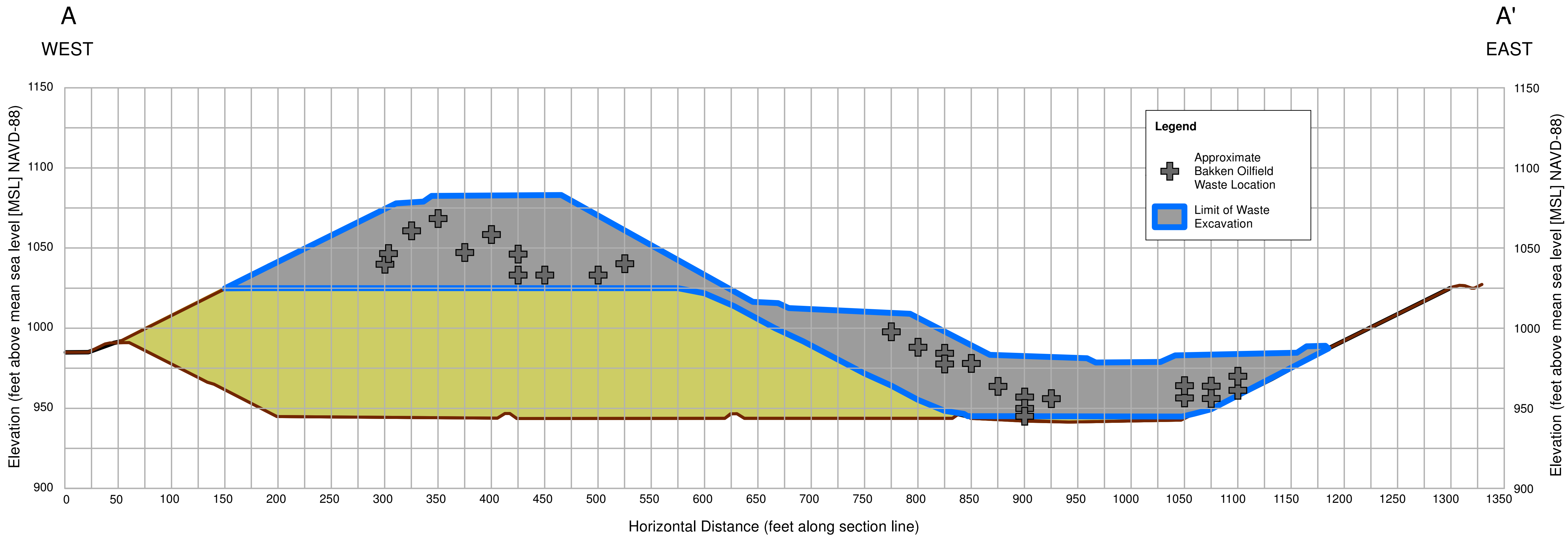
Bakken Oilfield
Waste Excavation Plan:
Post-excavation Grading

Arlington, OR

FIGURE
4.1

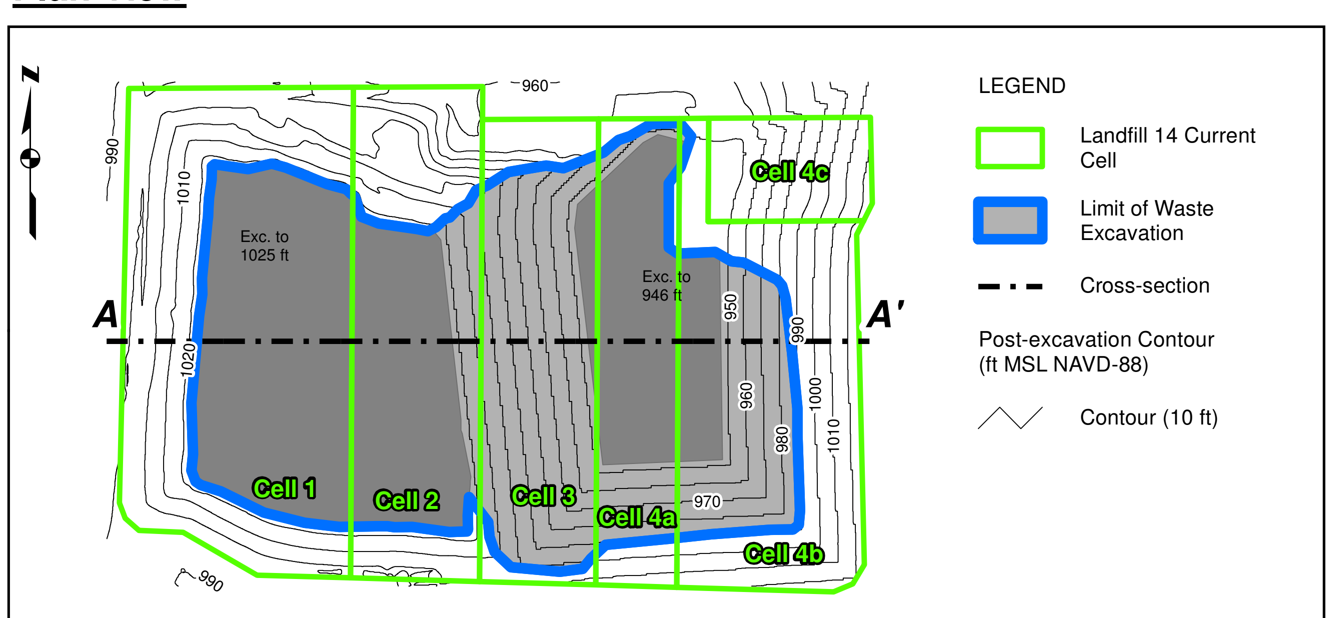
Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_08_ExcavationPlanView.mxd



Horizontal Scale: 1" = 100 ft
Vertical Scale: 1" = 66 ft

Plan View



NOTES:
1) MSL = Mean Sea Level.
2) NAVD-88 = North American Vertical Datum of 1988.
3) Cross-section A:A' based on "CWMNW Landfill 3D Model Cross-Section E-E'," Source 2.
4) The depth of each load was provided by Waste Management and calculated based on the difference between the placed waste grade level and the landfill grade level as of February 20, 2020.
5) All site features and locations are approximate.
6) The original figure was produced in color. Significant information will be lost if copied in black and white.

SOURCES:
1) Waste Management, Inc., 2020b.
2) Geosyntec Consultants, 2020.

GRADIENT

Bakken Oilfield
Waste Excavation Plan:
Cross-section A:A'

Arlington, OR

FIGURE
4.2

Date: 8/25/2020

File Path: G:\Projects\220061_WM_Arlington\GIS\CADGIS\300\220061_300_09_SectionAA.mxd

Attachment A

Key Regulatory Correspondence

Oregon
Kate Brown, Governor

OREGON DEPARTMENT OF ENERGY
550 Capitol St. NE
Salem, OR 97301
Phone: 503-378-4040
Toll Free: 1-800-221-8035
FAX: 503-373-7806
www.oregon.gov/energy

February 13, 2020

James Denson
PNW/BC Environmental Protection Manager
Waste Management
7227 NE 55th Ave
Portland, OR 97218

Mr. Denson:

Enclosed is a Notice of Violation issued to Chemical Waste Management of the Northwest, a subsidiary of Waste Management, Inc. for violations of Oregon Administrative Rules (OAR) prohibiting the disposal of radioactive materials within the state of Oregon.

As described in the Notice of Violation, the Department of Energy has determined Chemical Waste Management is in violation of OAR 345-050-0006. Chemical Waste Management has thirty (30) days from the receipt of this Notice of Violation to provide a written response to the Department with the information listed in Section V of the Notice. Please review this Notice of Violation carefully to ensure that all corrective measures are completed by the specified deadlines.

I appreciate that you met with my staff on January 24 and again on February 6 to review the facts of this case and respond fully to our inquiries. I appreciate also your openness to joining us in a public process to evaluate the safest and best path forward.

If you have any questions please contact Ken Niles, Assistant Director for Nuclear Safety, at 503-378-4960 or by e-mail at ken.niles@oregon.gov.

Sincerely,

Janine Benner
Director

CC:
Andrew Kennefick, J.D.
CT Corporation System, Registered Agent #003292-27
Patrick Rowe, Oregon Department of Justice

OREGON DEPARTMENT OF ENERGY
550 Capitol St. NE
Salem, OR 97301
Phone: 503-378-4040
Toll Free: 1-800-221-8035
FAX: 503-373-7806
www.oregon.gov/energy

	)	
In the Matter of:	)	Notice of Violation
Chemical Waste Management	)	OAR 345-050-0006
Of the Northwest, Inc.	)	
	)	
Responsible Party	)	

I. Authority

This Notice of Violation is issued by the Oregon Department of Energy (Department) pursuant to OAR 345-029-0020(1).

II. Statement of Facts & Findings

1. On September 11, 2019, the Department was made aware by a North Dakota citizen that potentially radioactive wastes from the company Goodnight Midstream, LLC were allegedly being disposed in an Oregon landfill. Goodnight Midstream provides brine water supply and recycling services to the oil and gas industry for fracking operations. The solid wastes derived from liquid management are of concern because they potentially qualify as Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) subject to the disposal prohibition in ORS 469.525 and OAR 345-050.
2. Upon receipt of the citizen notification, the Department contacted the Chemical Waste Management of the Northwest facility in Arlington, Oregon (CWM Arlington) to inquire whether they have a relationship with Goodnight Midstream. The Environmental Protection Manager from CWM Arlington promptly searched the company records and confirmed that no relationship existed. Also on September 11, the Department contacted the corporate offices of Goodnight Midstream in Texas to inquire whether the company or any of its subsidiaries were disposing of oilfield wastes in Oregon.

3. On September 13, the Department received a phone call from the Goodnight Midstream office in North Dakota, whereupon we were informed that Goodnight Midstream contracts with a Montana company named Oilfield Waste Logistics (OWL) to manage its solid wastes. Shipping manifests showed that OWL was sending Goodnight Midstream wastes to CWM Arlington. The Department contacted the CWM Arlington Environmental Protection Manager with this new information and was informed that he would investigate the matter.
4. On September 17, 2019, the CWM Arlington Environmental Protection Manager provided the Department with the Waste Profiles and associated analytical data submitted to CWM by OWL, as well as the Hazardous Waste acceptance authorization forms from Waste Management Inc. for the years 2016, 2017, and 2019, with an expiration on the latest authorization of 9/17/2019. The Environmental Protection Manager also notified the Department that acceptance of further waste from OWL was suspended until this matter was resolved.
5. Between 2016 and 2019, CWM Arlington accepted an estimated 1,284.66 tons of TENORM, the vast majority of which was subject to the disposal prohibition in ORS 469.525 and OAR 345-050-0006. This finding is based on waste documentation provided by the facility, which included the following facts:

    5.1. OWL submitted Waste Profiles and associated analytical data to CWM associated with the subject wastes. The Waste Profile document from OWL for 2016 stated, "Material meets ORD Exemptions 345-050-0025." The cited rule does not cover Radium-226 and Radium-228, which are primary constituents of concern for TENORM waste determinations. The Waste Profiles for subsequent years amend the regulatory compliance statement to include OAR 345-050-0030, which is the correct rule for pursuing a Specific Exemption for Ra-226 and Ra-228. However, the provided analytical data clearly show that the samples exceeded the concentration-based exemption limits for radium-bearing materials (less than 5 picocuries per gram of Ra-226) and thorium-bearing materials (less than 20 picocuries per gram of Ra-228). Specifically, the Ra-226 and Ra-228 concentrations for filter socks exceeded the acceptable concentrations in OAR-345-050-0030 in all three waste profiles submitted in 2016, 2017, and 2019. An email from OWL to CWM Arlington, included in the submission to the Department, indicated that approximately 80 percent of the total waste consisted of filter socks.

    5.2. No analytical data are provided for pipe scale materials listed in the Waste Management "EZ Profile" submitted by OWL. Pipe scale contains Naturally Occurring Radioactive Materials (NORM) for which the Department would normally require testing prior to disposal.

    5.3. The submission materials from 2016 contain analytical data from a waste source called "Nuverra Tank Farm." This waste type does not appear to be associated with a waste type listed in the waste profile submitted by OWL. Furthermore, this waste was not analyzed for Ra-226 or Ra-228, but readings for Gross Alpha and Gross Beta exceed the values in Table 1 of OAR 345-050-0025 (see further discussion below).

5.4. The laboratory selected for waste analysis was not accredited in the State of Oregon for Thorium or Uranium isotopes.
5.5. The Gross Alpha and Gross Beta readings for all analyzed wastes exceeded the standard in Table 1 of OAR-345-050-0025.
5.6. Based on the information described above, CWM Arlington provided Hazardous Waste acceptance authorization forms to OWL for the years 2016, 2017, and 2019, with an expiration on the latest authorization of 9/17/2019. In accepting these wastes despite data either missing for some wastes or clearly showing that other wastes exceeded allowable limits, CWM Arlington failed to perform due diligence regarding compliance with Oregon radioactive material disposal rules.
5.7. In a voluntary reporting letter provided to the Department by CWM Arlington on November 13, 2019, CWM Arlington stated that the total waste received under the OWL waste profile was 1,284.66 tons. CWM stated that the waste would have been disposed in landfill modules 2, 3, and 4 – each approximately 12 acres in size – and at all levels of these modules, which are currently approximately 90 feet thick. In subsequent clarifying discussion, CWM Arlington reported that the waste has been disposed no shallower than ten feet from the current landfill surface. CWM Arlington also presented results of preliminary risk modeling, further discussed in Section IV of this Notice.

6. Subsequent to receipt of the Waste Profile information from CWM Arlington, the Department received data from the State of North Dakota consisting of shipment tracking information of TENORM by OWL, Inc. to the CWM Arlington facility. This second source confirmed the approximate volume disposed and reported analytical results for wastes that appear to exceed the concentrations of radionuclides in the Waste Profiles submitted by OWL to CWM Arlington. The maximum combined radionuclide concentration was 1,731 pCi/g for a small quantity of waste (approximately 1.5 tons), while nearly 300 tons contained concentrations between 100 and 400 pCi/g and nearly 150 tons contained concentrations above 400 pCi/g.
7. The Department has determined based on the information in this section that the date of discovery of this violation is September 17, 2019.

III. Violations

The Department has determined that CWM Arlington is in violation of OAR 345-050-0006.

IV. Classification of Violations

Pursuant to OAR 345-029-0020(2)(e)(A) through (C) the Department considered the following factors in determining the classification of the above violations:

a. The performance of the responsible party in taking necessary or appropriate action to correct or prevent the violation.
b. Any similar or related violations by the responsible party in the previous 36 months.
c. Any adverse impact of the violation on public health and safety.

Pursuant to OAR 345-029-0030, a violation of any applicable rule in divisions 22 through 60 of the Rule (Division 50 is the chapter concerning disposal of radioactive material) or violation of any applicable provision of ORS Chapter 469 typically qualifies as a Class I violation. However, the Department has authority to escalate a Class I violation to Class II based on factors including:

". . . whether the responsible party reported the conditions or circumstances of the violation, the duration of the violation, whether the responsible party implemented prompt and effective corrective actions, the impact on public health and safety or on resources protected by Council standards, and the past performance of the responsible party." (OAR 345-029-0030(2))

Furthermore, OAR 345-029-0030 states that in order to escalate a violation to Class II, the Department must find that the violation meets one of the following criteria:

(a) It is a repeated violation. The Department shall consider whether the successive violation could reasonably have been prevented by the responsible party by taking appropriate corrective actions for a prior violation;
(b) It resulted from the same underlying cause or problem as a prior violation;
(c) It is a willful violation; or
(d) The violation results in a significant adverse impact on the health and safety of the public or on the environment.

Based on the following factors, <u>the Department has determined the acts and omissions of CWM as described in this notice to be a Class I Violation</u> as described in OAR 345-029-0030(1)(c).

1. Representatives of CWM Arlington reviewed analytical data provided by OWL Inc. that clearly showed an exceedance of allowable concentrations of naturally occurring radioactive materials per the Oregon Administrative Rules. Nevertheless, CWM Arlington provided disposal authorization on three separate occasions over the course of three years. However, because this Notice of Violation is the first formal violation, the subject disposal actions do not qualify as a "repeated violation" or a violation that, "resulted from the same underlying cause or problem as a prior violation."

2. While the Department determines that the violation resulted from a lack of due diligence on the part of CWM Arlington, there is no evidence to suggest that the violation was willful in nature. In meetings with the Department following discovery of this incident, staff of CWM Arlington stated that they thought they had understood the waste in question to be exempt from the administrative rules associated with radioactive waste disposal, but this incident demonstrated to them that their interpretation of the exemption requirements was in error.
3. The Department has concluded, based on a preliminary assessment of available data, that the disposal action has not resulted in a significant adverse impact on the health and safety of the public or on the environment. This determination is based on the following factors:
    a. Any potential impacts to groundwater resources are currently controlled via the liner and leachate collection system at the landfill. Potential future groundwater risk will need to be determined and appropriately managed as part of a corrective action process (described in Section V of this Notice).
    b. There is currently no exposure pathway that could present a direct exposure, ingestion, or inhalation risk to human receptors from the subject waste in its present location and configuration. Based on statements by CWM Arlington, all subject wastes have been covered by at least ten feet of cover material. This cover provides shielding from direct radiation exposure and prevents potential inhalation or ingestion risks via airborne particulates. The depth of disposal also significantly reduces the emanation of radon gas at the surface of the landfill. Based on radon emanation modeling performed on behalf of CWM Arlington and independently by the Department, the risk to workers or members of the public associated with radon exposure is negligible.
    c. The past risk to landfill operators as a result of exposure to the subject waste materials at the time the waste was emplaced may be estimated to be within regulatory and safety limits based on two recent analyses performed for TENORM disposal questions in other states.
        i. A risk assessment of 1,150 tons of similar TENORM wastes disposed at the Blue Ridge Landfill in Estill County, Kentucky (Risk Assessment Corporation, 2016) determined that the maximum total dose to a landfill worker would be 4.7 millirems if the same worker attended all 92 waste offloading events.
        ii. A study of landfill disposal of TENORM conducted by the Argonne National Laboratory determined that the dose to the maximally exposed landfill worker would be below a regulatory limit of 100 millirem/year for wastes containing an average concentration of less than or equal to 50 pCi/g of total radium, assuming no more than 25,000 tons of TENORM wastes are disposed of in a single landfill per year (Harto et al., 2014, Tables 6.17 and 6.18). Given that the waste disposed at the Arlington

facility totaled 1,284 tons over a span of three years, and the total dose scales linearly to the amount of waste disposed per year, the dose to a worker at the Arlington facility can be reasonably estimated to not have exceeded regulatory limits, even though the concentrations of individual loads disposed at the Arlington facility in some cases exceeded 50 pCi/g.

iii. CWM Arlington staff indicated that landfill workers operate within pressurized vehicle cabins during most waste operations, using personal respiratory protective equipment when operating outside their vehicles. This represents another safety factor in addition to the low values calculated in the above two examples and all but completely cuts off an exposure pathway to workers for inhalation or ingestion of radioactive materials.

4. The violation was not discovered and reported by CWM Arlington via their own auditing efforts. While CWM Arlington has made voluntary efforts to provide the Department with information concerning this violation, the reporting of the violating circumstances only occurred after Department staff brought them to CWM Arlington's attention.
5. Once the unlawful disposal was brought to the attention of CWM Arlington, they immediately and voluntarily ceased acceptance of waste from OWL and have been forthcoming with information regarding the subject waste material.
6. The Department reserves the right to reclassify the violation, should the Department learn of additional information relevant to the classification. Were the Department to reclassify the violation as a Class II violation and issue a notice of assessment of civil penalty as described in OAR 345-029-0060, CWM Arlington would have the right to request a contested case proceeding as provided for in OAR 345-029-0070.

V. Action Required

Pursuant to OAR 345-029-0020(2)(c) CWM Arlington has thirty (30) days from the receipt of this Notice of Violation to provide a written response to the Department. Pursuant to OAR 345-029-0040, the response must include, at a minimum, the following:

(1) Admission or denial of the violation;
(2) If CWM Arlington admits the violation and can determine suitable corrective action:
- (a) The corrective action taken, and results achieved;
- (b) Corrective action that CWM Arlington plans to take to minimize the possibility of recurrence; and
- (c) The date by which the responsible party expects to achieve full compliance.

If CWM Arlington admits the violation and cannot determine suitable corrective actions <u>within the 30-day or other time period</u> specified in the notice of violation, CWM Arlington must provide a preliminary response that includes a date by which they will submit a final response that includes all information described in (2) above.

(3) In order to determine the appropriate corrective action in response to this violation, CWM Arlington shall complete a comprehensive compliance process that entails the following:

(a) Within 30 days, CWM Arlington shall submit a Draft Risk Assessment and Corrective Action Plan (RA/CAP) to the Department for review. The Draft RA/CAP shall follow all substantive requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process, including the following:

- A quantitative evaluation of past, present, and future potential health risk to reasonably anticipated human receptors resulting from exposure to the subject waste materials.
- An evaluation of reasonable alternatives consistent with the nine evaluation criteria in CERCLA (National Contingency Plan (40CFR300.430(e)(9))).
- Alternatives shall include at minimum two alternatives: exhumation and lawful disposal of all wastes exceeding the definition of "radioactive materials" in OAR 345-050-0006; and in-situ closure.
- Alternatives shall include technological and/or administrative provisions to minimize the possibility of recurrence of the violation.
- Based on the risk assessment and evaluation of alternatives, CWM Arlington shall propose a preferred alternative for final corrective action.

(b) Within 30 days of receiving Department comments on the Draft RA/CAP, CWM Arlington shall submit a Final RA/CAP that adequately responds to all comments and requested revisions. CWM Arlington may request an extension of this deadline with good cause as determined by the Department.

(c) The Department will make the final RA/CAP open to a public comment period of 30 days, with an option to extend upon request by the public.

(d) The Department will consider and respond to all substantive public comments on the RA/CAP and accept or reject the completeness of CWM Arlington's justification for their preferred alternative.

Issued this 13th day of February, 2020 by the Oregon Department of Energy

By:

REFERENCES

Risk Assessment Corporation, 2016. FINAL REPORT Dose and Risk Assessment of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) Disposals at the Blue Ridge Landfill. RAC Report No. 1 - BRLFTENORM-2016. Obtained from the Commonwealth of Kentucky via open records request.

Harto, C., Smith, K., Kamboj, S., and Quinn, J., 2014. Radiological Dose and Risk Assessment of Landfill Disposal of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in North Dakota. Argonne National Laboratory Environmental Science Division. ANL/EVS-14/13.

Oregon
Kate Brown, Governor

OREGON DEPARTMENT OF ENERGY
550 Capitol St. NE
Salem, OR 97301
Phone: 503-378-4040
Toll Free: 1-800-221-8035
FAX: 503-373-7806
www.oregon.gov/energy

March 27, 2020

James S. Kincaid
Cable Huston
1455 SW Broadway, Suite 1500
Portland, OR 97201

Re: Disposal of Technologically Enhanced Naturally Occurring Radioactive Wastes (TENORM) at Chemical Waste Management of the Northwest, Inc's Arlington, Oregon Facility - Response to Request for Extension of Time Related to Notice of Violation

Dear Mr. Kincaid,

Thank you for your letter of March 13, 2020. We acknowledge and grant your request for more time for Chemical Waste Management of the Northwest to fully develop a comprehensive Risk Assessment and Corrective Action Plan as required by the Oregon Department of Energy's February 13, 2020 Notice of Violation. Based on our on-going conversations with Chemical Waste Management and its technical resource developing both the Risk Assessment and the Corrective Action Plan, we are so far in agreement on the scope and methodology that is planned to be employed in the development of this analysis. We further want to ensure that the analysis is a quality product, both comprehensive and technically sound, that assures the state that public health is protected from risk.

In addition, we acknowledge that the COVID-19 outbreak and resulting efforts to curb its spread will likely slow the ability to take necessary groundwater and leachate samples at the Arlington facility and also to conduct baseline background radiation measurements. The fact that so many people are now working from home – including at the state level – also does impact to some extent the ability to move forward as quickly as if there were no outbreak.

For these reasons, we accept the proposed schedule of *no later than* September 1, 2020 to receive the final review draft of the full Risk Assessment and the Corrective Action Plan. However, to respond to the high degree of public interest and concern regarding this situation and ensure timely progress, by April 30, 2020, Chemical Waste Management should provide the Department of Energy with publicly releasable technical summaries for the following topics:

- An annotated outline of the TENORM dose and Risk Assessment report under development, including a description of the purpose of each document section and any key methods of analysis.

- An annotated outline of the Corrective Action Plan under development, including a description of the purpose of each document section and any key methods of analysis.

- An evaluation of past and present worker doses and risks during the TENORM waste disposals, including quantitative or semi-quantitative analysis depending on the progress of the Risk Assessment.

- A three-dimensional, location-specific map and description of all subject TENORM wastes within the specific disposal cell. For the purposes of presentation, a series of two-dimensional slices communicating key waste locations is also requested.

- A site-specific discussion of the geology and hydrogeology of the impacted cell at the Chemical Waste Management Arlington facility and the potential for future migration of radionuclides to underlying groundwater resources or surface waters in the vicinity of the site, including the Columbia River. This discussion need not achieve the level of quantitative modeling at this early juncture but should be based on site-specific data and current research.

- An explanation of the survey plan for the specific disposal cell and for characterizing the radiological background of the area.

Further, as we understand leachate data will not be available in time to support an April 30 deadline, by May 29, 2020, Chemical Waste Management should provide the following:

- A technical discussion of the facility's leachate management system relative to the subject TENORM waste. This discussion should include: the current presence or absence of radionuclides in landfill leachate; the potential risk to workers or the public if future leachates are shown to contain radionuclides associated with the subject TENORM waste; and any new leachate management practices necessary to safely manage any potential future risk from TENORM radionuclides in facility leachates.

The technical summaries may take the form of white papers that could inform the basis for chapters in the final Risk Analysis and Corrective Action Plan.

We appreciate the on-going dialogue that is occurring between my agency and Chemical Waste Management.

Sincerely,

Ken Niles
Assistant Director for Nuclear Safety

Cc: Patrick Rowe, Oregon Department of Justice
Jim Denson, Chemical Waste Management
Andrew Kenefick, Waste Management, Inc.
David Anderson, Oregon Department of Environment Quality

Oregon
Kate Brown, Governor

OREGON DEPARTMENT OF ENERGY
550 Capitol St. NE
Salem, OR 97301
Phone: 503-378-4040
Toll Free: 1-800-221-8035
FAX: 503-373-7806
www.oregon.gov/energy

March 24, 2021

James Denson
PNW/BC Environmental Protection Manager
Waste Management
7227 NE 55th Ave
Portland, OR 97218

Mr. Denson,

The Oregon Department of Energy (ODOE) has completed its review of the Corrective Action Plan submitted by Chemical Waste Management of the Northwest (CWMNW) on September 8, 2020 and all comments submitted to ODOE during the public comment period between September 8 – November 8, 2020. As described below, ODOE concurs with CWMNW's preferred Alternative 1 as the final remedy, provided that it incorporates the amendments described in this determination.

During the comment period, ODOE held two public meetings, one virtual and one in-person, at which we described the alternatives analysis and proposed monitoring actions in the Corrective Action Plan, and fielded questions and comments from the public. We have responded in writing to all public comments as an attachment to this determination.

The Corrective Action Plan (CAP) with its addenda presents the findings of a preliminary screening and evaluation of a number of remedial technologies to address the Bakken Oilfield Waste that was subject to ODOE's Notice of Violation on February 13, 2020. The CAP included a detailed analysis and comparative risk assessment for two remedial alternatives: Alternative 1: Closure-in-Place with Monitoring, and Alternative 2: Excavate and Redispose the Bakken Waste. Based on the comparative analysis and risk assessment, and on the criteria established in the Notice of Violation, the CAP indicated the preferred alternative was Alternative 1: Closure-in-Place with Monitoring.

ODOE conducted an extensive review of the CAP, its addenda, subsequent supplemental analyses, and comments submitted by members of the public. ODOE has determined that either alternative would likely meet the regulatory standards of long-term protectiveness of human health and the environment, but agrees that the CAP's preferred alternative is more protective of human health and the environment in the short-term. ODOE therefore largely accepts implementation of Alternative 1 as the final remedy, with amendments described below.

ODOE came to its conclusion to concur with CWMNW's plan after carefully considering the CAP, its addenda, and public comments. The comments submitted to ODOE (attached hereto) expressed several important concerns with the proposed alternative and recommend a number of additional radiological monitoring requirements for the facility. ODOE agrees with many of these recommendations and requires the following modifications to CWMNW's preferred alternative.

1. ODOE finds that modifications to the groundwater monitoring program proposed in the CAP are necessary. The modifications are as follows:
    a. The default groundwater monitoring program will follow CWMNW's proposed 5-year interval for radionuclide analysis in the wells immediately upgradient and downgradient from Landfill L-14 during landfill operations and post-closure. The next radionuclide groundwater sampling event will occur in 2021.
    b. If, in the future, the higher-frequency monitoring data for non-radionuclides suggest that there may be a potential release from the lined landfill (i.e., failure of the landfill liner), the Oregon Department of Environmental Quality as the permitting authority will require the facility to enter a Compliance Monitoring phase including increased monitoring. Upon initiation of the Compliance Monitoring phase, CWMNW would notify ODOE and include monitoring for radionuclides in the Compliance Monitoring schedule. Radiological monitoring results would be directly reported to ODOE.
    c. The final enacted alternative shall be amended to state that the groundwater monitoring plan shall require monitoring for radionuclides following landfill closure, during the 30-year post-closure period.
2. ODOE finds that annual radiological sampling and analysis is required for the onsite wastewater treatment plant solid media, including flocked solids, spent filters, and carbon filter beds. CWMNW is responsible for confirming on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.
3. ODOE finds that annual radiological sampling and analysis is required for the leachates produced by Landfill L-14 during the operational and post-closure periods for that landfill. The analytical results of this sampling shall be reported to ODOE upon receipt. CWMNW is responsible for confirming on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.
4. ODOE finds that annual radiological sampling and analysis is required for the combined leachate stream from all onsite landfills during the operational and post-closure periods for the CWM facility. A sample shall be collected from each of the two retention ponds that receive effluent from the wastewater treatment facility. The analytical results of this sampling shall be reported to ODOE upon receipt. CWMNW is responsible for

confirming on an annual basis that these materials do not constitute radioactive waste prior to their disposal in the landfill.

5. The Radiological Monitoring Plan in Attachment G of the CAP shall be implemented, and ODOE encourages CWMNW to complete installation of the proposed radiation portal monitor at the earliest possible opportunity. The plan shall be subject to revision by ODOE and CWMNW as deemed necessary to minimize the risk of noncompliance with applicable disposal laws.
6. ODOE further requires that a standalone annual compliance report be submitted to ODOE containing the following information:
    a. List of any radiological portal alarm occurrences, a description of the waste, associated waste profile and analytical/investigatory information, description of correspondence with the state, and ultimate waste disposition;
    b. Description of any incidents (e.g., portal alarms) involving materials known or suspected to contain Naturally Occurring Radioactive Material or other radiological materials above screening limits;
    c. Profile certification of leachate and onsite wastewater treatment plant solids including radioanalytical data;
    d. Listing of waste profiles for which CWMNW reviewed and sought concurrence with ODOE that the profile does not appear to qualify as "radioactive waste" for purposes of disposal in Oregon; and
    e. A calibration/maintenance log of portal monitor and associated equipment.

A revised CAP with the amendments required above, CAP addenda, all pertinent supporting documentation, all supplemental analyses, and any other corrections or clarifications shall be compiled into a single, comprehensive report submitted to ODOE. Please label this report "Final Corrective Action Plan" with the date of submission.

Please submit the Final Corrective Action Plan as described in this determination within thirty (30) days of receiving this letter.

We appreciate CWMNW's cooperation in the Corrective Action process over the past year. If you have questions, please feel free to contact Maxwell Woods at 503-551-8209 or at Maxwell.Woods@oregon.gov.

Sincerely,

Janine Benner
Director
Oregon Department of Energy

Attachment B

Landfill L-14 Gamma Survey

Gamma Survey Report

September 2020

Submitted to and Prepared for:

Chemical Waste Management of the Northwest (CWMNW)

17629 Cedar Springs LN

Arlington, OR 97812

Prepared by:

Environmental Restoration Group, Inc.

8809 Washington St NE Suite 150

Albuquerque, NM 87113

And

K2 Environmental LLC

40330 Kelly Park Rd

Leetonia, OH 44431

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1.0 Executive Summary

As part of Chemical Waste Management of the Northwest's (CWMNW) overall response to the notification that Technologically Enhanced Naturally Occurring Radiological Material (TENORM) waste shipped from sources in the Bakken oilfield region had been disposed of in Landfill L-14, a gamma survey was commissioned to map the gamma footprint of the current surface of Landfill L-14. The objective of the radiological investigation was to identify the nature and extent of external gamma radiation exposure and to determine the statistical differences, if any, between the survey area, consisting of the Landfill L-14 (constructed waste boundary) and excavation layback area, and the operational material and background locations. Landfill L-14 presents several challenges with respect to traditional gamma surveys as it is a hazardous waste disposal facility with steep slopes and uneven terrain. Due to the potential hazards and limitations posed by having personnel perform a ground survey of Landfill L-14, which is operational, the unmanned aerial vehicle (UAV) survey option was selected because of the following benefits:

- The UAV does not require workers to traverse steep slopes and mitigates the potential exposure to chemical and hazardous wastes.
- UAV technology is the state-of-the-art method for performing large area gamma surveys due to the technologies' precise mapping and geo-location capabilities.
- The UAV methodology provides complete survey coverage due to its ability to traverse steep hills and fly over small obstacles.
- The UAV height and speed are controlled variables that may be adjusted to reach the desired detection sensitivities.

The gamma radiological investigation was performed at the CWMNW Facility located in Arlington, OR. The investigation was completed by Environmental Restoration Group, Inc. (ERG), in collaboration with K2 Environmental LLC. The two companies have over 40 years combined experience in performing gamma surveys. The purpose of this investigation was to determine the external gamma radiological conditions at the CWMNW Facility and to compare these conditions to onsite "operational materials" (used as landfill cover or reagents) and offsite (natural background) areas unimpacted by landfill activities that are representative of undisturbed geology.

The investigation consisted of gamma surveys using a UAV equipped with radiation detection and GPS equipment to measure gamma count rates across the CWMNW Facility and at the operational material and background areas. Additionally, exposure rate measurements were taken at the operational material and background locations using a high-pressure ionization chamber (HPIC). A correlation was developed between the HPIC and UAV-based measurements that enabled the conversion of UAV-based gamma survey data to exposure rate data.

The CWMNW Facility survey indicates the survey area average gross exposure rate of approximately 8.2 μR/hr is lower than all background location exposure rate measurements. The average gross exposure rate was derived by averaging the over 12,000 individual survey points without background subtraction.

Measured background results are consistent with background gamma measurements made in other areas of Oregon (including Pendleton, OR) and Idaho. The measured background results are also consistent with average and median levels of published background gamma exposure rates for nationwide studies. The average of the background measurements is subtracted from gross measurements within the survey area to calculate the net exposure rates reported in Table 1 below.

Table 1. Survey area gamma summary statistics

Area	Number of Measurements	Gross Exposure Rate (μR/hr)			Net Exposure Rate (μR/hr)		
		Mean	Min	Max	Mean	Min	Max
Excavation Layback	1,812	8.47	5.90	16.31	-1.20	-3.76	6.65
Constructed Waste Boundary	10,414	8.15	5.27	12.88	-1.51	-4.39	3.22

Small areas of activity greater than 1.5 times the background conditions were identified in the cell excavation layback area north of the lined portion of the landfill. CWMNW has reviewed these locations and confirmed that no waste has been placed in this area. It is likely the elevated measurements are due to the clayey lenses in the natural geology exposed during excavation of the cell.

The results of the radiological survey demonstrate that external gamma measurements observed within the Landfill L-14 waste boundary are within the distribution of radiation levels observed at the background areas.

2.0 Introduction

Environmental Restoration Group, Inc. (ERG), in collaboration with K2 Environmental LLC, conducted a gamma survey for Chemical Waste Management of the Northwest (CWMNW) at their property at 17629 Cedar Springs LN, 97812 from June 15 to 19, 2020. The CWMNW Facility is shown below in Figure 1. This report documents the survey activities, results, and conclusions.

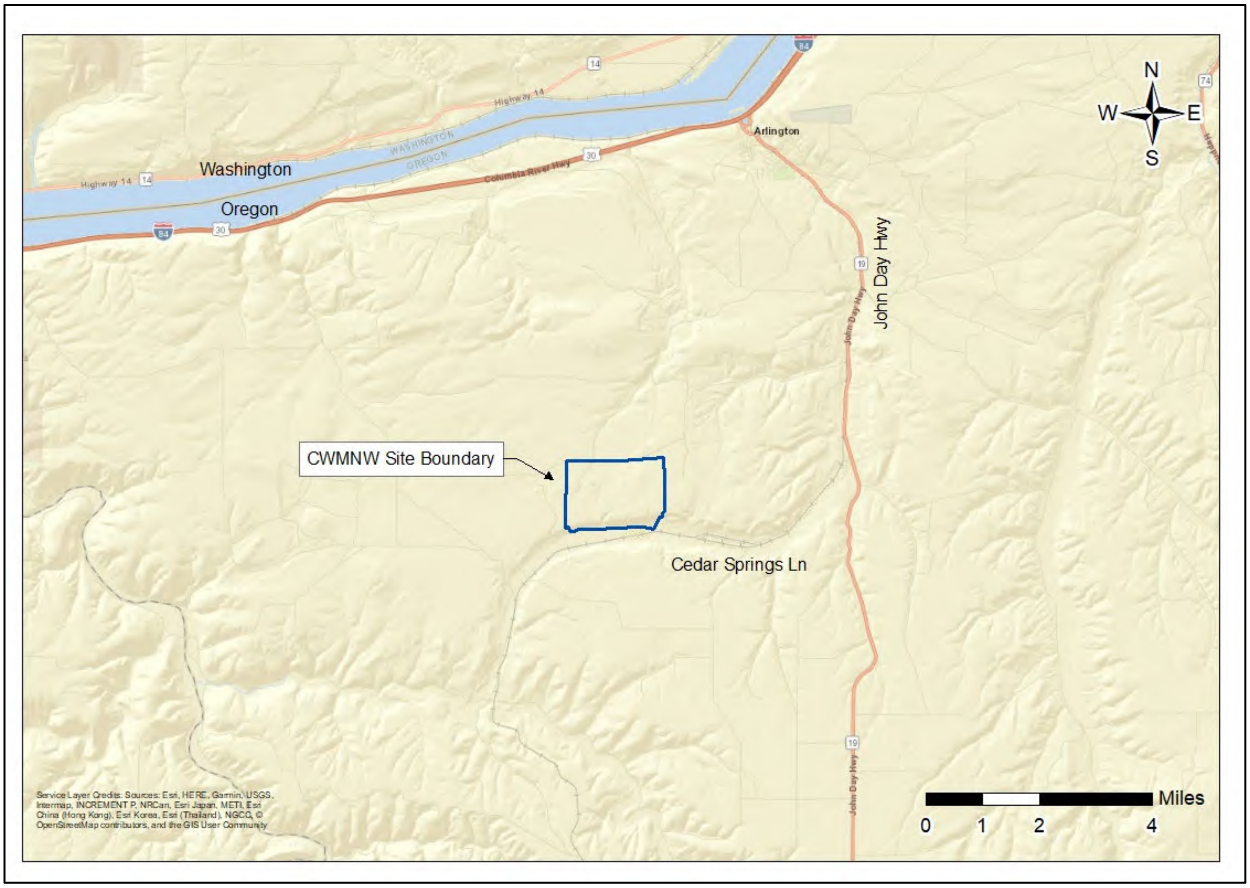


Figure 1. CWMNW Facility location

The focus of the survey was on Landfill L-14, where Bakken oilfield wastes had been disposed between 2016 and 2019. The purpose of the survey was to determine the gamma radiation across Landfill L-14, and to identify relative statistical differences, if any, between the survey area and background areas.

To achieve the stated objective of the survey, it was important to ascertain the natural gamma background (in areas clearly not impacted by landfill operations). It was equally important to understand the gamma radiation for non-waste materials placed on the landfill as cover or used in the processing of wastes (virgin cover soils and reagent).

2.1 Gamma Survey

The gamma survey was performed to delineate the radiation count rates across the area of investigation and to compare to the operational materials and background. The gamma survey was conducted using an Unmanned Aerial Vehicle (UAV) equipped with radiation detection equipment and GPS to measure gamma count rates as a function of location in the following areas:

- **Constructed Waste Boundary** - The active area of Landfill L-14 where the Bakken oilfield waste is known to be buried (Figure 2). This area is referred to the "constructed waste boundary" throughout this report.
- **Cell Excavation Layback Area** - The area where excavation occurred to reach the correct elevation for landfill grades (Figure 2). No waste has ever been placed in this section of the landfill[1]. This area is referred to as the "excavation layback" area for the purpose of this report.

For the purposes of this report, the **survey area** is defined as the combined area of both the constructed waste boundary and the excavation layback area. The areas are shown in Figure 2.

Figure 2. Gamma survey areas

[1]*Personal Communication with Jim Denson, CWMNW Environmental Protection Manager 07/28/2020.*

2.2 Operational Materials and Background Survey

In addition to the gamma survey of Landfill L-14, the gamma exposure rate was measured using a high-pressure ionization chamber (HPIC) at various locations within the CWMNW Facility boundary where operational materials are obtained, at background locations around the CWMNW Facility perimeter, and at offsite locations. The HPIC measurements were performed to determine the gamma exposure rate for various operational materials and to estimate a natural background exposure rate outside of the facility boundary. UAV measurements were also performed at each of these locations using the same detector height as that used for the gamma radiation survey so that the UAV-based gamma survey data could be converted to gamma exposure rate data. Gamma count rate (UAV) and gamma exposure rate (HPIC) measurements were performed at the following locations:

- **Gravel Lot** – This area is used to stockpile virgin stone used in landfill construction. The gravel cover is referred to as "operational material" throughout this report. The gravel lot material is shown in Figure 3.

Figure 3. Gravel lot operational material

- **Reagent** – This material is commonly used to treat waste prior to landfill disposal. The reagent is also referred to as "operational material" throughout this report. The reagent material is shown in Figure 4.

Figure 4. Reagent operational material

- **Borrow Area** – Soil and small smooth rocks used for landfill cover. The borrow area soil is used as landfill cover and is referred to as "operational material" throughout this report. The borrow area material is shown in Figure 5.

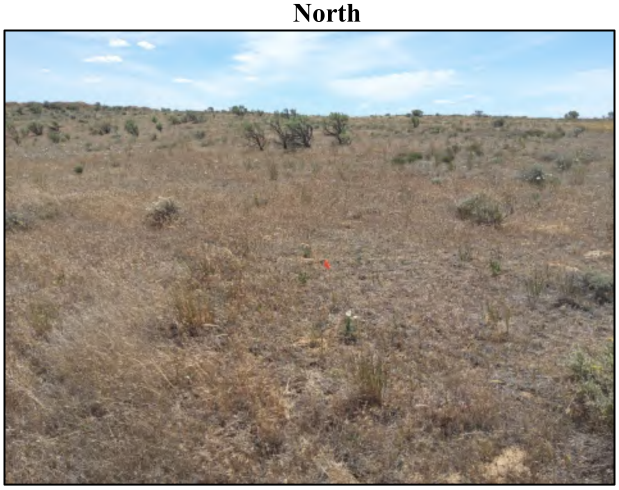
Figure 5. Borrow area operational material

- **White Clay** – This layer is part of the natural subsurface at the CWMNW Facility. This virgin clay is mined from unimpacted sections of the owner-controlled property and is also exposed in excavations for the landfill cells. The clay is used as landfill cover and is referred to as "operational material" throughout this report. The clay area measurement location is shown in Figure 6.

Figure 6. White clay operational material

- **Owner Controlled Perimeter** – The perimeter of the owner-controlled property boundary. Four locations north, south, east, and west of the site were used to obtain perimeter measurements. The perimeter background locations had no visible geological disturbance and encompassed a range of natural geologies within the area as shown in Figure 7. Perimeter location East was in the predominate downwind direction from the CWMNW.

North **East**



South **West**

Figure 7. Perimeter background locations

- **Offsite Background** – Areas located outside the owner-controlled property boundary representing natural unimpacted geology. Two locations upwind of the CWMNW Facility were used to obtain the offsite background measurements. The offsite background locations had no visible geological disturbance and encompassed the natural geologies within the area as are shown in Figure 8 and Figure 9.

Figure 8. Offsite background location #1

Figure 9. Offsite background location #2

The location of each operational material and background location relative to the CWMNW Facility is shown in Figure 10.

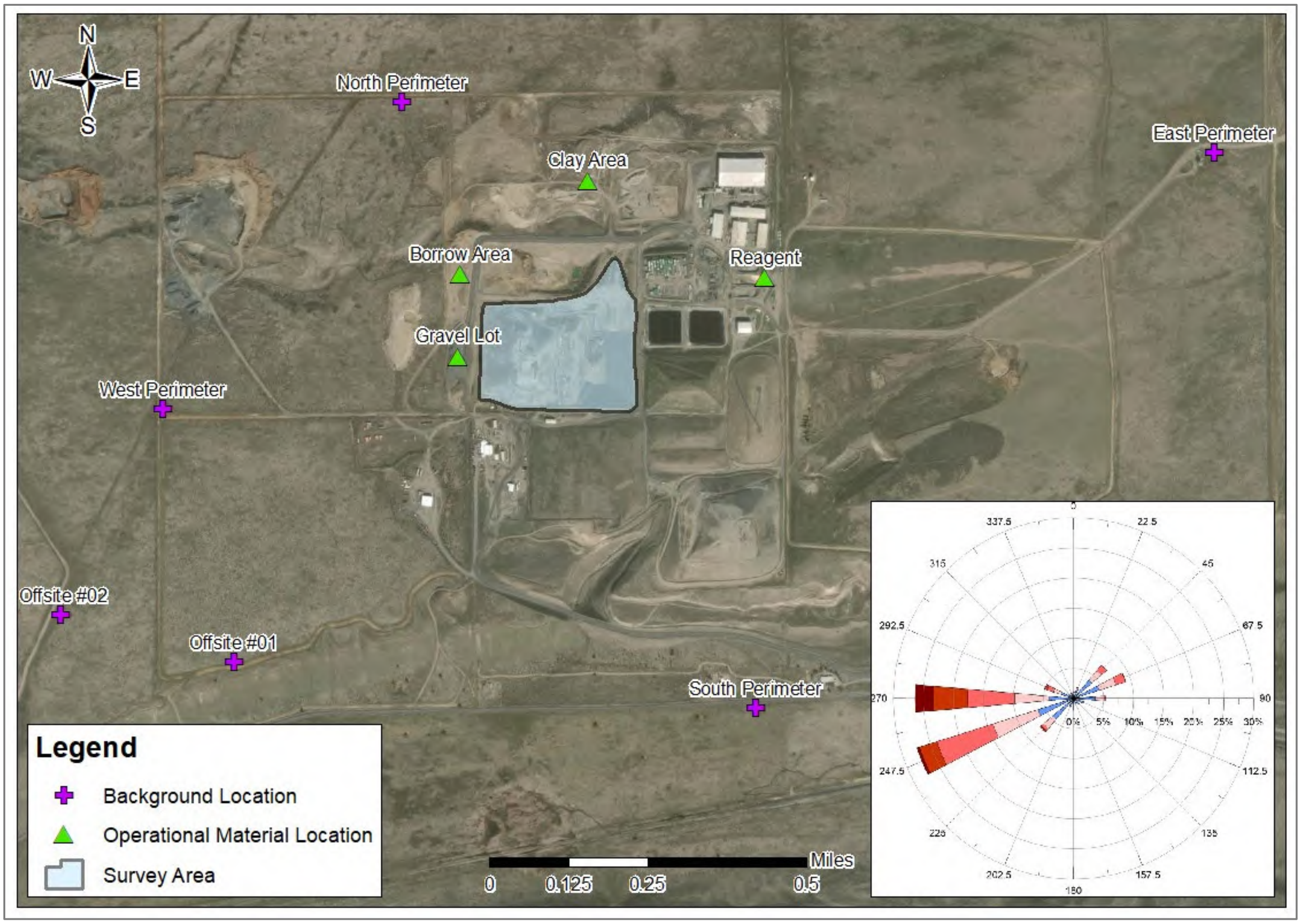


Figure 10. Operational material and background locations

2.3 Gamma Count Rate to Exposure Rate Correlation

To convert the gamma count rate data from the UAV gamma survey to gamma exposure rates, a correlation was developed. The correlation between count rate and exposure rate is a linear relationship between the UAV detector measurements and the ground-measured exposure rate. To do this, HPIC measurements were performed at each operational material and background location to determine the exposure rate. UAV measurements were also performed at these same locations using the same detector height (3 meters) used for the UAV gamma survey. A regression analysis between the exposure rate (HPIC) and count rate (UAV) data was completed. The resulting linear regression was used to approximate the exposure rates from the CWMNW Facility UAV gamma survey data, i.e. measured count rate data was converted to exposure rate.

3.0 Survey Instruments and Check Sources

The radiological survey instruments used in the investigation were:

- UAV equipped with a Ludlum Model 44-10 2-inch by 2-inch sodium-iodide high-energy gamma detector paired with a Ludlum Model 3000 scaler for making gamma radiation measurements. Used in performing UAV-based gamma surveys.
- General Electric (GE) RSDetection High-Pressure Ionization Chamber (HPIC). Used for taking exposure rate measurements above the operational material and at background locations.

The ERG UAV was equipped with a Model 44-10, 2-inch by 2-inch, sodium iodide gamma detector coupled to a Model 3000 scaler, which in turn was connected to an onboard logging system for coupling the radiological data to the UAV positional data. The Model 3000 was operated in scaler mode. The Model 3000 was coupled to an onboard computer that recorded the one-second integrated radiological count and corresponding GPS coordinate to an onboard Secure Digital (SD) card. The data were also transmitted to a remote computer at the UAV control station to provide real-time radiological updates to the technician. The log files were downloaded from the SD card and stored in a project database at the end of each day.

Table 2 lists the radiological instruments by model and serial number used in the investigation. The UAV instruments were function-checked before and after each day of use. The gamma detector was function-checked using a cesium-137 radiological check source (serial number 61). The responses of instruments used for more than one day were tracked for consistency over the course of the investigation. Tracking consisted of the following procedure: Prior to use in the field, ten initial function check values were recorded for each instrument. Each subsequent function check was compared to a range of plus or minus 10 percent of the instrument's initial 10 count average. All instrument calibration and function check forms are included in Appendix A.

Table 2. Survey instruments

Description	Model	Serial Number
UAV Meter	Ludlum Model 3000	25020100
UAV Detector	Ludlum Model 44-10	PR295016
HPIC	GE RSDetection HPIC	1001321

Notes:
UAV – Unmanned Aerial Vehicle
HPIC – High-Pressure Ionization Chamber

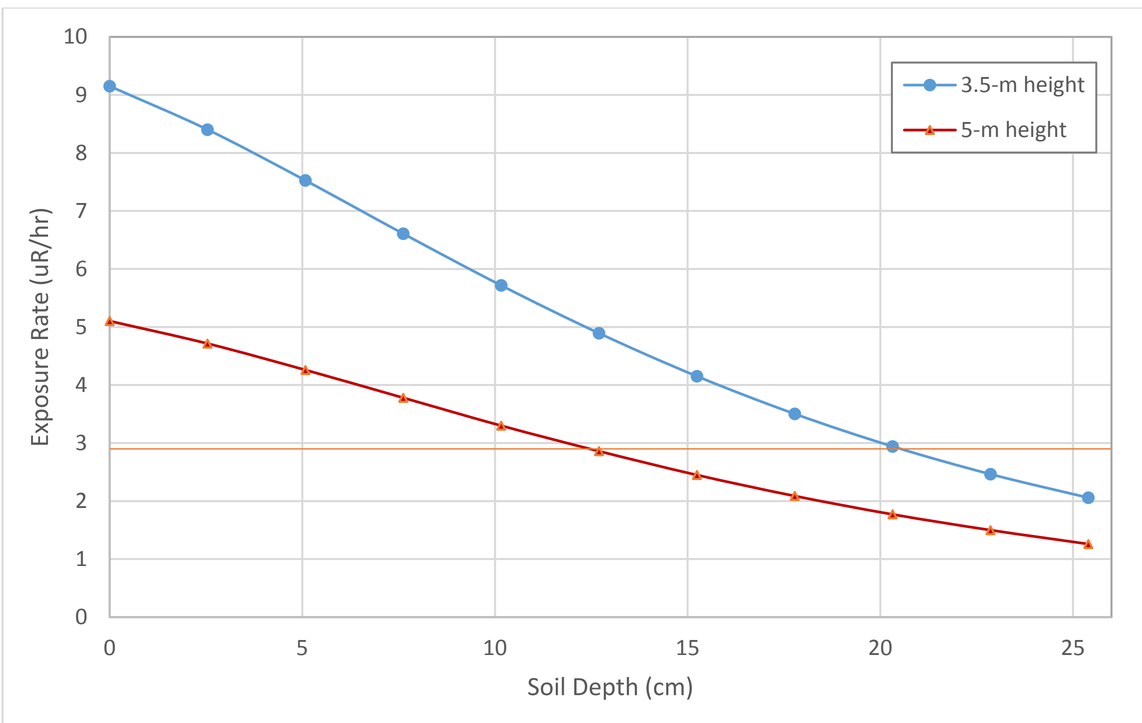
3.1 Detection Sensitivity

Prior to performing the gamma survey, the detection sensitivity of the NaI detector was calculated at various heights above an assumed source size. The calculations were performed to determine a scanning speed and detector height for the gamma survey that would ensure the source would be statistically identifiable by the UAV.

The calculations were performed by using the gamma transport code Microshield (Grove Software 2014) to model the expected exposure rate at various heights above a source. The source was modeled as a parallelepiped of dimensions 7.62 m by 2.44 m and 5-cm thick to approximate a typical truck load of Bakken oilfield waste homogenously distributed onto the ground surface. The source was modeled as radium-226 in equilibrium with its progeny and at a concentration of 75 pCi/g and 143 pCi/g to represent the average and maximum concentrations of the waste as determined by laboratory analysis.

The exposure rate was modeled at detector heights of 3.5 m and 5 m above the 143 pCi/g source, and at 3 m above the 75 pCi/g concentration. In both cases, the exposure rate was also calculated for varying thicknesses of soil placed over the source to simulate a buried source. The minimum detectable count rate (MDCR) of 2,665 counts per minute (cpm) was determined using an assumed background count rate of 11,000 cpm and an observation interval of 1-second. The scanning speed for the UAV of 2.5 m/s was calculated using the criteria that the UAV would be over the minimum source dimension of 2.44 m for at least one counting interval.

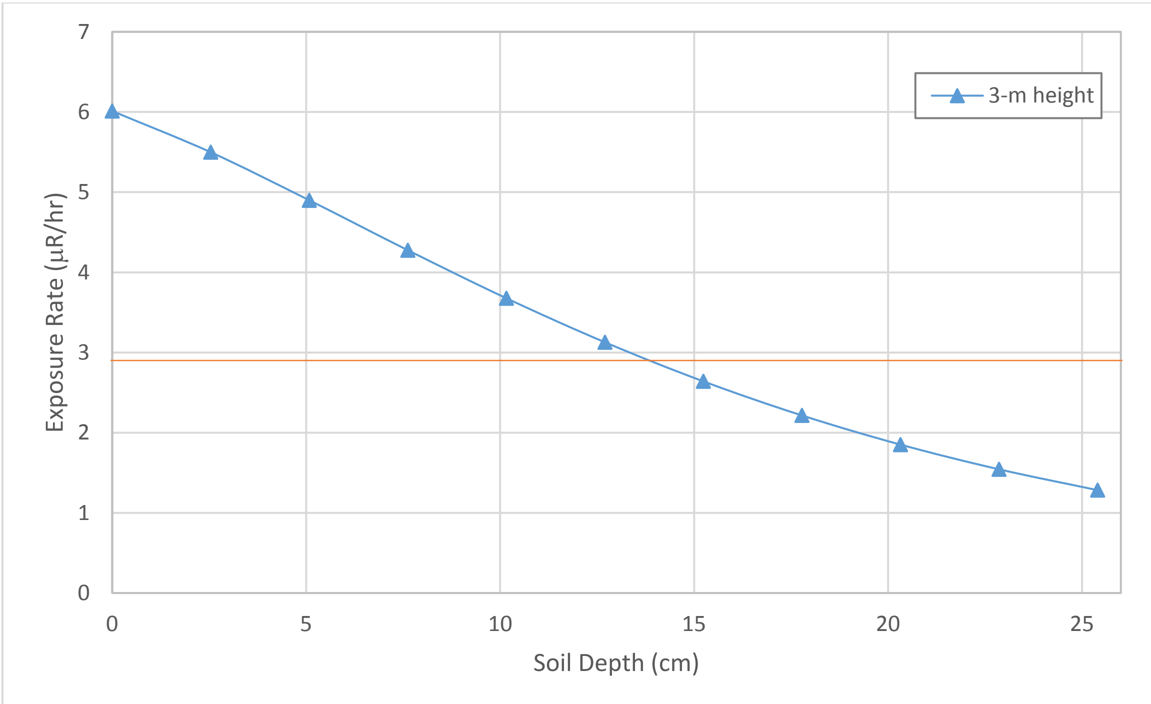
The Microshield model results for the 143 pCi/g source are shown in Figure 11. The results indicate that for no soil cover, both the 3.5-m and 5-m detector heights are capable of detecting the source above the minimum detectable exposure rate (MDER) of 2.96 µR/hr. When the UAV is 3.5-m above the surface, the source can be detected with up to 23-cm of soil cover. The soil cover depth decreases to approximately 13 cm for a 5-m detector height of 5 m.



Notes:
Horizontal line represents the minimum detectable exposure rate.

Figure 11. Microshield model results of exposure rate for 143 pCi/g source with varying soil cover thickness

The results of the 75 pCi/g source are shown in Figure 12. The results demonstrate that the detector can delineate the source with approximately 14 cm of soil cover.



Notes:
Horizontal line represents the minimum detectable exposure rate.

Figure 12. Microshield model results of exposure rate for 75 pCi/g source with varying soil cover thickness

Based on the simulations, a detector height of 3-m above the ground surface was selected to maximize the detection efficiency of the assumed source size while ensuring clearance above obstacles across the survey area. Derivation of the detection efficiency is described in detail in Appendix C.

4.0 Operational Material and Background Measurements

This section discusses the operational material and background measurements performed to obtain a representative baseline for the expected gamma count rate and exposure rate measurements. This section also summarizes the results of these measurements.

4.1 Methods

4.1.1 Operational Material and Background Measurement Locations

Operational material and background measurement locations previously described in section 2.2 were selected to:

- Compare survey-area data with undisturbed natural geology outside the Facility
- Quantify the operation materials commonly used onsite.

The operational material and background locations were selected based on the following criteria:

- Background locations, consisting of offsite and perimeter locations, were selected in areas identified as representative of natural, undisturbed geology.
- The perimeter locations were oriented around the CWMNW Facility in the north, east, south, and west directions relative to the CWMNW Facility.
- Onsite operational material locations consisting of the reagent pile, and areas containing uncontaminated cover or fill material commonly placed in the landfill.

The operational material and background measurement are shown in Figure 3 through Figure 9 and the locations are shown in Figure 10.

4.1.2 UAV Gamma Survey

The UAV hovered at each operational material and background location for a minimum of 10 minutes while collecting gamma data at a height of 3-m to match the survey height used during the gamma survey of the excavation layback and constructed waste boundary.

4.1.3 HPIC Measurements

The HPIC was positioned on a tripod at each operational material and background location and was set to collect data for a minimum of 10 minutes. The HPIC was positioned so the ionization chamber was at a height of 1-m off the ground surface. The HPIC recorded exposure rate data in consecutive one-minute intervals.

4.1.4 Determination of Background Levels

The background locations, consisting of the north, east, south, west, offsite #01, and offsite #02 locations, were selected as areas that were representative of background radiological conditions in the area, independent of the Facility. The background locations had no visible geological disturbance and encompassed a range of natural geologies within the area.

4.2 Results

4.2.1 UAV Gamma Survey

The gamma survey distributions for each operational material and background area are shown in Appendix B. A summary of the statistics for each operational material and background area is shown in Table 3 and a box plot for each area is shown in Figure 13.

The results confirm that gamma data were collected for enough time to obtain a relatively normal distribution of data with a statistically confident mean. The lowest average background count rate was observed in the gravel lot operational material area, with a mean of 4,713 cpm. The highest operational material location was observed in the clay area with a mean of 11,219 cpm and a max of 13,680 cpm. All background locations were relatively similar in count rates, with a mean of 8,119 cpm.

Table 3. Operational material and background area gamma survey summary statistics

Type	Area	N	Count Rate (CPM)			
			Mean	Standard Deviation	Min	Max
Operational Material	Borrow Area	908	6,067	627	4,320	8,460
	Clay	735	11,219	805	8,820	13,680
	Gravel Lot	648	4,713	506	3,360	6,180
	Reagent	924	7,922	684	5,760	10,020
Background	Offsite #1	721	7,994	690	5,700	10,440
	Offsite #2	775	8,911	731	6,780	11,280
	North Perimeter	622	7,931	688	5,880	10,020
	East Perimeter	770	9,018	739	6,600	12,240
	South Perimeter	1,367	7,413	673	5,100	9,600
	West Perimeter	608	7,899	673	6,060	10,020

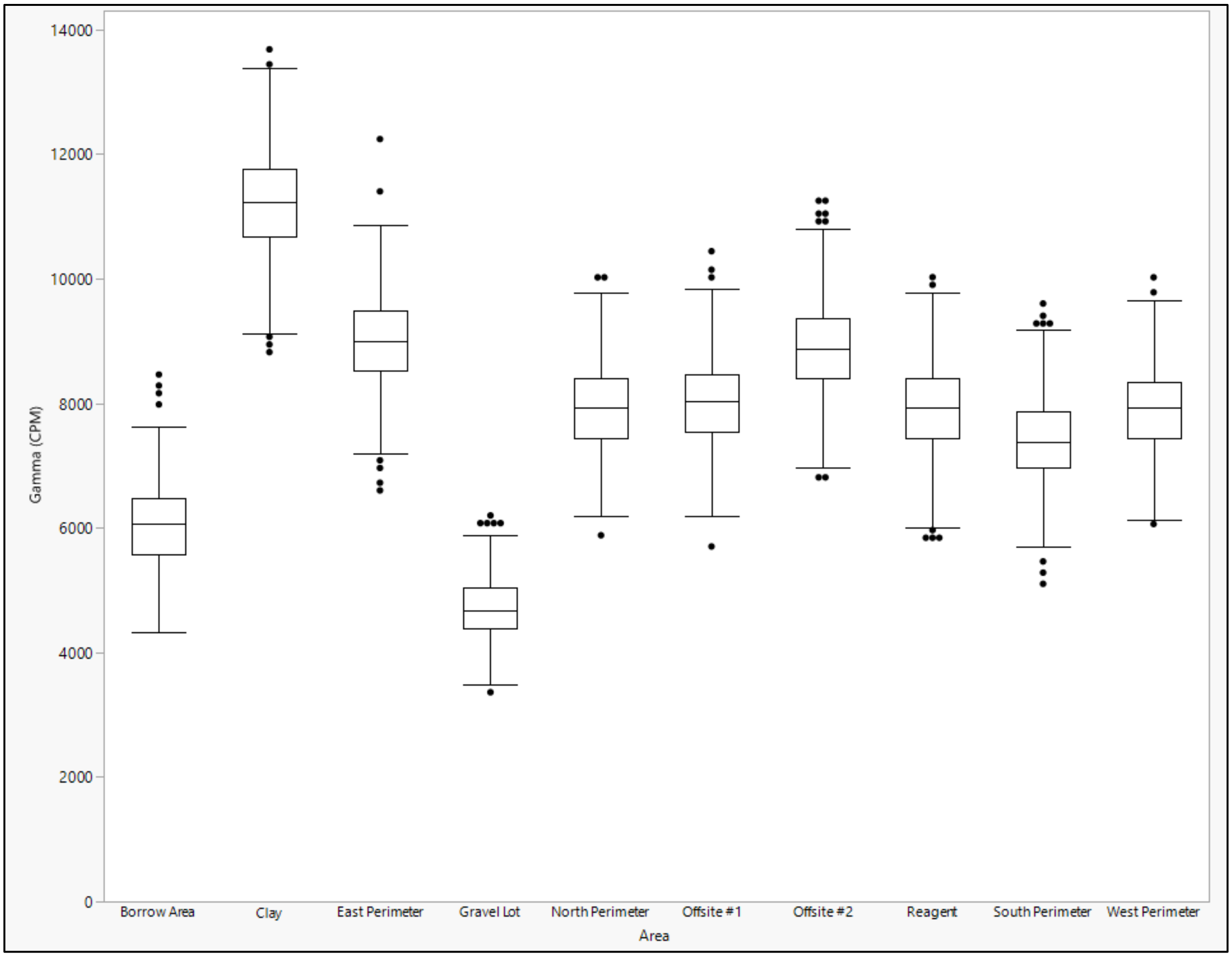


Figure 13. Operational material and background area box plot statistics

4.2.2 HPIC Measurements

The average HPIC exposure rate for each operational material and background area are shown, along with the average UAV count rate, in Table 4. The lowest exposure rate was observed at the gravel lot area with an average exposure rate of 7.27 µR/hr (micro roentgen per hour). The highest observed exposure rate was observed at the clay cover area with an average exposure rate of 13.9 µR/hr.

Table 4. Operational material and background area measurement summary

Type	Material	Average Gamma Count Rate (CPM)	HPIC Measurement (µR/hr)
Operational Material	Gravel Lot	4,713	7.27
	Borrow Area	6,067	7.69
	Reagent	7,922	10
	Clay Area	11,219	13.9
Background	Offsite #1	7,994	9.87
	Offsite #2	8,911	9.93
	West Perimeter	7,899	9.15
	North Perimeter	7,931	10.3
	East Perimeter	9,019	9.52
	South Perimeter	7,413	8.98

4.2.3 Determination of Background Levels

The background locations consist of the north, east, west, and south perimeter locations, and the offsite #01 and offsite #02 locations. A weather station next to the Facility shows the predominant wind direction between the January 1, 2010 to December 31, 2010 towards the north east direction (Figure 10). A comparison between the east perimeter location (approximately northeast of the Facility) and the west perimeter and offsite locations (approximately southwest of the Facility) indicate a maximum relative percent difference (RPD) of 4.2 percent. The comparison indicates that the background locations upwind and downwind, relative to the site, are not statistically different.

The HPIC measurements for each background location were averaged to obtain a background exposure rate of 9.66 µR/hr. The measured value was compared to published values from Bogen and Goldi (1981), which summarizes the estimated population exposure to external background gamma radiation across the United States. The report indicates an external background gamma radiation dose equivalent of 76.1 millirem per year (mrem/yr) for the state of Oregon. Using an assumed 8,760 hours in a year and a conversion of 0.98 of absorbed dose in tissue (rad) per roentgen in air (Shleien, 1992), the equivalent dose for the measured background can be approximated as 82.9 mrem/yr. The comparison demonstrates good agreement between the measured and published exposure rates based on the state-wide average for Oregon.

The measured value was also compared to nationwide studies of background radiation levels (Lindeken et al., 1972; Myrick et al., 1981). Myrick et al. (1982) reports background exposure rates across 356 locations and 33 states to range from 1 to 34 µR/hr, with an average of 8.5 µR/hr. For Oregon, nine measurements were taken with a range of 8.2 to 19 µR/hr and an average of 11 µR/hr. Measurements in Idaho ranged from 11-16 µR/hr with an average of 12 µR/hr. No measurements were taken in Washington state. In Lindeken et al. (1972), 107 locations were measured across the United States. A median exposure rate was reported to be 9.4 µR/hr with a range of 3.7 to 19.9 µR/hr. Four measurements were taken in Oregon. The range was 7.9 to 9.4 µR/hr, with the closest measurement occurring in Pendleton, OR (9.0 µR/hr). These studies suggest that the measured value of 9.66 µR/hr is within the expected range of exposure rates based on state and nationwide data.

The UAV gamma count rate measurements from all background locations in the current study were averaged to obtain a count rate of 8,119 cpm. The calculated background values for exposure rate and count rate are shown in Table 5.

Table 5. Background measurement results

Type	Value	Description
Exposure Rate	9.66 μR/hr	Average of HPIC measurements at operational materials locations – north, south, east, west perimeter locations, and offsite #01, offsite #02.
Count Rate	8,119 cpm	Average of the UAV measurements at operational materials locations – north, south, east, west perimeter locations, and offsite #01, offsite #02.

5.0 UAV-based Gamma Survey

This section addresses the methods and results for the UAV-based gamma survey. The objective of the UAV-based survey was to acquire position-correlated gamma count rates across the survey area. The survey data were subsequently used to:

- Determine the gamma variability, if any, across the survey area
- Compare to background gamma levels, and
- Estimate the exposure rate across of the survey area

5.1 Methods

The UAV-based gamma survey was performed over all accessible grounds, free of tall vegetation, heavy equipment, and active CWMNW Facility operations, within the boundary of the survey area.

The survey was performed with a detector transect spacing of approximately 5-meters, and at a scanning speed of approximately 2.5-meters per second. The transects were programmed into the flight controller software using imagery and topography data of the Facility collected prior to the gamma survey. The UAV was equipped with a Real-Time Kinematic (RTK) GPS unit capable of sub-centimeter accuracy to assist with autonomously maintaining a detector height of 3-meters above the ground surface over varying terrain.

5.2 Results

The results of the gamma survey are shown in Figure 14. Individual count rate measurements are presented as colored dots in multiples of the background level. The Kriged data of the background comparison is shown in Figure 15. Gaps in the coverage are due to physical obstacles, e.g., vegetation, vehicles, or areas where work was being performed while the survey was ongoing. Approximately 95,300 m^2 and 19,320 m^2 were surveyed in the constructed-waste and excavation layback area, respectively.

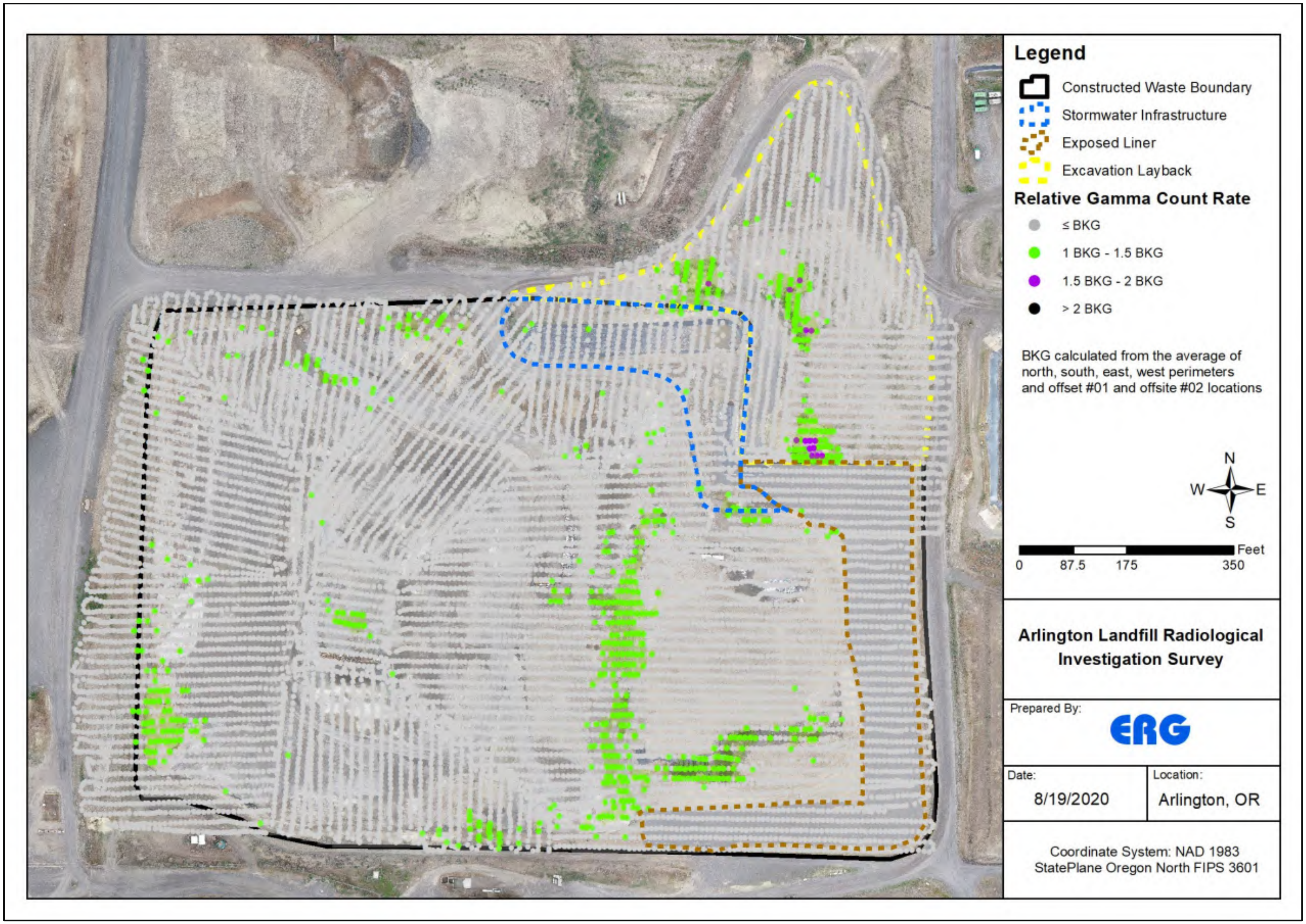


Figure 14. Gamma survey area results

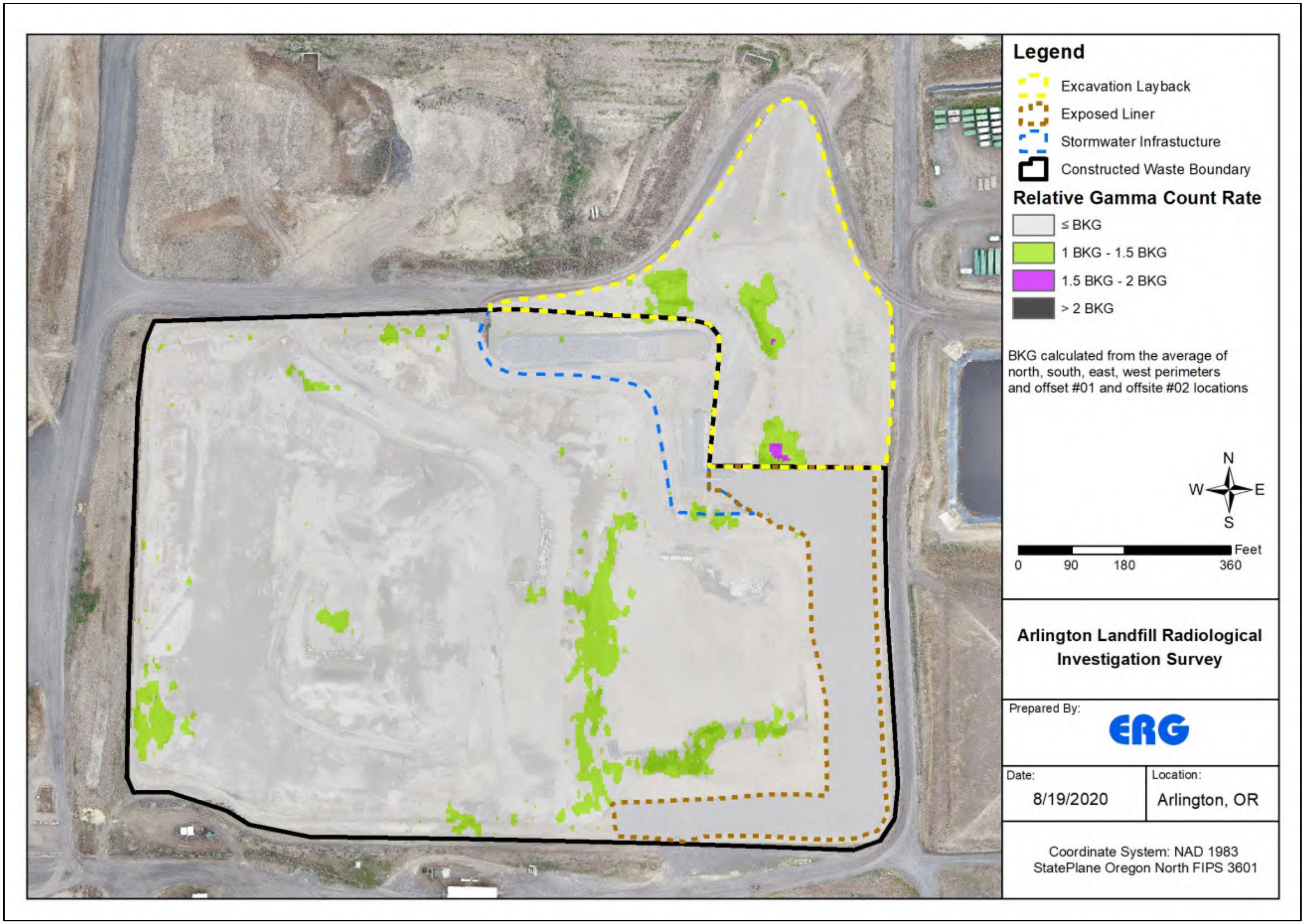
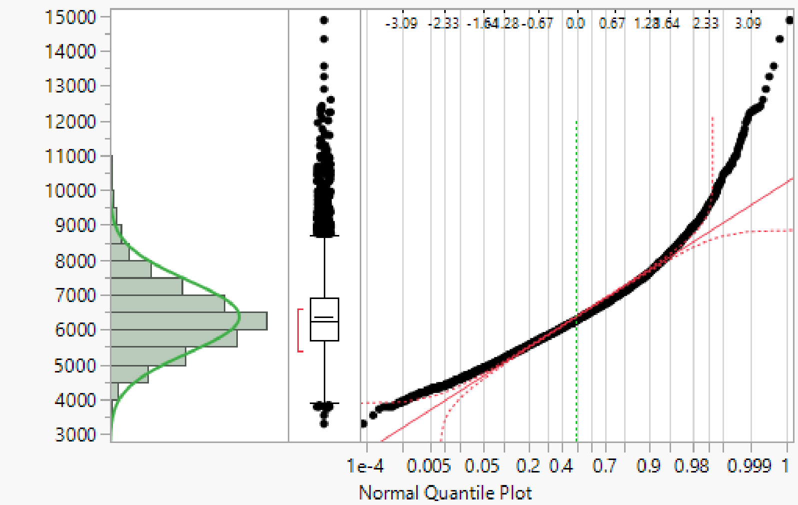


Figure 15. Kriged gamma survey area results

A histogram, summary statistics, and a goodness-of-fit test of the measurements are shown in Figure 16. The goodness-of-fit test shows non-normality in the distribution due to a right tail of the data which indicates a small percentage of measurements in the survey area fall outside of the typical distribution of data.

Gamma Statistics

Gamma Count Rate (cpm)



Compare Distributions

Distribution		AICc ^	BIC	-2*LogLikelihood
Normal	——	204511.74	204526.56	204507.74

Quantiles

100.0%	maximum	14880
99.5%		10320
97.5%		8760
90.0%		7620
75.0%	quartile	6900
50.0%	median	6240
25.0%	quartile	5700
10.0%		5160
2.5%		4680
0.5%		4260
0.0%	minimum	3300

Summary Statistics

Mean	6370.7721
Std Dev	1037.68
Std Err Mean	9.3847188
Upper 95% Mean	6389.1677
Lower 95% Mean	6352.3766
N	12226

Fitted Normal Distribution

Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	6370.7721	9.3847188	6352.3784	6389.1658
Dispersion	σ	1037.68	0.2060161	1037.2763	1037.8431

Measures	
-2*LogLikelihood	204507.74
AICc	204511.74
BIC	204526.56

Goodness-of-Fit Test

	A2	Prob > A2
Anderson-Darling	80.762313	<.0001*

Figure 16. Survey area statistics

The gamma survey data of the constructed waste boundary and excavation layback area were compared against the operational material and background data as shown in Figure 17. The results show that the average gamma count rate at the constructed waste boundary and excavation layback measurements are comparable to the borrow area operational material. The right tail of the excavation layback measurements reaches a maximum of 14,880 cpm which corresponds to the clay area operational material. Only two discrete points, or 0.016 percent, of the excavation layback measurements exceed the upper bounds of all operational material and background location measurements. The total survey statistics of the operational materials, background areas, and survey area are shown in Table 6.

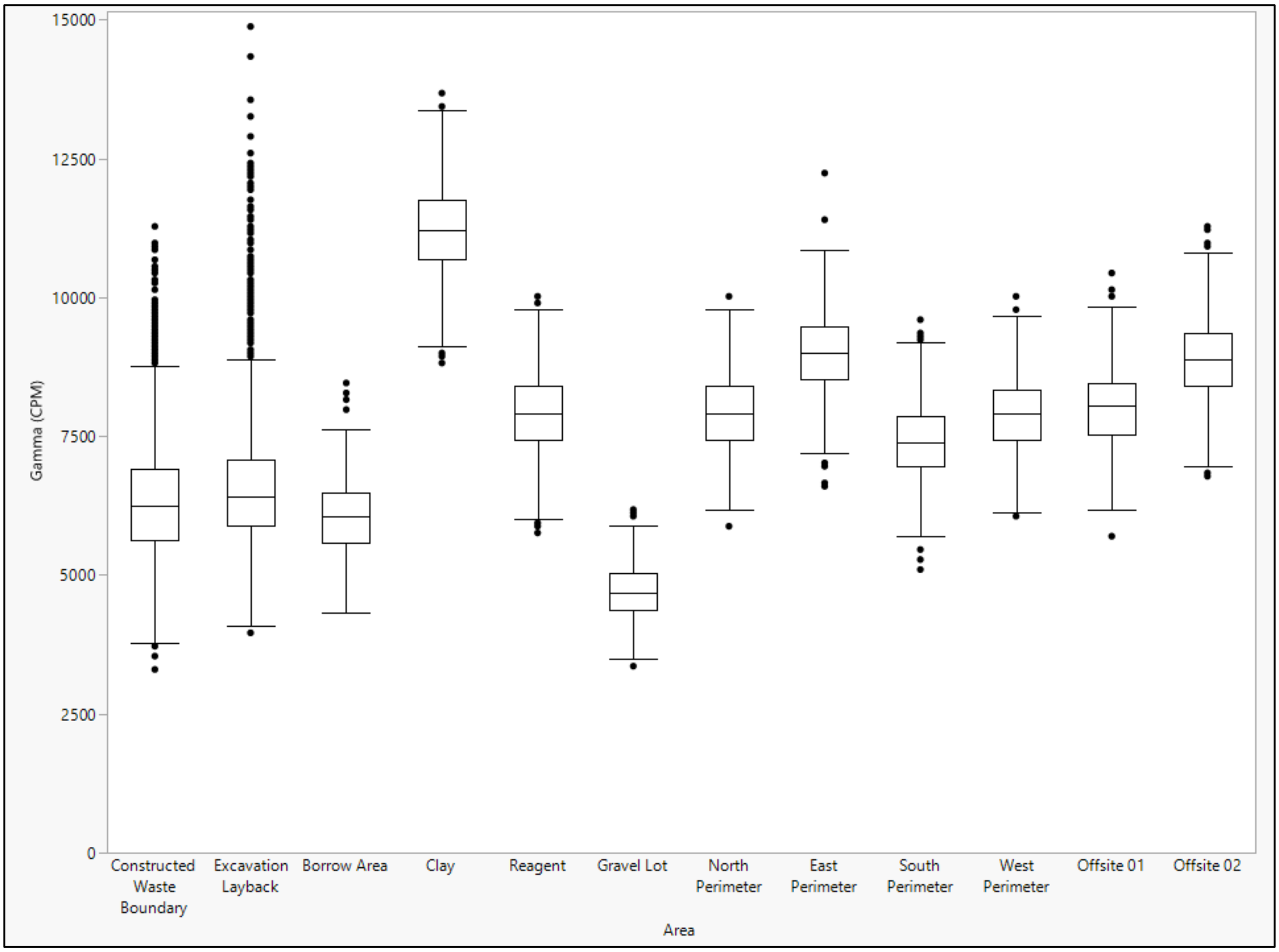


Figure 17. Box plots of survey area and operational material and background surveys

Table 6. Survey statistics of operational materials, background areas, and survey area

Type	Area	N	Count Rate (CPM)			
			Mean	Standard Deviation	Min	Max
Operational Material	Borrow Area	908	6,067	627	4,320	8,460
	Clay	735	11,219	805	8,820	13,680
	Gravel Lot	648	4,713	506	3,360	6,180
	Reagent	924	7,922	684	5,760	10,020
Background	Offsite #1	721	7,994	690	5,700	10,440
	Offsite #2	775	8,911	731	6,780	11,280
	North Perimeter	622	7,931	688	5,880	10,020
	East Perimeter	770	9,018	739	6,600	12,240
	South Perimeter	1,367	7,413	673	5,100	9,600
	West Perimeter	608	7,899	673	6,060	10,020
Survey Area	Excavation Layback	1,812	6,654	1,294	3,960	14,880
	Constructed Waste Boundary	10,414	6,321	978	3,300	11,280

Notes:
cpm – counts per minute

6.0 Exposure Rate Correlation

This section discusses the approach taken to convert the gamma count rate measurements to exposure rates.

6.1 Methods

The HPIC measurements and UAV gamma survey measurements taken at each operational material and background location were plotted against each other to develop a linear relationship between gamma count rates and exposure rates. No correlation measurements could be taken within the survey area boundary due to safety concerns and limited accessibility, however the entire range of the gamma survey count rates were adequately captured in the operational material and background location measurements.

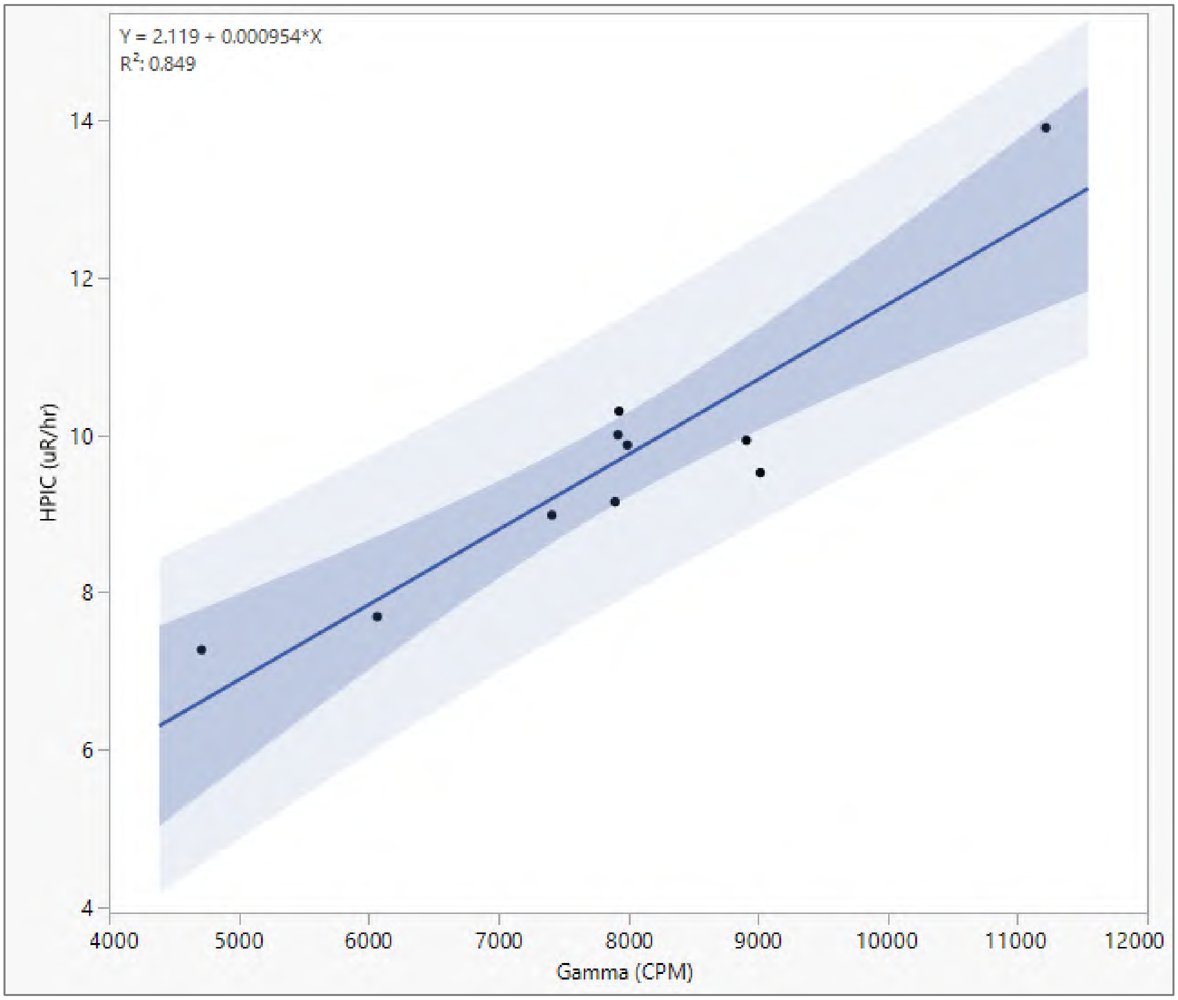
6.2 Results

The exposure rate regression is shown in Figure 18. The regression resulted in a Pearson's fit coefficient (R^2) of 0.85. The coefficient demonstrates a good fit between the UAV gamma count rate and the HPIC exposure rate measurements. From the regression, the following equation is used to convert the UAV gamma count rate measurements at 3-m height to exposure rate at 1-m:

$$\left[\frac{\mu R}{hr}\right] = 2.119 + 0.000954 * [cpm]$$

The function was used to convert all the gamma survey data to estimated exposure rate at one meter. The resulting box plot of each operational material and background location, in units of micro Roentgens per hour (μR/hr), is shown in Figure 19.

The conversion of gamma survey data in counts per minute to exposure rate assumes that the UAV is over areas of homogenous gamma fields, therefore the calculated exposure rates of the survey area are considered an average response across large areas.



Notes:
Light blue bars are 95th confidence intervals
Dark blue bars are 95th prediction intervals
Equation represents Y as exposure rate and X as count rate
R^2 – Pearson's correlation coefficient

Figure 18. Exposure rate and gamma count rate linear regression

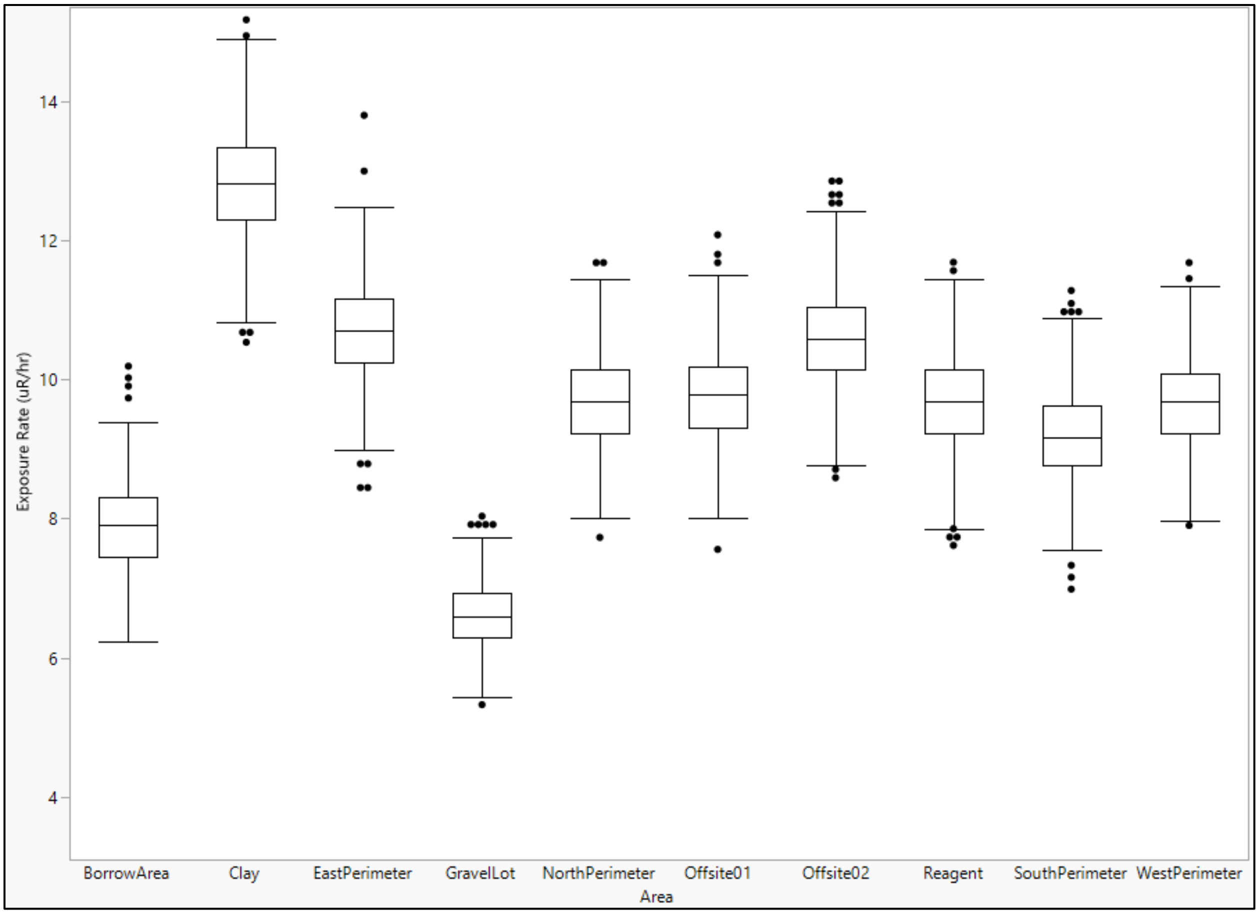


Figure 19. Operational area box plot statistics in micro Roentgen per hour

7.0 Summary and Conclusions

The objective of the radiological investigation was to identify the nature and extent of external gamma radiation exposure and to determine the statistical differences, if any, between the survey area (consisting of the constructed waste boundary and excavation layback area) and the operational material and background locations.

The average background response, consisting of the average exposure rate measurements of the perimeter and offsite locations, was used to calculate the net response of the gamma survey. This was achieved by subtracting the background response from each gross gamma survey record. The resulting gamma survey, in net exposure rate, is shown in Figure 20. The results indicate a maximum net exposure rate of approximately 6.7 µR/hr inside the boundary of the excavation layback area (no waste in place), and a maximum net exposure rate of 3.2 µR/hr inside the constructed waste boundary. The summary statistics for the survey area is shown in Table 7.

The following results and conclusions summarize the radiological observations as they pertain to the objective of the investigation:

- All background HPIC measurements were within the range of published average background exposure rates for the state of Oregon and surrounding states. The consistency between background measurements indicates no observable gamma radiological impacts from the CWMNW Facility at these background measurement locations.
- The survey area, consisting of both the excavation layback area and the constructed waste boundary, indicates an average gross exposure rate of approximately 8.2 µR/hr with a maximum of 16.3 µR/hr in the excavation layback area. When subtracting the measured average HPIC background response, the survey area indicates an average net exposure rate of -1.5 µR/hr and a maximum of 6.7 µR/hr. The survey area average is lower than all offsite background location measurements, and approximately equal to the borrow area operational material location average measurement.
- The highest measured gross exposure rate of 16.3 µR/hr was observed in the excavation layback area in the northeast corner next to the lined area of the facility where no waste has ever been placed[2]. Therefore, it is likely that the response is due to an operational material (clayey lens) exposed by the excavation in the area, as indicated in Figure 21. Figure 17 demonstrates that the highest measurements in the excavation-only area are within the distribution of measurements of the clay operational material.
- 99.98% of the survey area (excavation layback and constructed waste boundary) gamma measurements fall within the range of distributions of the operational material and background location measurements.
- All of the measurements within the constructed waste boundary (Landfill L-14) fall within the range of distributions of the background areas.

[2] Personal Communication. Jim Denson, CWMNW Environmental Protection Manager 07/28/2020.

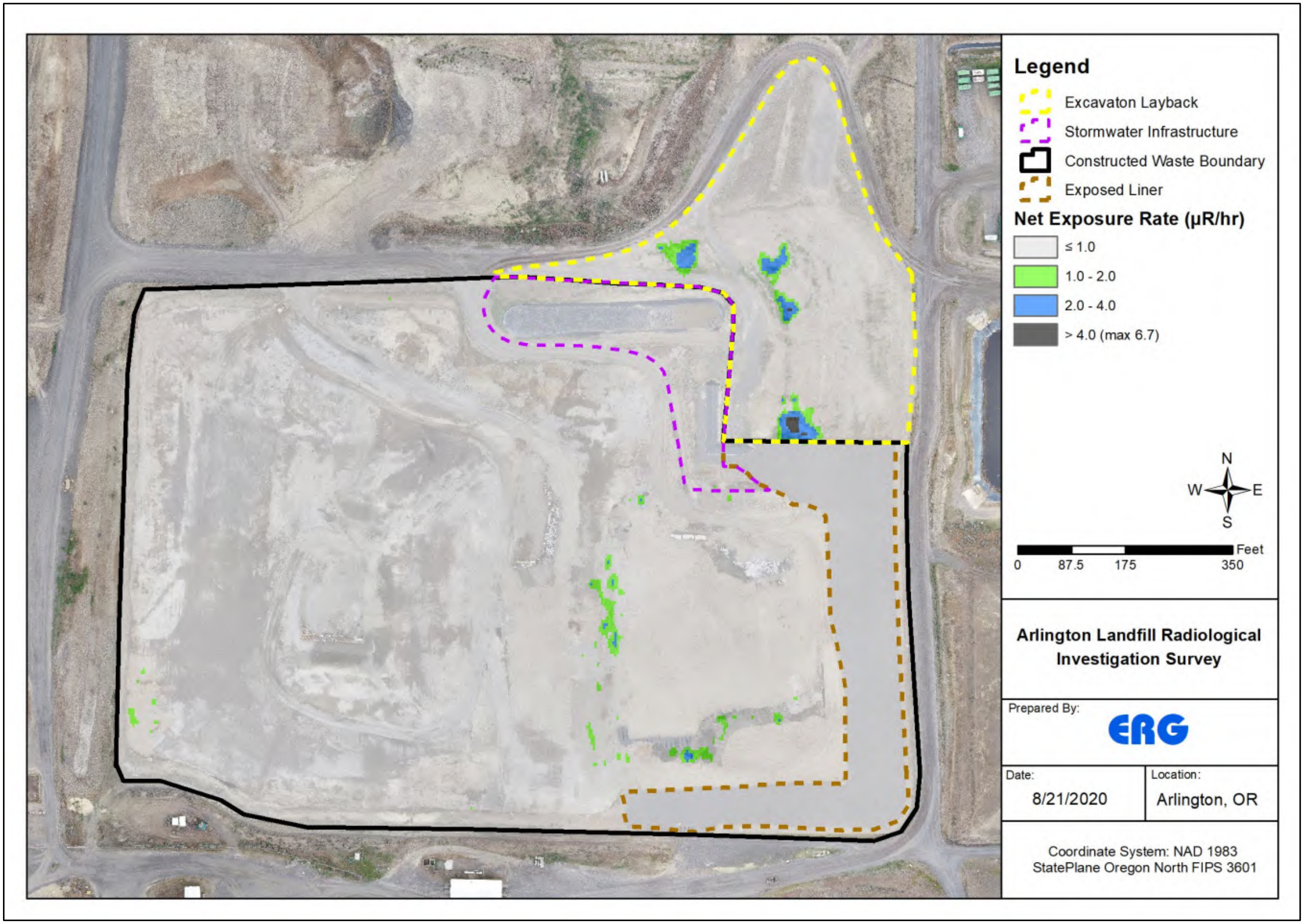


Figure 20. Gamma survey in net exposure rate

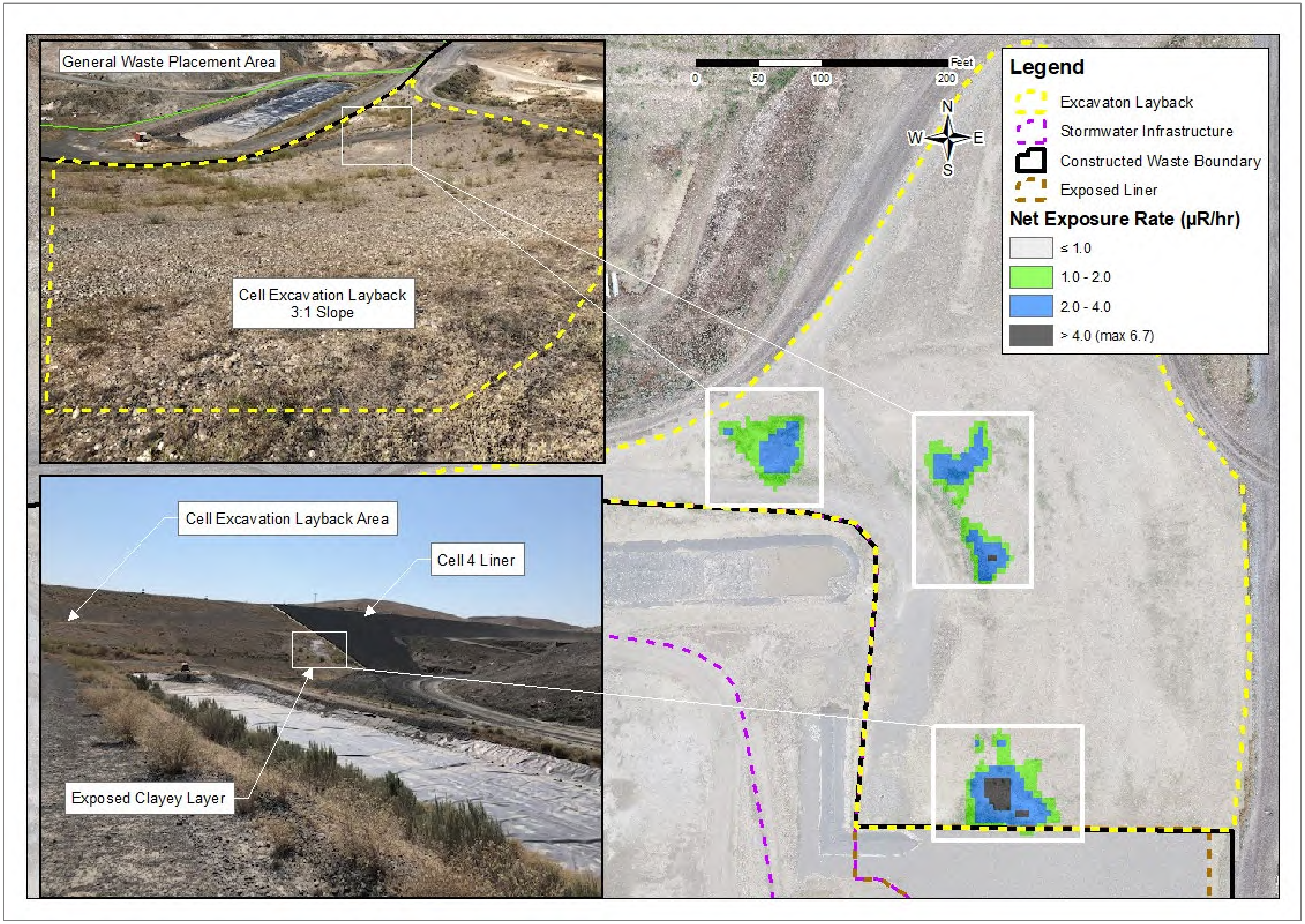


Figure 21. Details of excavation layback area survey

Table 7. Survey area gamma summary statistics

Area	N	Gamma Count Rate (CPM)			Gross Exposure Rate (μR/hr)			Net Exposure Rate (μR/hr)[1]		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Excavation Layback	1,812	6,655	3,960	14,880	8.47	5.90	16.31	-1.20	-3.76	6.65
Constructed Waste Boundary	10,414	6,321	3,300	11,280	8.15	5.27	12.88	-1.51	-4.39	3.22
Survey area[2]	12,226	6,371	3,300	14,880	8.20	5.27	16.31	-1.46	-4.39	6.65

Notes:
[1] The net exposure rate is calculated from subtracting the average of perimeter and offsite HPIC measurements from the gross exposure rate.
[2] The survey consists of both the excavation layback area and constructed waste boundary.

8.0 References

Bogen, K.T. and Goldin, A.S. 1991. Population Exposures to External Natural Radiation Background in the United States. U.S. Environmental Protection Agency, ORP/SEPD-80-12.

Grove Software. 2014. "Microshield Radiation Software, Version 9.07."https://www.radiationsoftware.com/microshield.

Lindeken, C.L., Peterson, K.R., Jones, D.E., and McMillen, R.E. 1972. Geographical Variations in Environmental Radiation Background in the United States. Lawrence Livermore National Laboratory, UCRL-73822. https://www.osti.gov/servlets/purl/4643327

Myrick, T. E., Berven, B. A., and Haywood, F. F. Sun. 1981. State background-radiation levels: results of measurements taken during 1975-1979. Oak Ridge National Laboratory, ORNL/TM-7343. https://www.osti.gov/servlets/purl/5801538

Shleien, B. 1992. The Health Physics and Radiological Health Handbook. Scinta, Inc., Silver Spring, MD. 20902 ISBN 0-917251-05-9.

Appendix A

Instrument Calibration and Daily Function Check Forms

ERG

Single-Channel Function Check Log

Environmental Restoration Group, Inc.
8809 Washington St. NE, Suite 150
Albuquerque, NM 87113
(505) 298-4224

METER	
Manufacturer:	Ludlum
Model:	44-10
Serial No.:	25016921
Cal. Due Date:	3-Feb-21

DETECTOR	
Manufacturer:	Ludlum
Model:	3000
Serial No.:	PR355767
Cal. Due Date:	3-Feb-21

Comments:
Transcribed from field notes

Source: Cs-137 Activity: 5 uCi Source Date: 09/2017 Distance to Source: 6 in

Serial No.: 61 Emission Rate: NA cpm/emissions

Date	Time	Battery	High Voltage	Threshhold	Source Counts	BKG Counts	Net Counts	Initials	Note(s):
06/15/20	0800	NA	850	10	48792	10567	38225	SP	Initial QC Counts
↓	↓	↓	↓	↓	48704	10388	38316	↓	↓
					47791	10542	37249		
					47601	10174	37427		
					47667	10279	37388		
					48781	9941	38840		
					47999	10108	37891		
					47741	10437	37304		
					47094	10644	36450		
					47181	10379	36802		

Reviewed by: T. [signature] **Review Date:** 06/17/20

ERG Form ITC.201.A

ERG

Single-Channel Function Check Log

Environmental Restoration Group, Inc.
8809 Washington St. NE, Suite 150
Albuquerque, NM 87113
(505) 298-4224

METER	
Manufacturer:	Ludlum
Model:	44-10
Serial No.:	25016921
Cal. Due Date:	3-Feb-21

DETECTOR	
Manufacturer:	Ludlum
Model:	3000
Serial No.:	PR355767
Cal. Due Date:	3-Feb-21

Comments:
Upper limit: 45,107
lower limit: 30,071

Source: Cs-137 Activity: 5 uCi Source Date: Sept. 2017 Distance to Source: 6 in

Serial No.: 61 Emission Rate: NA cpm/emissions

Date	Time	Battery	High Voltage	Threshhold	Source Counts	BKG Counts	Net Counts	Initials	Note(s):
6/15/20	0840	NA	850	10	49712	10531	39181	SP	
6/15/20	1620	NA	850	10	46404	10648	35756	SP	
6/16/20	0811	NA	850	10	49102	10632	38470	SP	
6/16/20	1715	NA	850	10	48807	10651	38156	SP	
6/17/20	0754	NA	850	10	47703	10581	37122	SP	
6/17/20	1911	NA	850	10	46378	10691	35687	SP	
6/18/20	0802	NA	850	10	47797	10821	36976	SP	
6/18/20	1928	NA	850	10	46434	10666	35768	SP	
6/19/20	0859	NA	850	10	48804	10563	38241	SP	
6/19/20	1612	NA	850	10	47798	10632	37166	SP	

Reviewed by: [signature] Review Date: 06/17/20

Designer and Manufacturer of Scientific and Industrial Instruments

www.ludlums.com

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
501 Oak Street
325-235-5494
Sweetwater, TX 79556, U.S.A.

ilac-MRA ACCREDITED CERT # 4084.01

Customer: ENVIRONMENTAL RESTORATION GROUP — ORDER NO. 20371999/489326

Mfg. Ludlum Measurements, Inc. — Model 3000 — Serial No. 25016921

Mfg. Ludlum Measurements, Inc. — Model 44-10 — Serial No. PR355767

Cal. Date 3-Feb-20 — Cal Due Date 3-Feb-21 — Cal. Interval 1 Year — Meterface 44-10 R

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 72 °F RH 20 % Alt 698.0 mm Hg

☐ New Instrument — Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☐ Meter Zeroed ☐ Background Subtract ☐ Input Sens. Linearity

☑ F/S Resp. ck ☑ Reset ck. ☐ Window Operation ☐ Geotropism

☑ Audio ck. ☑ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) 4.4 VDC

☑ Calibrated in accordance with LMI SOP 14.8 ☑ Calibrated in accordance with LMI SOP 14.9

Instrument Volt Set 850 V Input Sens. 10 mV Det. Oper. 850 V at 10 mV Threshold Dial Ratio = mV

☑ HV Readout (2 points) Ref./Inst. 600 / 599 V Ref./Inst. 1300 / 1305 V

COMMENTS:

```
             Deadtime: 7.4 µSec Overload checked but not set.
 Calibration Constant: 537 e+8  Pulser calibration RATEMETER READOUT performed without deadtime.
  Primary Units Alarm: 7 mR/hr  Pulser calibration SCALER READOUT reflects 6 second count.
Secondary Units Alarm: 999 kcpm
             Firmware: 49835N30
```

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

RANGE MULTIPLIER	REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING	RANGE MULTIPLIER	REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING
Digital	5 mR/hr	4.62 mR/hr	4.62 mR/hr				
Digital	1 mR/hr	998 µR/hr	998 µR/hr				
	800 µR/hr	795	795				
	200 µR/hr	193	193				

Range(s) Calibrated Electronically

Multimeter uncertainty within 1.3% of reading, Gamma uncertainty within 5.0% of reading, Neutron uncertainty within 7.0% of reading, Count rate uncertainty within 5.4% of reading

	REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING		REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING
Digital Readout	800K cpm	800 kcpm	800 kcpm	Scaler	800K cpm	80.0K	80.0K
	200K cpm	200	200		200K cpm	20.0K	20.0K
	80K cpm	80.1	80.1		80K cpm	8.00K	8.00K
	20K cpm	20.0	20.0		20K cpm	2.00K	2.00K
	8K cpm	8.00	8.00		8K cpm	800	800
	2K cpm	2.00	2.00		2K cpm	200	200
	800 cpm	800 cpm	800 cpm		800 cpm	80	80
	200 cpm	201	201		200 cpm	20	20

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques.
All pass/fail determinations are based on the manufacturer's specifications without considering uncertainty factors.
Measurement results represent expanded uncertainties expressed at approximately the 95% level of confidence, using a coverage factor of k=2.
The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323AB-2013

ISO/IEC 17025:2017(E)
State of Texas Calibration License No. LO-1963

Reference Instruments and/or Sources: Cs-137 S/N: ☐ 059 ☐ 2171CP ☐ 2261CP ☐ 720 ☐ 734 ☐ 781 ☐ 1131 ☐ 1616 ☐ 1696 ☐ 1909 ☐ 1916CP ☐ 2324/2521 ☐ 5717CO ☐ 5719CO ☐ 60646 ☐ 70897 ☐ 73410 ☐ E552 ☐ G112 ☑ 2168CP ☐ S-394 ☐ S-1054 ☐ T10081 ☐ T10082 Neutron Am-241 Be ☐ T-304 Ra-226 ☐ Y982 ☐ E551 ☐ 5105 ☐ CSV280

☐ Alpha S/N ☐ Beta S/N ☑ Other Am241(~0.66µCi)

☑ m 500 S/N 251106 ☐ Oscilloscope S/N ☑ Multimeter S/N 15060230

Calibrator James McBeth [signature] Title Calibrator Date 3FEB20

QC'd By [signature] Title Final QC Date 3Feb20

AC Inst Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test ☐ Failed:

Order #: 20371999/489326

Customer: ENVIRONMENTAL RESTORATION GROUP

Detector: 44-10 **Serial No.:** PR355767

Instrument: Model 3000 **Serial No.:** 25016921

BKG Time: 6

Distance: Surface

Selected HV: 850

Date: Monday, February 03, 2020

Notes:

Signature: James McBett

Channel(s)

Name	Threshold
Channel 1	10 mV

Source(s)

Name	ID	Activity	Time	Type
Am241		0.66 μCi	6	γ

High Voltage	Background	Am241
	Reading	Reading
600	455	2,144
650	518	10,708
700	521	12,329
750	525	12,614
800	469	12,470
- 850	499	12,427
900	510	12,379
950	534	12,741
1000	684	12,903
1050	1,154	13,998

Ludlum Device Parameters

Product: Model 3000
Serial Number: 25016921
2/3/2020 9:54:18 AM

Device

Device Firmware	5LC-N30.4364
Device Model	Model 3000
Device Serial Number	25016921
Device Real Time Clock Day	3
Device Real Time Clock Hour	9
Device Real Time Clock Minutes	54
Device Real Time Clock Month	2
Device Real Time Clock Seconds	13
Device Real Time Clock Year	2020
Device Real Time Clock Day of the Week	5
Device Backlight Threshold	0
Device Sleep	0
Device Dual Level Audio Setting	1
Device R to Sv Ratio	0.0106
Device Log Button	0
Device Backlight Threshold Low Turn On	0
Device Backlight Threshold Low Turn Off	120
Device Backlight Threshold High Turn On	0
Device Backlight Threshold High Turn Off	100
Device Backlight On	0
Device Count Display Mode	0
Device Count Audio Mode	0
Device Rate Reset Button	0
Device Setup Protect	Normal
Device Auxiliary Enabled	1
Device Auxiliary Mode	5
Device Auxiliary Auto Power Down	0
Device Auxiliary Write Protect	0
Device Auxiliary Encryption Enabled	0
Device Area Monitor enabled	0
Device Auxiliary Enabled	0
Device Auxiliary 375-Ethernet-Mode Port	0
Device Auxiliary AutoMode Interval	1
Device Button Handle RateMap 1	1
Device Button Handle RateMap 2	31
Device Button Handle RateMap 3	31
Device Button Handle CntMap 1	1
Device Button Handle CntMap 2	31
Device Button Handle CntMap 3	31

Device Calibration

Device Calibration High Voltage Slope	24
Device Calibration High Voltage Offset	-43
Device Calibration Channel [1] Pulse Threshold Offset	5

Detector 1

Detector [1] Serial Number	PR355767
Detector [1] Model	44-10
Detector [1] High Voltage	850
Detector [1] Overload	100
Detector [1] Count Time	60
Detector [1] Operation Mode	0
Detector [1] Auto Response Rate	0
Detector [1] Response Time	0
Detector [1] Audio Sigma	0
Detector [1] Enabled	0
Detector [1] Unit [1] Rate Unit Type	R/h
Detector [1] Unit [1] Rate Min Exponet	-8
Detector [1] Unit [1] Rate Max Value	0.007
Detector [1] Unit [1] Scaler Unit Type	R
Detector [1] Unit [1] Scaler Min Exponet	-6
Detector [1] Unit [1] Rate Alarm [1]	0.007
Detector [1] Unit [1] Rate Alarm [2]	0.007
Detector [1] Unit [1] Scaler Alarm [1]	0
Detector [1] Unit [1] Scaler Alarm [2]	0
Detector [1] Unit 1 Rate Unit Type	0
Detector [1] Unit 1 Rate Min Range	0
Detector [1] Unit 1 Rate Min Decimal Point	0
Detector [1] Unit 1 Rate Max Value	0
Detector [1] Unit 1 Rate Max Range	0
Detector [1] Unit 1 Rate Max Decimal Point	0
Detector [1] Unit 1 Rate Alarm Value	0
Detector [1] Unit 1 Rate Alarm Range	0
Detector [1] Unit 1 Rate Alarm Decimal Point	0
Detector [1] Unit 1 Scaler Unit Type	0
Detector [1] Unit 1 Scaler Min Range	0
Detector [1] Unit 1 Scaler Min Decimal Point	0
Detector [1] Unit 1 Scaler Alarm Value	0
Detector [1] Unit 1 Scaler Alarm Range	0
Detector [1] Unit 1 Scaler Alarm Decimal Point	0
Detector [1] Unit [2] Rate Unit Type	cpm
Detector [1] Unit [2] Rate Min Exponet	0
Detector [1] Unit [2] Rate Max Value	999000
Detector [1] Unit [2] Scaler Unit Type	counts
Detector [1] Unit [2] Scaler Min Exponet	0
Detector [1] Unit [2] Rate Alarm [1]	0
Detector [1] Unit [2] Rate Alarm [2]	999000
Detector [1] Unit [2] Scaler Alarm [1]	0
Detector [1] Unit [2] Scaler Alarm [2]	0
Detector [1] Channel [1] Pulse Threshold	10
Detector [1] Channel [1] Dead Time Correction	7.4
Detector [1] Channel [1] Dead Time Correction 2	0
Detector [1] Channel [1] Loss of Count Time	60
Detector [1] Channel [1] Calibration Constant	5.37E+10
Detector [1] Channel [1] Calibration Constant Exponent	0
Detector [1] Channel [1] Efficiency 4pi	15
Detector 1 Channel 1 CPSOffset	0

K&S Associates, Inc.
1926 Elm Tree Drive
Nashville, Tennessee 37210-3718
Phone 800-522-2325 Fax 615-871-0856

ACCREDITED
CALIBRATION CERT #1866.01

ACCREDITED DOSIMETRY CALIBRATION LABORATORY

CALIBRATION REPORT

SUBMITTED BY: ERG
8809 Washington Street Northeast
Suite 150
Albuquerque, NM 87113

INSTRUMENT: Reuter Stokes RS-S131-200-ER0000 , #1001321

REPORT NUMBER: 191877

TEST NUMBER(S): M191724

REPORT DATE: August 08, 2019

The CALIBRATION COEFFICIENTS contained in this report were obtained by intercomparison with instruments calibrated by, or directly traceable to, the National Institute of Standards and Technology (NIST). K • S Associates, Inc. is licensed by the State of Tennessee to perform calibrations, and is accredited by the American Association for Laboratory Accreditation (A2LA) and the results shown is this report have been determined in accordance with this laboratory's accreditation unless stated otherwise. As part of the accreditation K • S participates in a measurement assurance program conducted by the AAPM and NIST. K • S also certifies that the calibration was performed using quality policies, methods and procedures that meet or exceed the requirements of ANSI/ISO/IEC 17025:2005.

The calibration result(s) stated herein are valid under the conditions and parameters specified in this report. It is the instrument user's responsibility to perform the appropriate constancy tests prior to shipment and after return from calibration. It is also the responsibility of the user to assure that the interpretation of the information in this report is consistent with that intended by K • S Associates, Inc.

CALIBRATION CERTIFICATE

Calibration Date: 8/7/2019 Report Number: 191877 Test Number: M191724

K&S certifies that the environmental radiation monitor identified below has been calibrated for radiation measurement using collimated radiation sources whose output has been calibrated with instruments calibrated by or directly traceable to the National Institute of Standards and Technology. K&S is accredited by the American Association for Laboratory Accreditation to perform environmental level calibrations and further certifies that the calibration was performed using accredited policies and procedures (SI 25) that meet or exceed the requirements of ISO/IEC 17025:2005.

Sensor Type: 100 R/h

Serial Number: 1001321

Average Calibration Coefficient for the range of 0.012 mR/h – 0.22 mR/h*:
0.99 mR/"mR" reading
(Measured at 4 points)

Calibration Coefficient for the 50.0 mR/h point*:
1.02 mR/"mR" reading

Calibration Coefficient for the 80.0 mR/h point*:
1.02 mR/"mR" reading

Found Sensitivity: 2.294e-8
Left Sensitivity: 2.206e-8

*Multiply the reading in **mR/h** by the Calibration Coefficient to obtain true **mR/h**.

Calibrated By: Richard Hardison Reviewed By: [signature]
Richard Hardison
Title: Calibration Technician Title: Director

Log: M-68

K&S Associates, Inc
Nashville, Tennessee 37210-3718

ACCREDITED
CALIBRATION CERT #1866.01

AS FOUND DATA
Reuter-Stokes Chamber Calibration

August 07, 2019 — ***Test Number*** *M191724*

CHAMBER:

Mfgr: Reuter Stokes
Model: RS-S131-200-ER0000
Serial: 1001321

SUBMITTED BY:

ERG

Albuquerque, NM

ORIENTATION/CONDITIONS:

Serial number away from source

"True" background exposure rate of 6.7 uR/h, instrument reading was 7.2 uR/h

ATMOSPHERIC COMMUNICATION: SEALED

POLARIZING POTENTIAL 401.3V

LEAKAGE: negligible

BEAM QUALITY				CALIBRATION		
BEAM		**EXPOSURE RATE**		**COEFFICIENT**	**UNCERT**	**LOG**
CsEn220	(11mCi)	0.22mR/h	N_x=	1.04 mR/h/rdg	11%	M-68

Comments Batt: 7.9V, P: 0.998 bar, K&S Environment: Temp: 21 deg C , RH 51%, Press: 747 mmHg;
Report Number: 191877
Refer to Appendix I of this report for details on PIC ionization chamber calibrations. Procedure: SI 25
Sensitivity Found: 2.294e-8

Calibrated By Richard Hardison
Title: Richard Hardison, Calibration Technician

Reviewed By: [signature]
Title: Director

Checked By: [signature] **Prepared By:** REH

Form RSS

K&S Associates, Inc
Nashville, Tennessee 37210-3718

ACCREDITED
CALIBRATION CERT #1866.01

AS LEFT DATA
Reuter-Stokes Chamber Calibration

August 07, 2019 *Test Number* *M191724*

CHAMBER:

Mfgr: Reuter Stokes
Model: RS-S131-200-ER0000
Serial: 1001321-

SUBMITTED BY:

ERG

Albuquerque, NM

ORIENTATION/CONDITIONS:

Serial number away from source
"True" background exposure rate of 6.7 uR/h, instrument reading was 7.2 uR/h

ATMOSPHERIC COMMUNICATION: SEALED

POLARIZING POTENTIAL 401.3V

LEAKAGE: negligible

BEAM QUALITY BEAM		EXPOSURE RATE		CALIBRATION COEFFICIENT	UNCERT	LOG
CsEn220	(11mCi)	0.22mR/h	N_x=	1.00 mR/h/rdg	11%	M-68
CsEn80	(11mCi)	0.08mR/h	N_x=	1.00 mR/h/rdg	11%	
CsEnv12	(1mCi)	0.012mR/h	N_x=	0.98 mR/h/rdg	11%	
CsEnv15	(1mCi)	0.015mR/h	N_x=	0.97 mR/h/rdg	11%	
Cs199m	(20 Ci)	50mR/h	N_x=	1.02 mR/h/rdg	8%	
Cs252m	(20 Ci)	80mR/h	N_x=	1.02 mR/h/rdg	8%	

Comments Batt: 7.9V, P: 0.998 bar, K&S Environment: Temp: 21 deg C , RH 51%, Press: 747 mmHg;
Report Number: 191877 Due Date: 8/7/2020
Refer to Appendix I of this report for details on PIC ionization chamber calibrations. Procedure: SI 25
Sensitivity Left: 2.206e-8

Calibrated By Richard Hardison **Reviewed By:** [signature]

Title: Richard Hardison Calibration Technician **Title:** Director

Checked By: [initials] **Prepared By:** RGH

Form RSS

Test Number: M191724 **Report Number:** 191877

Appendix I

Pressurized Ion Chambers
& Reuter-Stokes Units

CALIBRATION COEFFICIENTS:

EXPOSURE CALIBRATION COEFFICIENTS (N_X)

R/RDG: Roentgen/reading calibration coefficients apply to the chamber-electrometer-readout system as a unit, with scales, switch settings and output mode specified. To obtain the exposure in Roentgens at the reference point*, in the absence of the chamber, the calibration coefficient is applied directly to the instrument reading corrected for temperature and pressure:

$$Exposure = RDG \cdot R/RDG$$

R/C: Roentgen/Coulomb calibration coefficients apply to the ion chamber alone. To obtain the exposure in Roentgens at the reference point*, in the absence of the chamber, an appropriately calibrated (Coulomb/reading) electrometer must be used.

$$Exposure = RDG \cdot R/C \cdot C/RDG$$

where C/RDG = calibration coefficient of electrometer

If the unit has been adjusted during the calibration, a separate data page is provided to show the calibration coefficients as found before adjustment.

* The reference point is the center of the radiation field at the appropriate distance for the dose rate shown on the calibration data page.

ENVIROMENTAL CONDITIONS:

The background radiation level in the Environmental Laboratory is continuously monitored using a pressurized ion chamber calibrated by or directly traceable to the National Institute for Standards and Technology (NIST).

The typical background rate is between six and seven micro-Roentgen per hour. Background spectrums are periodically measured with an HP Ge detector and compared to previous spectrums. The prevailing background is reported at the time of calibration.

The room scatter at each calibration position has been evaluated and found to be negligible.

CALIBRATION CONDITIONS:

The calibration is performed using a collimated Cesium-137 source calibrated with an ion chamber calibrated by NIST. Periodically, the working ion chamber is compared to an pressurized ion chamber calibrated by the National Physical Laboratory of the United Kingdom and an Exradin ion chamber calibrated by NIST.

Biannually, K&S participates in a Proficiency Test conducted by NIST and supervised by the Health Physics Society's Laboratory Accreditation Policy Committee.

The calibration distance from the source to the instrument center, ambient conditions and other physical data are stated on each calibration page.

UNCERTAINTY:

The best combined expanded uncertainty with a coverage factor k=2 of the reference exposure or air kerma is 11%. This value is twice the quadratic sum of the laboratory uncertainty and the uncertainty stated by NIST for the calibration of the transfer standards used by K&S. It is believed to have the approximate significance of the 95% confidence limit.

SHADOW SHIELD CALIBRATION METHOD:

In some cases a customer may specifically request the use of the shadow shield calibration method of calibration. The shadow shield method of calibration of an instrument is an older method used to calibrate an instrument with a source that was calibrated for activity content or dose rate by NIST or a secondary laboratory in open air. It consists of an initial measurement at a distance from a calibrated source and then placing a shield between the source and the instrument that shields only the instrument in order to measure room scatter. Subtracting the room scatter component from the initial measurement provides the net reading of the instrument from the calibrated source. When this method is used, it is noted on the page with the calibration coefficient.

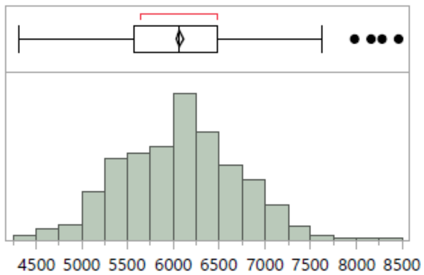
Present day methods with collimated sources standardized with NIST traceable instruments are equivalent to the shadow shield method and less labor intensive. They involve a replacement technique using a NIST traceable instrument to calibrate a collimated source at a specific distance and then placing the instrument at the same position to calculate the calibration coefficient. Room scatter is initially investigated to ensure that it is below an acceptable level within a specified range of operation. However, since the collimated source almost totally eliminates room scatter and since both the calibration standard and the instrument being calibrated see the same contribution from scatter, the scatter components cancel in the calculation of the calibration coefficient.

Appendix B

Operational Material and Background Gamma Survey Distributions

Distributions Area=Borrow Area

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	8460
99.5%		7783.8
97.5%		7216.5
90.0%		6900
75.0%	quartile	6480
50.0%	median	6060
25.0%	quartile	5580
10.0%		5280
2.5%		4920
0.5%		4560
0.0%	minimum	4320

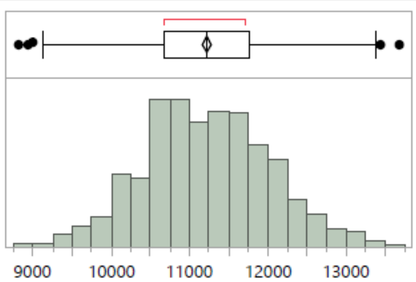
Summary Statistics

Mean	6067.467
Std Dev	626.57024
Std Err Mean	20.793464
Upper 95% Mean	6108.2759
Lower 95% Mean	6026.6581
N	908

Figure B 1. Borrow area operational material distribution

Distributions Area=Clay

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	13680
99.5%		13298.4
97.5%		12876
90.0%		12264
75.0%	quartile	11760
50.0%	median	11220
25.0%	quartile	10680
10.0%		10200
2.5%		9660
0.5%		9081.6
0.0%	minimum	8820

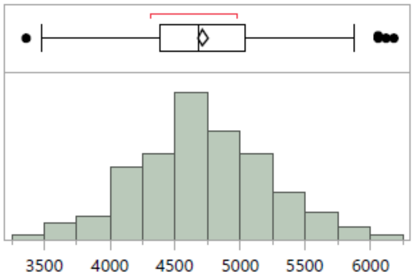
Summary Statistics

Mean	11219.02
Std Dev	805.191
Std Err Mean	29.699918
Upper 95% Mean	11277.327
Lower 95% Mean	11160.713
N	735

Figure B 2. Clay area operational material distribution

Distributions Area=Gravel Lot

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	6180
99.5%		6060
97.5%		5760
90.0%		5400
75.0%	quartile	5040
50.0%	median	4680
25.0%	quartile	4380
10.0%		4080
2.5%		3720
0.5%		3480
0.0%	minimum	3360

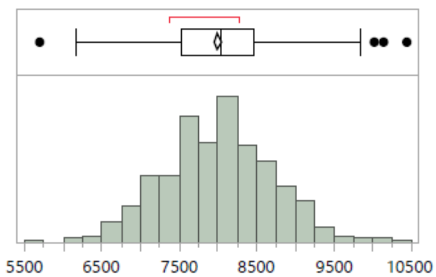
Summary Statistics

Mean	4713.4259
Std Dev	506.35466
Std Err Mean	19.89149
Upper 95% Mean	4752.4856
Lower 95% Mean	4674.3663
N	648

Figure B 3. Gravel lot operational material distribution

Distributions Area=Offsite 01

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	10440
99.5%		9910.2
97.5%		9417
90.0%		8880
75.0%	quartile	8460
50.0%	median	8040
25.0%	quartile	7530
10.0%		7080
2.5%		6720
0.5%		6240
0.0%	minimum	5700

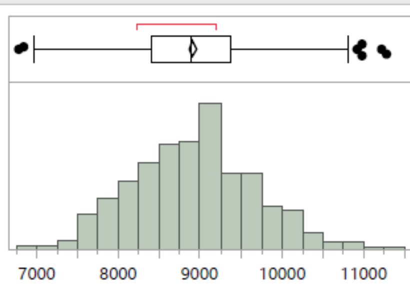
Summary Statistics

Mean	7994.3967
Std Dev	689.72998
Std Err Mean	25.686887
Upper 95% Mean	8044.8268
Lower 95% Mean	7943.9665
N	721

Figure B 4. Offsite #1 operational material distribution

Distributions Area=Offsite 02

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	11280
99.5%		10980
97.5%		10380
90.0%		9840
75.0%	quartile	9360
50.0%	median	8880
25.0%	quartile	8400
10.0%		7980
2.5%		7524
0.5%		7118.4
0.0%	minimum	6780

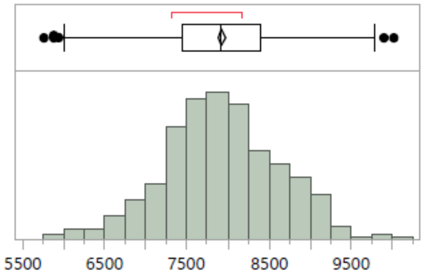
Summary Statistics

Mean	8911.0452
Std Dev	730.68147
Std Err Mean	26.246853
Upper 95% Mean	8962.5686
Lower 95% Mean	8859.5217
N	775

Figure B 5. Offsite #2 operational material distribution

Distributions Area=Reagent

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	10020
99.5%		9780
97.5%		9240
90.0%		8820
75.0%	quartile	8400
50.0%	median	7920
25.0%	quartile	7440
10.0%		7080
2.5%		6540
0.5%		5977.5
0.0%	minimum	5760

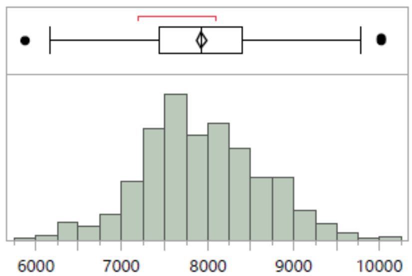
Summary Statistics

Mean	7921.6883
Std Dev	684.45656
Std Err Mean	22.516968
Upper 95% Mean	7965.8787
Lower 95% Mean	7877.4979
N	924

Figure B 6. Reagent area operational material distribution

Distributions Area=North Perimeter

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	10020
99.5%		9766.2
97.5%		9300
90.0%		8820
75.0%	quartile	8400
50.0%	median	7920
25.0%	quartile	7440
10.0%		7080
2.5%		6480
0.5%		6180
0.0%	minimum	5880

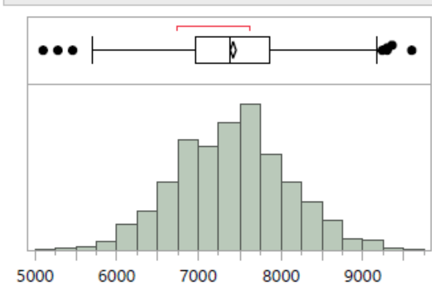
Summary Statistics

Mean	7931.0932
Std Dev	687.62029
Std Err Mean	27.571062
Upper 95% Mean	7985.2371
Lower 95% Mean	7876.9494
N	622

Figure B 7. North perimeter background distribution

Distributions Area=South Perimeter

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	9600
99.5%		9180
97.5%		8748
90.0%		8280
75.0%	quartile	7860
50.0%	median	7380
25.0%	quartile	6960
10.0%		6540
2.5%		6132
0.5%		5700
0.0%	minimum	5100

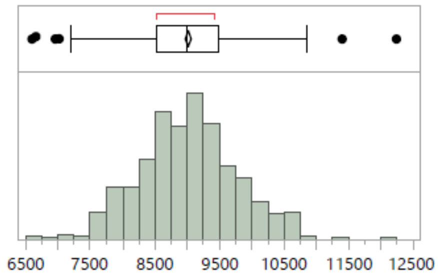
Summary Statistics

Mean	7412.9627
Std Dev	673.07249
Std Err Mean	18.204451
Upper 95% Mean	7448.6744
Lower 95% Mean	7377.251
N	1367

Figure B 8. South perimeter background distribution

Distributions Area=East Perimeter

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	12240
99.5%		10860
97.5%		10560
90.0%		9960
75.0%	quartile	9480
50.0%	median	9000
25.0%	quartile	8520
10.0%		8040
2.5%		7680
0.5%		7011.3
0.0%	minimum	6600

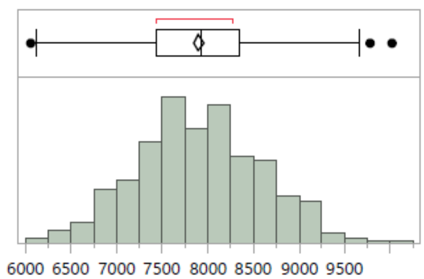
Summary Statistics

Mean	9018.3896
Std Dev	738.78507
Std Err Mean	26.623966
Upper 95% Mean	9070.6539
Lower 95% Mean	8966.1253
N	770

Figure B 9. East perimeter background distribution

Distributions Area=West Perimeter

Gamma Count Rate (CPM)



Quantiles

100.0%	maximum	10020
99.5%		9654.6
97.5%		9180
90.0%		8820
75.0%	quartile	8340
50.0%	median	7920
25.0%	quartile	7440
10.0%		7020
2.5%		6613.5
0.5%		6128.1
0.0%	minimum	6060

Summary Statistics

Mean	7898.7829
Std Dev	673.485
Std Err Mean	27.313423
Upper 95% Mean	7952.4232
Lower 95% Mean	7845.1426
N	608

Figure B 10. West perimeter background distribution

Appendix C

Technical Memorandum - Gamma Radiation Detector Modeling Using Microshield to Approximate UAV Detection Sensitivity

Technical Memorandum

To:	Chemical Waste Management of the Northwest
From:	Environmental Restoration Group, Inc. and K2 Environmental
Date:	August 28, 2020
Subject:	Gamma Radiation Detector Modeling Using Microshield to Approximate UAV Detection Sensitivity

Environmental Restoration Group (ERG), in collaboration with K2 Environmental, were asked to evaluate the potential effectiveness of using an unmanned aerial vehicle to survey Landfill 14 at Chemical Waste Management in Arlington, Oregon. The team used Microshield version 9.07 (Grove Software 2014) to estimate the response in μR/hr to a dose point in air from gamma radiation. The response was modeled to emulate a sodium iodide (NaI) detector at varying heights over a source of fixed dimensions with a varying thickness of soil cover over the source. The modeling was performed to estimate the minimum detectable count rate (MDCR) that can be achieved using a UAV-mounted detector.

Microshield was used to model the exposure rate over a source of radium-226 in equilibrium with its daughters. The model was designed to simulate the response of a detector mounted to a UAV over a collection of Bakken oilfield waste. It should be noted that this type of survey primarily addresses surface gamma dose rates and is not capable of detecting waste buried deep within the landfill. In order to calculate the depth at which the detector could identify a load of Bakken oilfield waste, several variables were considered including the response rate of the detector, elevation above the source, and varying thicknesses of soil cover on top of the source. The geometry of the source and soil cover is shown in Figure 1. The following assumptions and parameters were used for the model.

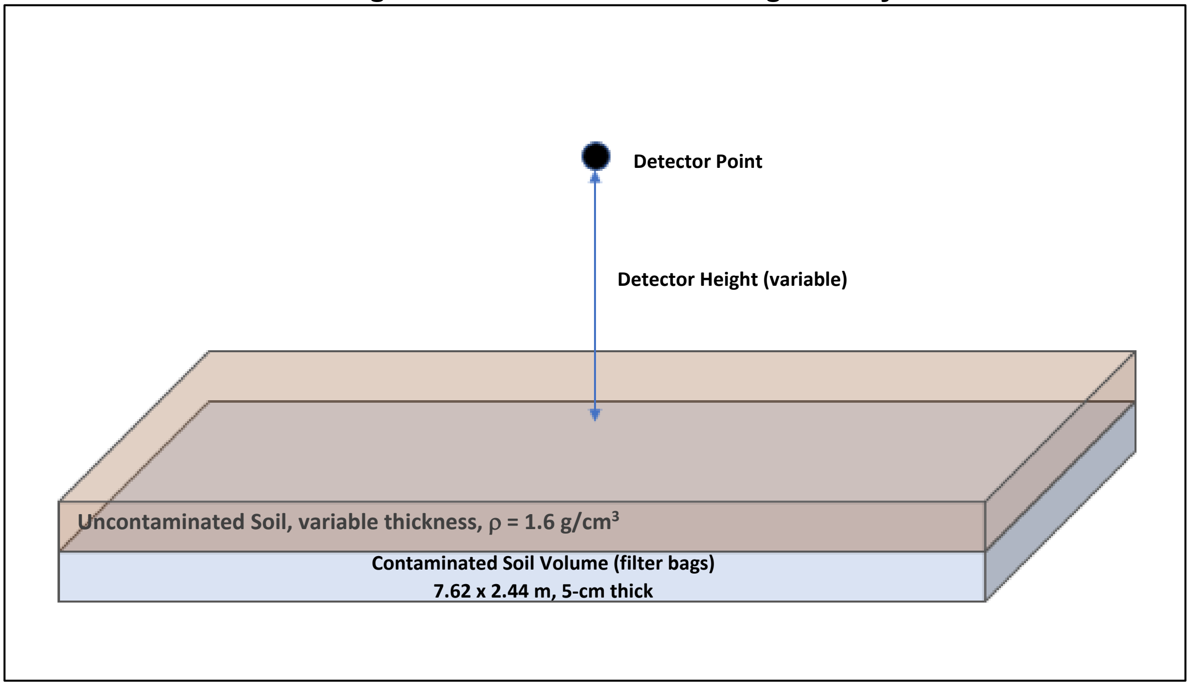
- The size of the source size was 7.62 m by 2.44 m and 5 cm thick. The condition assumes a typical truck load of Bakken oilfield waste homogenously distributed onto the ground surface.
- Both the source and the shielding material were modeled using a composition of soil as shown in Table 1.
- The density of the Bakken Oilfield waste was 1.31 g/cm^3 and the shielding soil was 1.6 g/cm^3.
- The source was modeled as radium-226 in equilibrium with its daughters at a concentration of 142 picocuries per gram (pCi/g) and 75 pCi/g to represent the maximum and average concentration of the Bakken oilfield waste, according to laboratory results.
- The model neglects the contribution of photons scattered from soil beneath, and around the source.
- The results account for buildup of photons occurring within the shielding soil cover.
- Background exposure rate at the site was assumed to be 12 uR/hr.

- The detector point was assumed to be stationary above the source. When considering the UAV, the approach assumes that the UAV is over the source for a minimum of one counting interval to approximate the response while flying over the source. The detector recorded one counting interval per second. The approach neglects the worst-case scenarios of the UAV covering half of the 2.44-m dimension of the source during a counting interval, or straddling the source due to the transect spacing of 5-m. These factors are likely to be outweighed by the conservative assumption of the source having a thickness of 5 cm. An actual truck load of material is expected to have a greater volume of material and different geometry which will significantly affect the detection sensitivity as will be discussed below.
- The detector was modeled at heights of 3.5- and 5-meters above the ground surface for the 142 pCi/g source, and at 3-m above the ground surface for the 75 pCi/g source.

Table 1. Soil Composition

Element	Composition (by fraction)
O	0.5134
Na	0.006
Si	0.2764
Ti	0.0045
Al	0.013
Ca	0.014
Fe	0.0007

Figure 1. Source and detector geometry



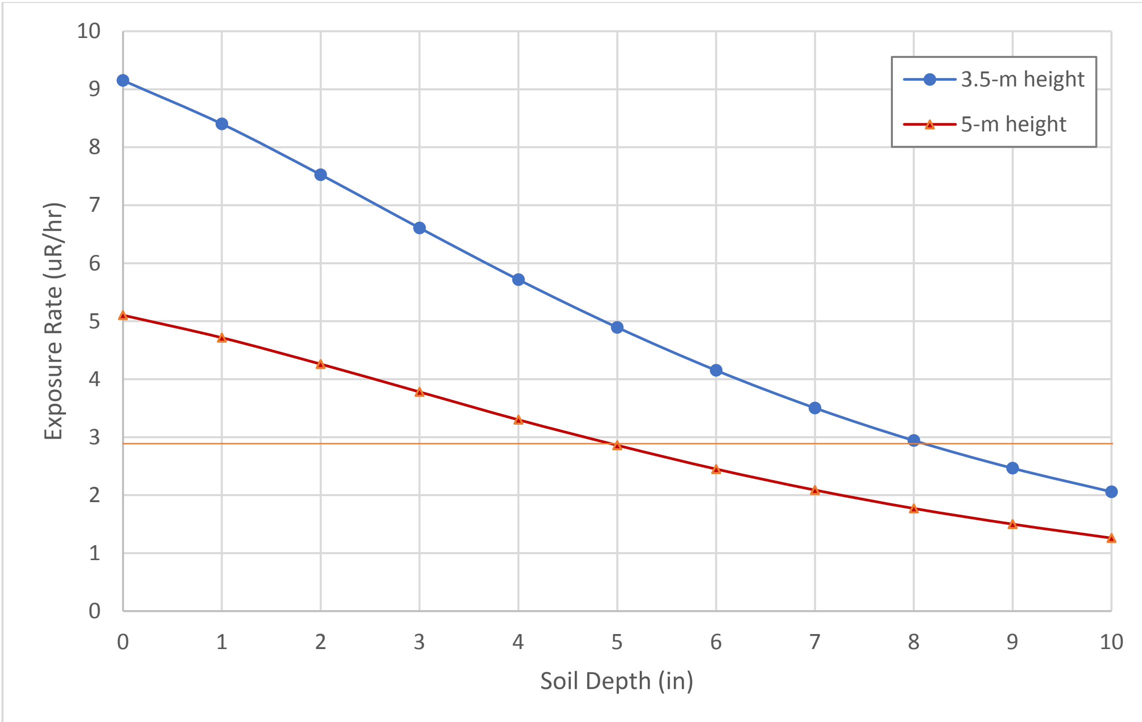
Notes:

μR/hr	Micro Roentgen per hour
in	inches
m	meters
g/cm^3	grams per cubic centimeter

Using the assumed background of 11,000 counts per minute (cpm) at the site for a 2-in by 2-in NaI detector, the minimum detectable count rate (MDCR) was calculated using the MDCR formula in NUREG-1507 for a one-second counting interval (USNRC, 1998). The MDCR of 2,665 cpm was converted to the minimum detectable exposure rate (MDER) of 2.96 uR/hr using the Ludlum calibration constant of 900 cpm/uR/hr for the 2x2 NaI detector.

The Microshield model results for the 143 pCi/g source are shown in Figure 2. The results indicate that for no soil cover, both the 3.5- and 5-m detector heights are capable of detecting the source above the MDER of 2.96 uR/hr. When the UAV is 3.5-m above the surface, the results indicate that the source is detectable when up to 8-inches of soil are covering the source. The soil cover depth drops to approximately 5 inches for the 5-m detector height.

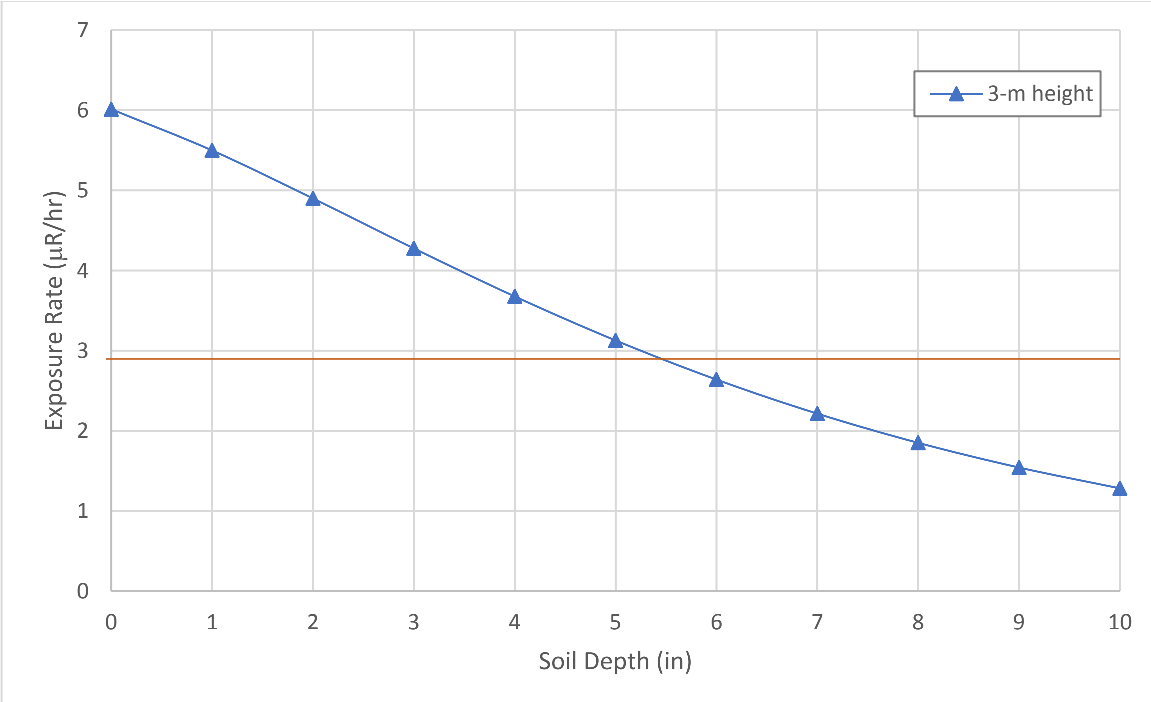
Figure 2. Microshield model results of exposure rate for 143 pCi/g source with varying soil cover thickness



Notes:
pCi/g Pico Curies per gram
μR/hr Micro Roentgen per hour
in inches
m meters
Horizontal line represents minimum detectable count exposure rate of a 2x2 sodium iodide detector.

The results of the 75 pCi/g source are shown in Figure 3. The results demonstrate that the detector can detect the source at a depth of approximately 5.5 inches of soil cover.

Figure 3. Microshield model results of exposure rate for 75 pCi/g source with varying soil cover thickness



Notes:

pCi/g	Pico Curies per gram
µR/hr	Micro Roentgen per hour
in	inches
m	meters

Horizontal line represents minimum detectable exposure rate of a 2x2 sodium iodide detector.

The simulated results assume a relatively thin source thickness of 5-cm. Considering different geometries and source thicknesses has a major impact on the detection sensitivity. To illustrate this point, the following example is described. Using the methodology in Alecksen and Whicker (2016), the minimum detectable concentration (MDC) for a cylindrical source of 5-m diameter, near-infinite thickness, scanning speed of 3 m/s, and a detector height of 3 m can be approximated as 10.5 pCi/g. The MDC drops to 4.5 pCi/g when considering a source of 10-m diameter using the same scanning conditions.

Based on the simulation results and methodology used, the following observations and conclusions can be made:

- For the assumed source size, the detector can delineate the 75 and 143 pCi/g sources buried beneath approximately 5 inches of soil when flying at elevations lower than 5-m above the ground surface.
- The detection limits expressed in this technical memo represent a single occurrence of a one-second counting interval using a false-positive rate of 5 percent. When spatially evaluating data macroscopically for an entire survey of thousands of records, it is likely that sources may be detectable at concentrations lower than the detection limits by

showing as the clustering of data in the false-positive range (Alecksen and Whicker, 2016).

- The source size used for this technical memo is provided as an example based on an assumed size for a truck load of filter bags. The detector may detect smaller areas of contamination at higher concentrations, or larger areas of contamination at lower concentrations.

REFERENCES

Alecksen, T. and Whicker, R. 2016. *Scan MDCs for GPS-Based Gamma Radiation Surveys. Operational Radiation Safety*, Health Physics 111 (Supplement 2): S123-S132.

Grove Software. 2014. "Microshield Radiation Software, Version 9.07." https://www.radiationsoftware.com/microshield.

U.S. Nuclear Regulatory Commission (USNRC). 1998. *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions.* NUREG-1507. Division of Regulatory Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555-001.

Attachment C

TENORM Dose and Radiological Risk Assessment

science › environment › community

September 1, 2020

FINAL REPORT

CWMNW Arlington, OR

Chemical Waste Management of the Northwest, Inc., Landfill Radiological Dose and Risk Assessment for Bakken Oilfield Waste Disposals in Arlington, OR

Submitted to Waste Management

RAC Report No. 06-CWMNW Arlington-2020-FINAL

RAC RISK ASSESSMENT CORPORATION

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September 1, 2020

FINAL REPORT
CWMNW Arlington, OR

Chemical Waste Management of the Northwest, Inc., Landfill Radiological Dose and Risk Assessment for Bakken Oilfield Waste Disposals in Arlington, OR

Authors
Emily A. Caffrey, Ph.D., Radian Scientific, LLC
Arthur S. Rood, M.S., K-Spar, Inc.
Helen A. Grogan, Ph.D., Cascade Scientific, Inc.
Colby D. Mangini, Ph.D., CHP, Paragon Scientific, LLC

Principal Investigator
John E. Till, Ph.D., Risk Assessment Corporation

RAC Report No. 06-Arlington Landfill-2020-FINAL

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Executive Summary

This radiological dose and risk assessment was conducted by Risk Assessment Corporation (RAC) on behalf of Chemical Waste Management of the Northwest, Inc. (CWMNW) in response to the Oregon Department of Energy (ODOE) Notice of Violation (DOE-NOV) dated February 13, 2020. This report addresses the dose and health risks from the disposal of specific technologically enhanced naturally occurring radioactive materials (TENORM, referred to as Bakken oilfield waste in this report) and for two hypothetical remediation alternatives: a leave-in-place option and an excavate- and-remove option.

The Bakken oilfield waste originated in the Bakken oilfields of North Dakota and is a byproduct of oil and natural gas production. In total, an estimated 1,285 tons of waste were received between May 2, 2016, and September 16, 2019, delivered in a total of 64 loads. The majority of the waste, roughly 80%, was filter socks. Maximum, or worst-case and weighted-average source terms were calculated. This was done to ensure potential doses and associated risks were not underestimated for the relevant exposure scenarios discussed herein.

The assessment was conducted using widely accepted computational methods and models coupled with available and generated site-specific data, where possible. For atmospheric pathways, EPA's AP-42 Compilation of Air Emissions Factors and Air Dispersion Modeling Software AERMOD were used. The Mixing Cell Model (MCM) code was used to evaluate the groundwater pathway. This code has been implemented at both the Idaho National Laboratory and at the U.S. Ecology Site on the Hanford Reservation.

To assess the risk associated with the past disposal activities, individuals who could have been or were potentially exposed (referred to as receptors) were identified for each exposure scenario. During waste disposal, the maximally exposed receptor was the waste handler—i.e., the person who drove the truck at the landfill and operated the trailer controls during disposals. Natural background dose, on average, for persons in the United States is 311 mrem per year. The maximum one-time dose during the disposals was 3.3 mrem total to the waste handler, or 94 times lower than the continuous annual exposure from natural background. The only viable exposure pathway to members of the public during disposals was potential inhalation of the subject material that may have become airborne and potentially blown off-site. The estimated maximum dose to the off-site resident was determined to be negligible at 0.00000076 (7.6×10^{-7}) mrem per year, which is essentially zero.

As part of this risk assessment, two possible remediation alternatives were identified and quantified to determine their viability and future risk potential. These are described fully in the Corrective Action Plan (Gradient 2020). Alternative 1 assumes the waste is left in place and normal landfill operations continue until closure per the CWMNW permit. Alternative 2 assumes the waste is excavated and trucked to an off-site disposal location.

For Alternative 1, the maximally exposed receptor is a hypothetical on-site resident who lives on top of the landfill after it closes sometime in the distant future. This scenario is extremely unlikely and assumes the failure of the long-term land use restrictions that are required to be in place following closure of the landfill. The on-site resident is assumed to draw groundwater from the immediate downgradient edge of the disposals, despite the fact that this water is not potable and not sufficient to support a family; thus, this represents an extremely pessimistic scenario. To assess the most conservative, or upper-bound, exposure scenario, a hypothetical future intruder is assumed to live on the site and drill a water well through the waste. The intruder is assumed to use the drill cuttings in the foundation for a home. Further, an ecological assessment was conducted to ensure that the environment is adequately protected.

For the leave-in-place alternative, the maximum dose in a given year post closure to the hypothetical future on-site resident assuming the maximum source term was very low at 0.12 mrem. This does not occur until 260,000 years into the future. This dose assumes that the person is utilizing a water well located at the immediate downgradient edge of the disposals, which is an extreme worst-case scenario. The dose to the inadvertent intruder was predictably higher than that calculated for the hypothetical future on-site resident, but still very low at a maximum of 1.02 mrem. The ecological assessment demonstrates that doses to ecological receptors were well below the threshold where deleterious effects are likely to occur.

For Alternative 2, the excavate-and-remove option, the maximally exposed receptor is the remediation project supervisor, assumed to be on the ground during removal operations to ensure they are conducted safely. The total dose to the supervisor during hypothetical removal operations is estimated at approximately 46 mrem.

Doses for the excavate-and-remove alternative were substantially higher than those during disposals or for the leave-in-place alternative. This report does not address the risks associated with potentially disturbing the chemical and hazardous wastes that are safely disposed in the landfill. Disturbing these wastes during the excavation of the Bakken oilfield waste is ill-advised since comingling of previously disposed and properly sequestered chemical and hazardous wastes could reasonably be expected to create unplanned mixtures of unidentifiable chemicals, which would lead to unknown management challenges and unknown risks to the local community.

This assessment has demonstrated that maximum doses that may have been received by workers on the site and to the public from the disposal of the Bakken oilfield wastes were minimal and negligible when compared to radiation exposures received from natural and other man-made sources. Radiological doses were higher for the excavate-and-remove alternative. A full comparison of the potential risks for each remediation alternative is presented in the corrective action plan (CAP) (Gradient 2020).

Contents

Figures

Tables

Acronyms and Abbreviations

BRLF	Blue Ridge Landfill
Bq	Becquerel, SI unit of radioactivity
C	Coulomb, SI unit of electric charge
CAP	Corrective action plan
Ci	Curie, imperial unit of radioactivity
EPA	U.S. Environmental Protection Agency
ICRU	International Commission on Radiation Units and Measurements
ICRP	International Commission on Radiological Protection
KY	Kentucky
MSW	Municipal Solid Waste
NCRP	National Council on Radiation Protection and Measurements
NORM	Naturally occurring radioactive materials
NRC	U.S. Nuclear Regulatory Commission
R	Roentgen, imperial unit of exposure
RAC	Risk Assessment Corporation
SI	Système international d'unités (International System of Units)
TENORM	Technologically enhanced naturally occurring radioactive materials

Scientific Notation (E-format)

Some of the numbers in this report are presented in scientific notation. Scientific notation is useful for presenting very large or very small numbers, or numbers that are different by many orders of magnitude. In scientific notation, numbers are expressed as the product of two terms: a digit term and an exponential term. For example, the number 723 expressed in scientific notation would be 7.23×10^2 where 7.23 is the digit term and 10^2 (10 raised to the power of 2 or 100) is the exponential term. The power is the number of places to shift the decimal point to present the number in long format. If the power is positive, then shift the decimal point to the right. If the power is negative, then shift the decimal point to the left. Here are some examples.

$$4{,}231 = 4.231\times10^3$$
$$1{,}230{,}000 = 1.23\times10^6$$
$$0.0361 = 3.61\times10^{-2}$$

Computers print scientific notation in a slightly different format where the exponential term is reported as “E” followed by the power term. Thus, in the preceding example, 723 in computer scientific notation is 7.23E+02. Both forms of scientific notation are used in this report. Finally, for numbers between 1 and 10, the power term is zero because any number raised to the zero power is 1. Thus 7.23 expressed in scientific notation is 7.23×10^0 or 7.23E+00 in computer scientific notation.

Unit Conversions and Radiation Dose Terminology

Imperial unit	SI unit
Radiation activity	
1 Ci	3.7×10^{10} Bq
~27 pCi L^{-1} or pCi m^{-3} or pCi kg^{-1}	1 Bq L^{-1} or Bq m^{-3} or Bq kg^{-1}
Radiation dose quantities	
100 rad	1 Gy
100 mrem	1 mSv
100 µrem hr^{-1}	1 µSv hr^{-1}
Other	
3.9×10^3 Roentgen	1 C kg^{-1}

Exposure, R, is a quantity that is defined only for photons in air. Ion chambers directly measure exposure (Roentgen, R or C kg^{-1}), which can be converted to dose as follows:

1 R ≈ 0.869 rad (8.69 mGy) in air and ≈ 0.87 rem (8.7 mSv). The exact conversion is found in ICRU (1962) and includes temperature as well as absorption coefficients of tissue and air for the appropriate photon energy. For safety purposes only, an approximation of 1 R = 1 rad = 1 rem is frequently utilized.

Absorbed Dose or Dose, *D*
Units: rad or Gy
Equation: $D = \frac{\text{energy}}{\text{mass}}$
Absorbed dose is a measure of energy absorbed per unit mass in a material or tissue.

Dose Equivalent, H_T, ($\dot{H}$ for dose rates)
Units: rem or Sv
Equation: $H_T = D \times w_R$
The product of the absorbed dose in tissue and the radiation-specific quality factor, w_R, that considers radiation type and its biological effect ($w_{R\alpha}$=20; $w_{R\beta}$=1; $w_{R\gamma}$=1).

Effective Dose, *E*
Units: rem or Sv
Equation: $E = \sum_T w_T \times H_T$

E is the sum of the product of the dose equivalent to the organ or tissue (H_T) and the tissue-weighting factor (w_T) applicable to each of the body organs or tissues that are irradiated. The tissue weighting factors, w_T, reflect the relative radiosensitivities of the various organs and tissues of the body from stochastic effects (cancer and heritable effects). The weighting factors are normalized to unity and thus the effective dose is equivalent to a hypothetical uniform irradiation of the body called whole body dose. The effective dose is a convenient quantity for regulating radiation exposure and is not appropriate for epidemiological studies where organ-specific dose is required.

Common Unit Prefixes

p	pico	10^{-12}
μ	micro	10^{-6}
m	milli	10^{-3}
k	kilo	10
M	mega	10^{6}

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1. Introduction

This Dose and Risk Assessment report has been prepared by Risk Assessment Corporation (RAC) on behalf of Chemical Waste Management of the Northwest, Inc. (CWMNW) in response to the Oregon Department of Energy (ODOE), Notice of Violation (DOE-NOV) dated February 13, 2020. Pursuant to the DOE-NOV and subsequent discussions with the Department, this report provides a quantitative evaluation of past, present, and future potential health risk to reasonably anticipated human receptors resulting from potential exposure to Bakken oilfield waste materials disposed at the CWMNW facility in Arlington, OR, between 2016 and 2019.

1.1. Scope and Background

This report addresses the dose and health risks from both the disposal and hypothetical remediation alternatives for the estimated 1,285 tons of waste received from Bakken oilfield sites. The waste was transported by third parties and disposed of in Landfill Unit L-14 at the CWMNW facility located in Arlington, OR, between May 2, 2016, and September 16, 2019.

The Bakken oilfield wastes originated from a contractor performing liquid management and water recycling services for oil and gas industry customers in North Dakota. The DOE-NOV described these wastes as technologically enhanced naturally occurring radioactive material (TENORM) subject to the disposal prohibition in ORS 469.525 and OAR 345-050.

This report uses the waste characteristics, radionuclide composition, details of the disposal facility design and operations, and the types of persons likely to be exposed to these radionuclides to quantify the doses and risks to humans during and following the disposal process. To quantify the potential doses and risks in the distant future (i.e., centuries), the potential for radionuclide transport to the subsurface from groundwater is also evaluated.

This report also quantifies potential radiological health risks for two corrective action scenarios identified by ODOE:

1) In-situ closure (“closure-in-place”)
2) Hypothetical exhumation, transportation, and redisposal of all Bakken and comingled wastes (“excavate and redispose”).

For the closure-in-place alternative, an ecological assessment is also provided to evaluate the potential for radiological impacts to non-human receptors and the environment. The results are compared to acceptable risk levels at which no deleterious health effects are likely to occur.

These risk assessment results provide important input information to the corrective action plan (CAP) prepared by Gradient (2020) on behalf of CWMNW to propose a preferred alternative to ODOE for final corrective action.

2. CWMNW Arlington Facility Environmental Setting

The CWMNW facility is located in Gilliam County, about 11 km (7 miles) south-southwest of the City of Arlington, OR, and south of the Columbia River (Figure 2-1). The CWMNW facility property occupies about 270 acres and is surrounded by approximately 14,000 acres of buffer land owned by Waste Management within the south-central portion of the Columbia physiographic province (Deschutes-Umatilla Plateau). The Deschutes-Umatilla Plateau is incised by Alkali

Canyon to the south. Most of the site's activities, including operations in Landfill Unit L-14, are located on the plateau above the canyon. Only a small portion of the site, including the main office, is in Alkali Canyon.

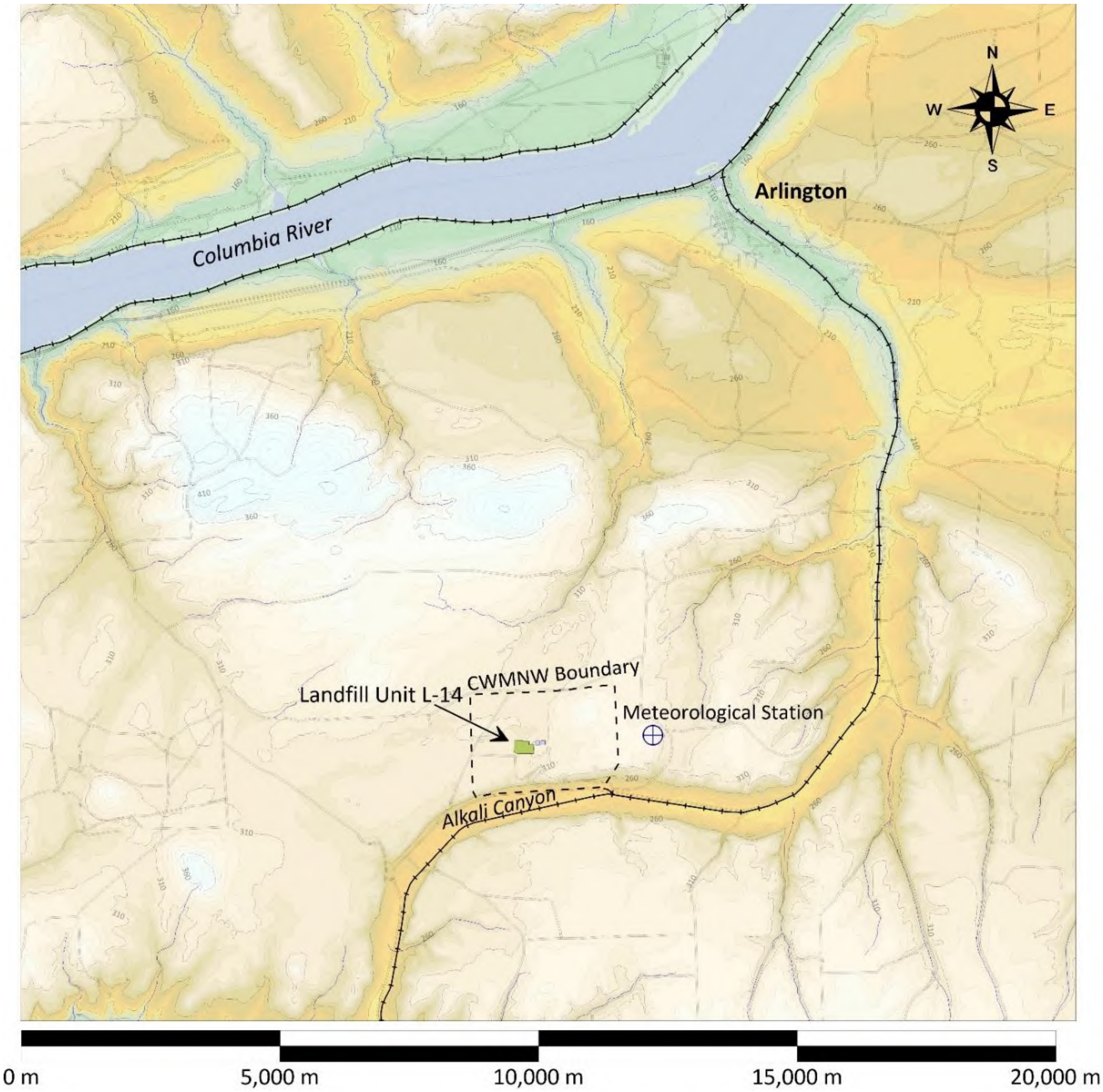

Figure 2-1. Location of CWMNW relative to the City of Arlington and the Columbia River. Also shown is the meteorological station.

2.1. Disposal Facility

Landfill Unit L-14 is located on the west side of the CWMNW facility. Figure 2-2 shows the location of Landfill Unit L-14, the evaporation ponds (Pond-A, Pond-B), the wastewater treatment plant-1 (WWT-1), the CWMNW Laboratory, and the facility entrance.

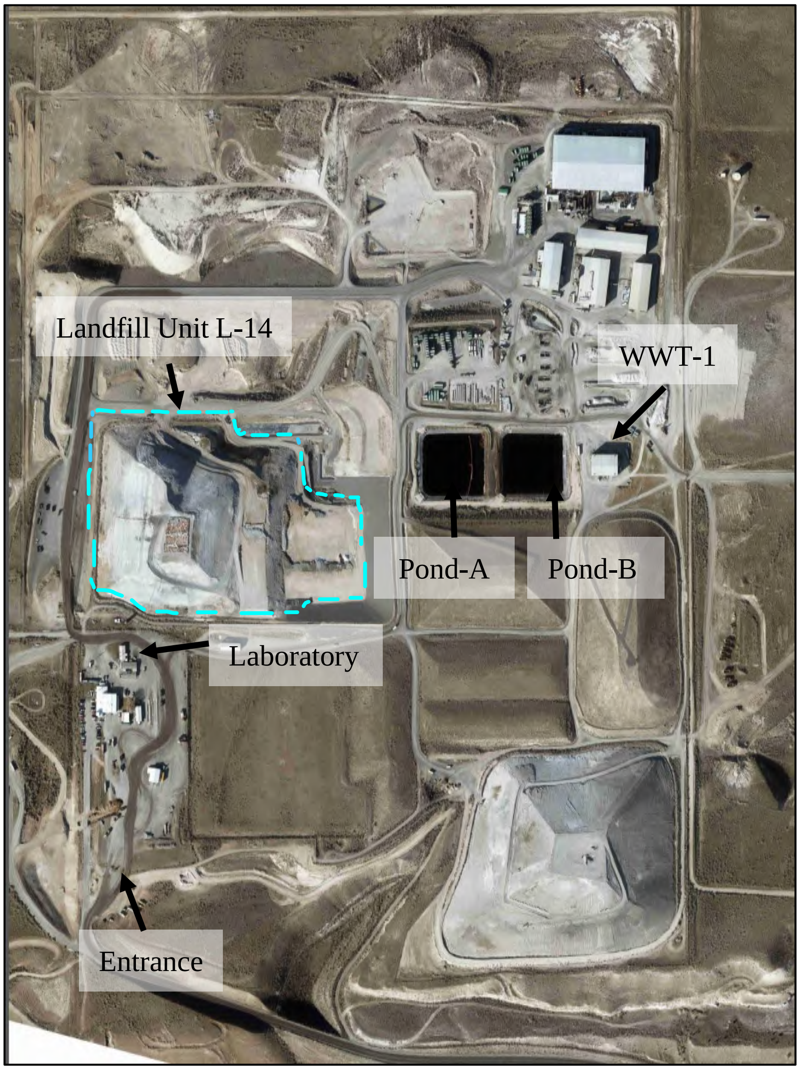

Figure 2-2. Layout of CWMNW Arlington landfill. The rough edge of Landfill Unit L-14 is outlined with a dotted blue line. Other salient features of the landfill are indicated.

2.1.1. Construction and Environmental Protection Features

Landfill Unit L-14 at CWMNW is a double-lined Subtitle C hazardous waste landfill. The disposal cells are designed to meet stringent U.S. Environmental Protection Agency (EPA) and state requirements. The disposal cells are monitored by a leachate collection system, groundwater monitoring network, and leak detection systems (Figure 2-3).

Upon the closure of Landfill Unit L-14, an engineered evapotranspiration final cover system will cap the landfill to restrict infiltration of rainwater and thereby reduce or eliminate leachate production. Post-closure maintenance activities will last for at least 30 years after landfill closure. These activities include semi-annual and/or annual inspection of the cap and its vegetative cover, checking the security fencing, and monitoring and maintenance of the leachate collection system. The post-closure activities also include groundwater monitoring for at least 30 years after the landfill closure.

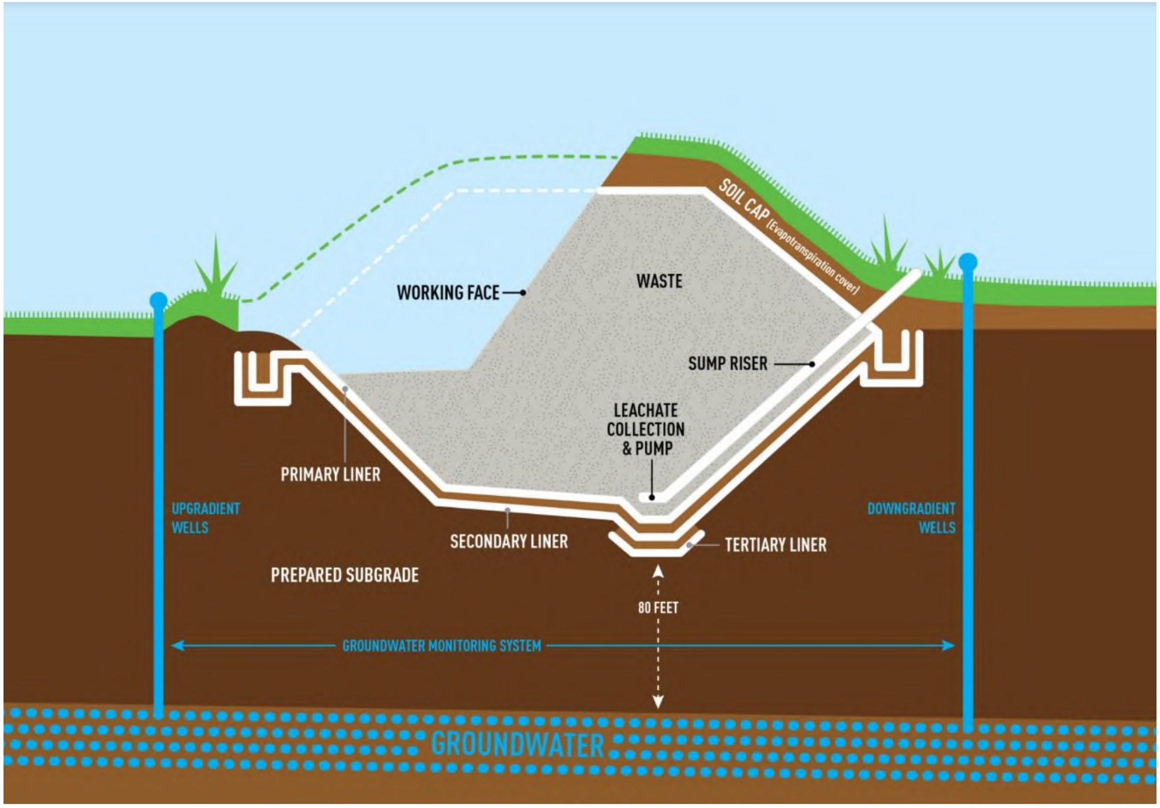

Figure 2-3. This figure shows a stylized cross section of the landfill and identifies key environmental protection features.

2.1.2. Waste Handling Procedures

Waste is transported to the CWMNW facility by public roads or by rail to the rail yard east of the facility. All wastes transported by rail are loaded onto trucks and enter the CWMNW facility over a private road between the rail yard and the facility entrance. The Bakken oilfield wastes were transported by rail initially and later over the road by third-party transporters. Upon entry to the site, the vehicles were cleared through the receiving department, and the truck driver was escorted by a landfill inspector in a separate vehicle to the designated disposal location within Landfill Unit L-14. The truck drivers for the Bakken oilfield wastes, referred to as waste handlers, donned the required personal protective equipment (PPE) prior to entering Landfill Unit L-14 disposal area. While in the active area of the landfill, respiratory protection is required. Waste handlers are not Waste Management employees. On reaching the designated disposal location, the waste handler exited the cab of the truck and walked to the space between the cab and bed of the truck where the controls for the trailer were located. The load was deposited on to the landfill surface in the designated disposal area, and once the offload was complete and the rear door was secured, the driver reentered the cab of the truck and departed the landfill. The waste handler spent approximately seven minutes outside of the cab of the truck per disposal load. The landfill inspector (escort) remained inside their truck at least 15 ft away from the transport vehicle in full PPE the entire time and never exited the truck. Following the offloading, landfill operators in full PPE, enclosed in heavy equipment cabs, pushed the waste into the disposal location where it may have been comingled with other non-reactive wastes before finally being covered with clean soil from on-site cover borrow areas. The wastes may have remained uncovered for up to a week prior to being covered by a landfill operator. Landfill operators are required to wear designated PPE, including a respirator as a protective measure to mitigate the risks associated with disposal of hazardous wastes.

2.1.3. Leachate Management System

Landfill Unit L-14 at CWMNW has four lined leachate collection sumps that consist of a primary sump, secondary leak detection sump, and tertiary leak detection sump collecting leachate from the current 86,490 m^2 (21 acre) landfill. The landfill is divided into four cells, with each cell designed to drain into a sump (Figure 2-4). For a detailed review of the CWMNW leachate management methods please refer to "Analysis of CWMNW Leachate Management Practices" Technical Memorandum (Rood et al. 2020)[1].

As described in the memorandum referenced above, water infiltrates the landfill surface due to precipitation and to a lesser extent from using leachate for dust control by applying it to the top surface of the landfill. Liquids that filter down through the waste mass are conveyed by the primary liner to the leachate collection sumps at the base of the landfill. Leachate pumped from the sumps is generally applied as dust control on the surface of the landfill and has been demonstrated not to result in a large amount of water infiltration as the facility is situated in an arid climate and the leachate is readily evaporated from the surface of the landfill. CWMNW employs an alternate leachate management practice during periods when leachate cannot be applied as dust control. Filtered leachate is placed in one of two on-site evaporation ponds as described in Section 2.1.3.2. An overview of the leachate management practices is given in Figure 2-5.

2.1.3.1. Leachate Applied as Dust Control

When leachate is used for dust control, the leachate is pumped from the sumps via a hose and sprayed over the surface of the landfill where it evaporates. CWMNW is located in an arid climate that has 109 inches of dry pan evaporation per year. The spraying process continues until the area is adequately wetted. Once the area is adequately wetted to control dust, the sprayer is repositioned to a new location and the process is repeated. Spraying is performed in areas of no disposal activity, mainly across L-14 cell 1, L-14 cell 2, and L-14 cell 3. Annually, the use of leachate for dust control will be distributed over all three cells. Any runoff from the spray operations is collected using the landfill internal stormwater collection system and sent to a separate lined stormwater pond at the north end of the current landfill. The approximate area of a single spray is 337 m^2 (Rood et al. 2020).

[1] Available here: https://www.oregon.gov/energy/safety-resiliency/Documents/2020-05-29-CWM-Prelim-Leachate-Analysis.pdf.

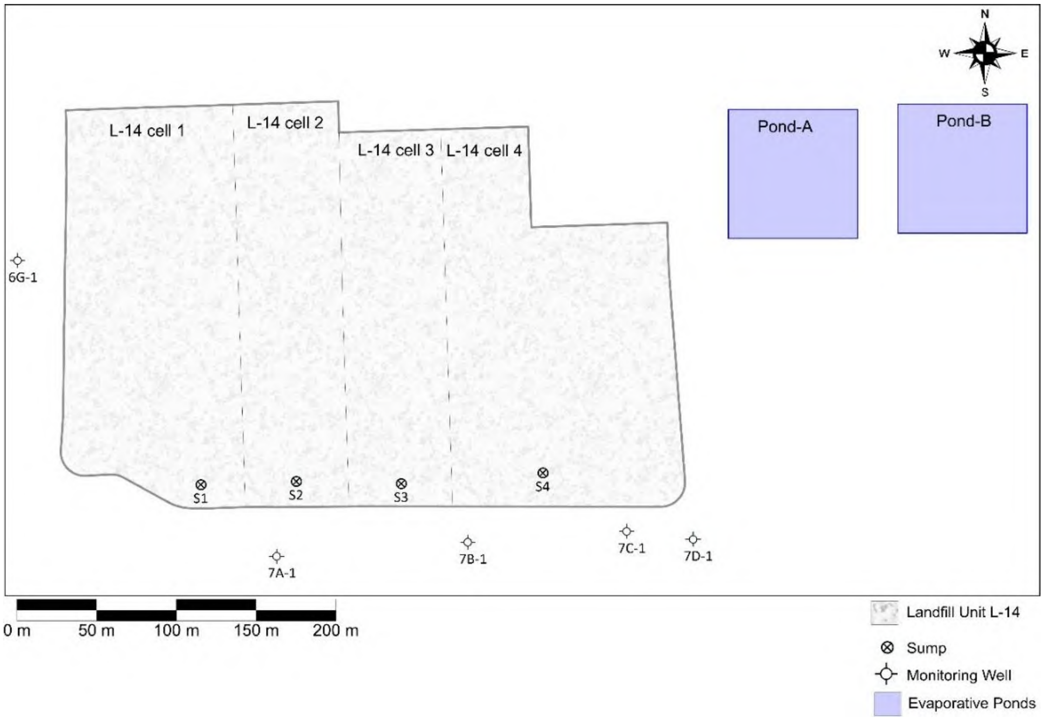

Figure 2-4. Landfill Unit L-14 showing the four cells (L-14 cell 1, L-14 cell 2, L-14 cell 3, and L-14 cell 4), the sumps (S1, S2, S3, and S4), evaporations ponds (Pond-A and Pond-B), and nearby monitoring wells.

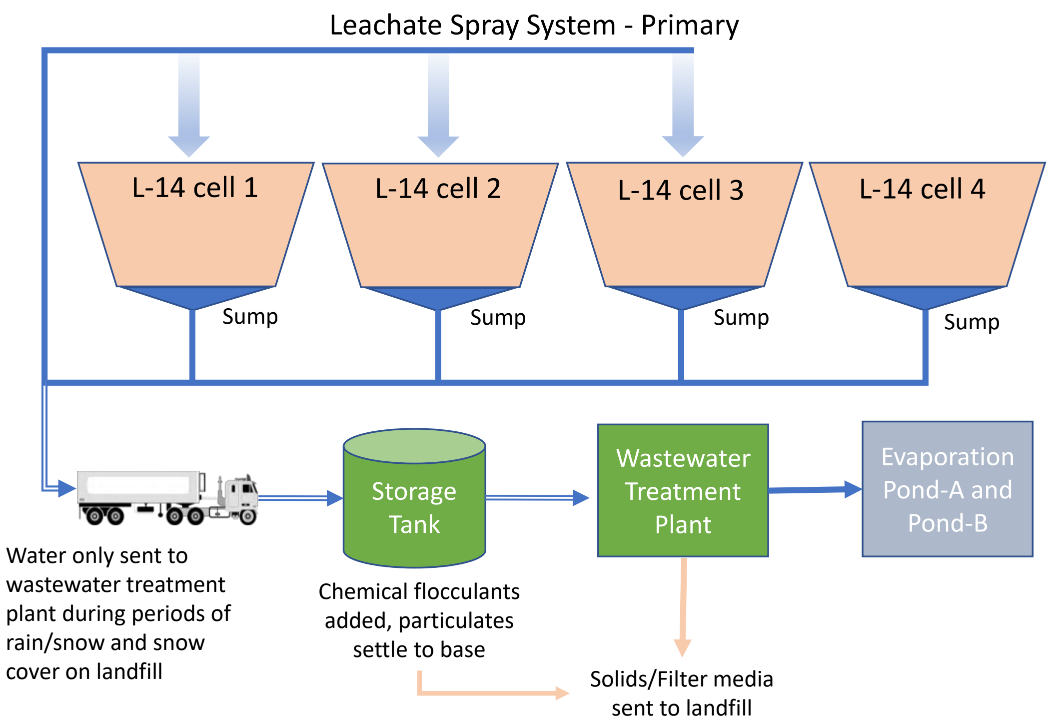

Figure 2-5. Overview of leachate management at CWMNW.

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2.1.3.2. Alternative Leachate Management Methods

An alternative leachate management practice is used when evapotranspiration is poor and leachate removal from sumps is required. Leachate is pumped into a tanker truck and transported to the wastewater treatment plant-1 (WWT-1) where it is offloaded into a storage tank. Chemical flocculants are added to the leachate so that flocked solids precipitate to the base of the tank. The remaining liquid is passed through carbon filters and stored in a separate tank that is later pumped into one of two lined ponds (Pond-A, Pond-B) east of L-14 following compatibility and land disposal restriction (LDR) clearance testing. Periodically, the flocked solids and carbon filter media from the WWT-1 are removed and disposed in the landfill. This happens approximately six times per year.

2.2. Site Geology and Hydrogeology

Geologic units (from shallowest to deepest) beneath Landfill Unit L-14 at CWMNW are:

- Sedimentary deposits of the Dalles Group (Alkali Canyon Formation)
- Selah Member and associated sedimentary deposits of the Ellensburg Formation
- Priest Rapids Member of the Wanapum Basalt (PRB) of the Columbia River Basalt Group (CRBG).

Older Members of the Wanapum Basalt and the Grande Ronde Basalt of the CRBG are also present beneath the site but are not discussed here. Detailed descriptions of each of the geologic units are presented below.

The Alkali Canyon Formation of the Dalles Group outcrops at the surface and overlies the Selah. As seen in Figure 2-6, Landfill Unit L-14 penetrates the Alkali Canyon Formation and its base is in the Selah Member. The Alkali Canyon Formation is unsaturated at the site. It consists of three distinct sedimentary deposits (or facies): the basal portion, which consists of a conglomerate facies; a tuffaceous siltstone facies; and a channel gravel facies that incises down to the top of the Selah Member in the vicinity of Landfill Unit L-14 (Dames and Moore 1987; RUST 1998a; RUST 1998b).

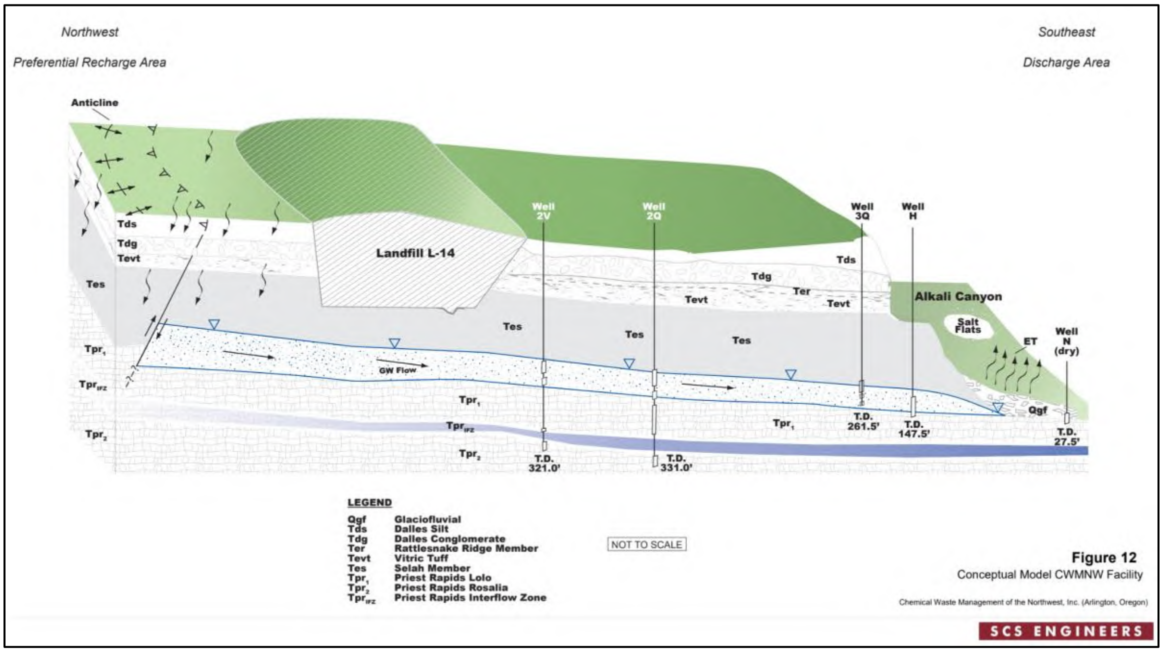

Figure 2-6. Conceptual model and geologic cross section of the CWMNW facility showing Landfill Unit L-14, aquifer in the Selah Member, and the deeper Priest Rapids basalt flow. The axis of the east-west trending anticline is shown north of Landfill Unit L-14.

Two minor units of the Ellensburg Formation are found below the Alkali Canyon Formation and above the Selah Formation. The two units have previously been classified as the Rattlesnake Ridge Member and the Vitric Tuff Member of the Ellensburg Formation based on their tuffaceous characteristics (RUST 1998b; CH2M Hill 2008). The Rattlesnake Ridge Member is a 4- to 6-ft-thick weathered tuffaceous siltstone that overlies the Vitric Tuff. The Vitric Tuff is composed of a soft-to-medium-hard, blue-grey, well-sorted, fine-grained tuffaceous siltstone/sandstone. The vitric tuff is up to 30 ft thick. Both units have been eroded and are absent in localized areas where they were eroded during deposition of the Dalles Group (RUST 1998b; CH2M Hill 2008).

Underlying these two members of the Ellensburg Formation is the Selah Member. The Selah Member ranges in thickness from 35 to 49 m (115 to 160 ft) beneath the upland plateau where the active area of the CWMNW facility is located. The upper portion of the Selah is unsaturated, with groundwater present in the lowest 6.1 to 21.3 m (20 to 70 ft) of the Selah (CH2M Hill 2008). Immediately south of the facility, the Selah Member is fully exposed in the face of the bluff in Alkali Canyon, where it was eroded away by catastrophic floods of glacial origin that inundated the Columbia Plateau during the Pleistocene Epoch. Even though the Selah is heterogeneous, the primary lithologic character of the Selah is a siltstone with varying degrees of clay and sand content.

The PRB consists of two flows at the site, a younger Lolo flow and the older Rosalia flow. The two flows have the typical characteristics of a basalt flow consisting of dense to columnar-jointed flow interior between a brecciated flow bottom and weathered flow top. The Lolo and Rosalia flows are separated by a partially lithified sedimentary interbed of the Ellensburg Formation composed of silt and clay. This interbed lies 15.2 to 22.9 m (50 to 75 ft) below the Selah/PRB contact and ranges in thickness from 6.1 to 36.6 m (2 to 12 ft) across the site (CH2M Hill 2008).

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2.2.1. Geologic Structure

Tectonic activities folded and faulted the older geologic units of the Selah and PRB after they were deposited. An east-west trending anticline fold is present along the northern portion of the site based on geological borehole data and surface geophysical surveys. The fold dips to the north of the site and towards Alkali Canyon to the south. Additionally, a thrust fault that offsets beds within the Selah and PRB trends roughly parallel to the anticline in the portion of the site north of Landfill Unit L-14. The thrust fault is truncated by intact Holocene glacial flood deposit, indicating the fault pre-dated Holocene deposition (Dames and Moore 1987; RUST 1998a).

2.2.2. Groundwater Hydrology

The Selah contains the uppermost saturated zone beneath the CWMNW facility. Depth of the uppermost saturated layer is from about 40 to 60 m (130 to 200 ft) below the upland plateau where the active portion of the landfill is located. The Selah underlies the more permeable sands and gravels of the Alkali Canyon Formation of the Dalles Group and overlies the PRB of the Columbia River Basalt Group. The regional groundwater source(s) are much deeper in the older CRBG units of the Frenchman Springs Member of the Wanapum Basalt and older flows of the Grande Ronde Basalt.

Recharge to the Selah occurs along the northern portion of the site near the structural features and through the unsaturated zone, which varies between approximately 90 ft thick in the central area of the site to 135 ft in the northern part of site to 220 ft thick towards the western and eastern areas of the site. Recharge to groundwater is primarily from precipitation and has been previously estimated to be approximately 0.1 ft/year (RUST 1998b). Groundwater flow within the saturated portion of the Selah is generally toward the southeast and towards Alkali Canyon and away from the Columbia River to the north, consistent with the structural dip of the underlying PRB. Water balance calculations in CH2M HILL (2008) indicates groundwater does not discharge from the Selah south into Alkali Canyon but is lost through evapotranspiration. Water that may accumulate in the winter in Alkali Canyon is attributed rainfall, snowmelt, and poor drainage conditions in the bottom of the canyon.

In general, the Selah is a partially confined groundwater system at the site, although more confined conditions may exist toward the northwestern and southeastern portions of the site. In the northwestern area, a clay-rich horizon (designated the “grey clay” layer by Dames and Moore [1987]), indicated by the natural gamma geo-physical logs, likely acts as a confining to semi-confining layer below which is a zone of lower clay content (and potentially higher hydraulic conductivity). The lower portion of the Selah contains low-conductivity materials that limits the movement of water from the lower Selah to the PRB.

The Selah has horizontal hydraulic conductivity values (K_h) ranging from 1×10^{-6} to 1×10^{-4} cm s^{-1} based on pumping test data, packer testing, and core sample testing (Dames and Moore 1987; RUST 1998a; CH2M Hill 2008). Horizontal hydraulic conductivity values estimated for test intervals crossing the Selah/PRB contact and the vertical hydraulic conductivity of the Selah Member have been estimated to range from 5×10^{-9} cm s^{-1} to about 5×10^{-6} cm s^{-1} with a geometric mean of about 5×10^{-8} cm s^{-1} (CH2M Hill 2008). For comparison, the horizontal hydraulic conductivity of materials used for engineered landfill liner materials to prevent releases of leachate from a landfill to the environment is typically less than 1×10^{-6} cm s^{-1}. Using the historic average hydraulic gradient of approximately 0.015 to 0.035 m m^{-1} and the estimated hydraulic conductivity of the Selah, groundwater flows laterally at an estimated rate of between 0.23 to 2.1 m yr^{-1} (0.77 to 6.9 ft yr^{-1}).

Isotopic age dating of groundwater at the site is consistent with the long travel times for groundwater from the surface to the saturated zone of the low permeability Selah and horizontally within the Selah. Available radiocarbon dating using carbon-14 suggests that the age of the shallow groundwater in the Selah is greater than 770 years with a probable age range of between 1,000 to 4,000 years (CH2M Hill 2008). For comparison, the maximum age range for the upper Priest Rapids is estimated to be between 9,600 and 12,900 years old, and the deeper Frenchman Springs Basalt used for water supply at the site is estimated to be between 14,000 to 16,000 years old. These much older ages of groundwater from the basalt interflows suggest limited hydraulic connection, if any, between the shallow Selah water-bearing zone and the deeper basalt aquifers.

2.2.3. Surface Water

Except for the on-site storm water management ponds, which themselves do not consistently contain water, permanent surface water is absent at the facility. During the few storm runoff events, surface water exterior to the facility generally drains from the upland plateau via overland flow into Alkali Canyon, then down into the broad canyon floor where it disperses or collects into ephemeral ponds. During winter and early spring, shallow seasonal ponds occasionally form in Alkali Canyon, south of the site. The only permanent surface water bodies are located several miles from the site and include the Columbia River, approximately 11 km (7 miles) north of the site; the John Day River, approximately 12 km (7.5 miles) west of the site; Rock Creek, approximately 5.5 km (3.5 miles) southwest of the site; and Cedar Springs, approximately 2.5 km (1.5 miles) west of the site. None of these water bodies are hydraulically connected to the surface water from the site. All stormwater from the facility is moved by on-site stormwater conveyances to on-site stormwater retention ponds that do not discharge to any of the local rivers, streams, or other water bodies.

2.3. Background Radiation Levels and Site Survey Data

A radiation survey of the CWMNW Arlington site was conducted June 15 to 19, 2010, by Environmental Restoration Group, Inc. (ERG), in collaboration with K2 Environmental, LLC (ERG and K2 2020). The survey was designed to measure gamma radiation across the site to determine the natural background gamma radiation in the area and if there were any evidence of increased gamma radiation associated with the disposal of the Bakken oilfield wastes in Landfill Unit L-14. To do this, gamma radiation was measured across Landfill Unit L-14, at off-site background locations representative of natural undisturbed geology in the area, and at on-site locations free of waste where materials were taken and later used for cover and fill in Landfill Unit L-14.

The investigation consisted of gamma radiation surveys using an unmanned aerial vehicle (UAV) equipped with radiation detection and GPS equipment to measure gamma count rates across the site, at locations with cover and fill materials, and at background areas. In addition, exposure rate measurements were taken at locations with cover and fill material and background locations using a high-pressure ionization chamber (HPIC). A correlation was developed between the HPIC and UAV-based measurements that enabled the conversion of UAV-based gamma survey data to exposure rate data.

The results of the radiological investigation showed no evidence of increased gamma radiation from waste disposals in Landfill Unit L-14. Observed differences in gamma radiation corresponded to the location and use of waste-free cover and fill materials. The radiation survey results showed that all background measurements were within the expected variability of natural background and agreed with published estimated exposure rates for the area. Complete details of the survey and its results are provided in ERG and K2 (2020), which is attachment B to the CAP (Gradient 2020).

3. Characterization of the Bakken Oilfield Waste

The Bakken oilfield waste originated in the Bakken oilfields of North Dakota and is a byproduct of oil and natural gas production. A total of approximately 1,285 tons (1.17×10^6 kg) were disposed of in the landfill from May 2, 2016 to September 16, 2019 in 64 loads. The waste was primarily filter socks, but also contained filters, contaminated soils and equipment, pipe scale, rags, and liquids. Filter socks are essentially large bags that are shaped like human socks and are used to capture particulates that are separated from water during the fracking process.

3.1. Radiological Characterization of the Bakken Oilfield Waste

The radiological characterization, or source term, refers to the total activity, volume, and radionuclide composition of the Bakken oilfield waste that was disposed in the landfill. The source term uses the inventory estimates and the geographical location of the Bakken oilfield waste, coupled with release mechanisms and models to estimate both the weighted-average and potential worst-case quantity of radioactive material that could have been released to the environment (air, soil, and water) per unit time. In this case, the inventory was calculated based on generator waste disposal manifests, the time frame in which the material was disposed in the landfill, the estimated volume of material disposed, available radioanalytical data for the materials, and pertinent published radiological data.

TENORM radionuclides considered in this assessment are presented in Table 3-1. Numerous short-lived radioactive progeny would also be present if any of the parents are present in the source term, these are also accounted for in this analysis. The U-238 and Th-232 decay series are the primary TENORM decay series of concern in the Bakken oilfield waste (see Figure 3-1 and Figure 3-2).

Table 3-1. Relevant TENORM Radionuclides and Their Half-lives[2]

Radionuclide	Half-life (years)
U-238	4.47×10^9
U-234	2.46×10^5
Th-230	7.54×10^4
Ra-226	1.6×10^3
Pb-210	22.2
Th-232	1.4×10^{10}
Ra-228	5.75
Th-228	1.91

[2] The rate at which a radionuclide decays is measured in half-life. The term half-life is defined as the time it takes for one-half of the atoms of a radioactive material to disintegrate.

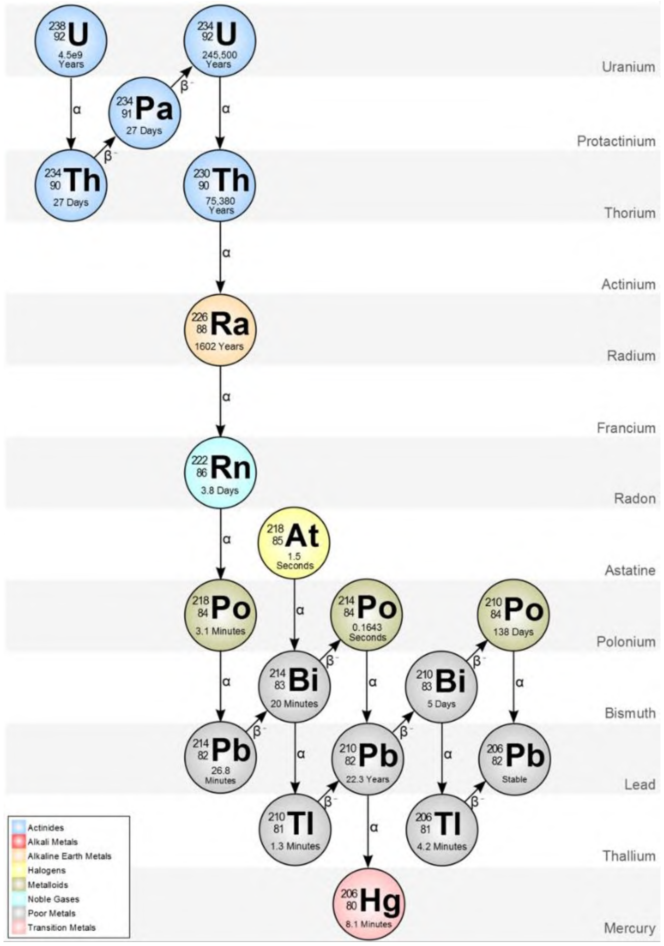

Figure 3-1. Uranium-238 decay scheme showing the short-lived progeny that will be present alongside the parent. Taken from http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html.

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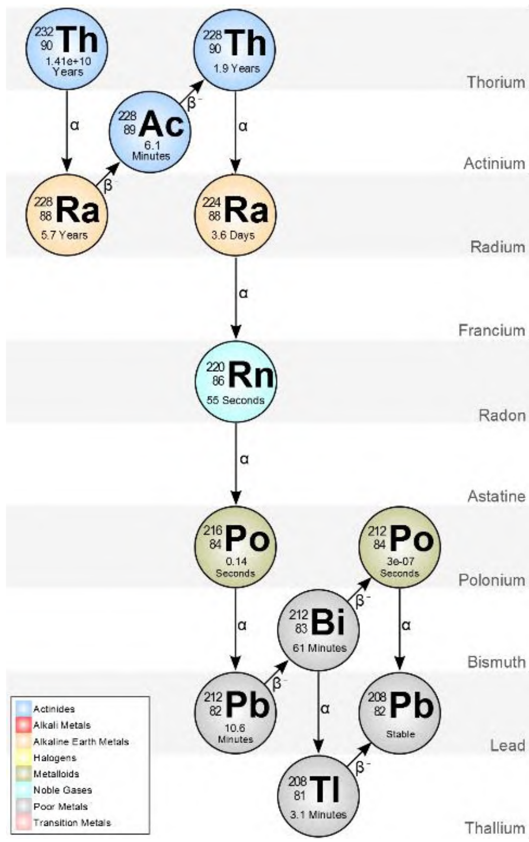

Figure 3-2. Thorium-232 decay series showing the short-lived progeny that will be present alongside the parent. Taken from http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html.

3.2. Radiological Source Term for Disposal Operations

Two source terms were developed for this analysis. The first is a weighted-average source term based on waste type that most likely represents the actual radiological composition of the Bakken oilfield waste, and the second is an upper-bound or maximum source term to ensure that doses and risks were not underestimated.

3.2.1. Weighted-average Source Term

The weighted-average source term was calculated using the available radioanalytical data for the Bakken oilfield waste and published data specific to North Dakota from Argonne National Laboratory (ANL 2014). Where possible, the waste type breakdown was obtained from data provided by CWMNW Arlington. Where the waste type was unknown, it was assumed to be filter socks, which comprised most of the disposed waste (Table 3-2).

Table 3-2. Summary of Available Data on Waste Type

Waste type	Mass (g)	Percent of total
Filter socks	6.99×10^{8}	81%
Contaminated soils	1.74×10^{7}	2%
Mixed	3.02×10^{7}	3%
Rags	6.12×10^{6}	1%
Contaminated equipment	1.34×10^{4}	0.002%
Scale	1.04×10^{6}	0.1%
Filters	9.78×10^{7}	11%
Liquid	6.69×10^{4}	0.01%
Pipe	1.14×10^{7}	1%
Soil	4.54×10^{5}	0.1%

Radioanalytical data was available for four categories of waste: filter socks, filters, pipe scale, and other. Where the category for the waste type in Table 3-2 was not immediately obvious the following assumptions were used:

- "Pipe" and "Scale" were assigned to the category Pipe Scale
- "Contaminated soil", "Soil", "Mixed", and "Rags" were all assigned to the category Other
- Contaminated equipment and liquid were not considered in the analysis as they represent a negligible quantity of total mass (<<1%).

Table 3-3 provides the waste type breakdown used in calculating the weighted-average source term.

Table 3-3. Waste Type Breakdown for Bakken Oilfield Waste

Waste type	Mass (g)	Percent of total
Filter socks	9.43×10^{8}	81%
Filters	1.32×10^{8}	11%
Pipe scale	1.68×10^{7}	1%
Other	7.31×10^{7}	6%

Weighted-average radionuclide concentrations were then calculated using average values from both the available published radioanalytical data and from ANL (2014, Table 2.1). The ANL data is specific to North Dakota, represents a reasonable approximation for the Bakken oilfield waste, and increases the robustness of the source term characterization.

For each category of waste in Table 3-3, weighted-average radionuclide concentrations were computed with the following assumptions (see Table 3-4):

- Filter socks and pipe scale
    - Pb-210, Ra-226, and Ra-228 values are based on single measurement of Bakken oilfield waste and average filter-sock values from ANL (2014, Table 2.1)
    - Th-232 is based on average filter-sock/pipe-scale values from ANL (2014, Table 2.1)
    - Th-228, Th-230, U-234, and U-238 values are assumed to be the same as filters.

- Filters
  - Average of measurements from Bakken oilfield waste data.
- Other
  - Assumed to be average of filter socks, pipe scale, and filters.

The weighted-average radionuclide concentration is given by

$$CA_j = \sum_{i=1}^{n} \frac{C_{i,j} \times M_i}{M_T} \quad (3\text{-}1)$$

where

CA_j = weighted-average concentration for radionuclide j (pCi g^{-1})
$C_{i,j}$ = concentration of radionuclide j for waste category i (pCi g^{-1})
M_i = mass of Bakken oilfield waste in category i (g)
M_T = total mass of Bakken oilfield waste (g).

The weighted-average concentrations are provided in Table 3-4.

Table 3-4. Weighted-Average Radionuclide Concentrations in Bakken Oilfield Waste

Radionuclide	Weighted-average radionuclide concentration (pCi g^{-1})
U-238	2.83×10^{-2}
U-234	9.67×10^{-2}
Th-230	3.87×10^{-2}
Ra-226	8.93×10^{1}
Pb-210	4.98×10^{2}
Th-232	1.31×10^{1}
Ra-228	4.10×10^{1}
Th-228	4.96

3.2.2. Maximum Source Term

The maximum source term was computed assuming that the entirety of the Bakken oilfield waste contained the maximum measured concentration obtained from the supplied laboratory analytical data for each radionuclide listed in Table 3-1 and represents an extreme upper bound on the likely radiological concentrations. A summary table and the raw analytical data sheets from the analytical laboratory are provided in Appendix B. Maximum concentrations used in this assessment are provided in Table 3-5.

Table 3-5. Maximum Radionuclide Concentrations in Bakken Oilfield Waste

Radionuclide	Maximum radionuclide concentration (pCi g^{-1})
U-238	1.18
U-234	2.01
Th-230	7.99×10^{-1}
Ra-226	1.43×10^{2}
Pb-210	8.14×10^{2}
Th-232	4.74×10^{-1}
Ra-228	6.17×10^{1}
Th-228	8.40

3.3. Radiological Source Term for an Excavation and Redisposal Alternative

The purpose of this section is to describe the source term for the excavation and redisposal alternative. The Bakken oilfield waste was disposed in the CWMNW Landfill Unit L-14, comingled with other chemical and hazardous wastes, and covered with on-site cover materials. The total quantity of the mixed wastes was estimated in the CAP (Gradient 2020). This other waste effectively causes dilution of the Bakken oilfield source term per unit mass in the landfill, and this dilution effect is accounted for by computing a mass dilution factor. The dilution factor was calculated based on a 25% fluff factor (Gradient 2020):

$$Dilution\ Factor = \frac{Bakken\ Oilfield\ Waste\ Mass}{Total\ Waste\ Mass} = \frac{1.17\times10^{6}\,kg}{3.50\times10^{6}\,kg} = 0.33$$

Varying the fluff factor between 15% and 50% yielded dilution factors of 0.31 and 0.40, respectively, which demonstrated the results were not sensitive to this parameter. Mixed waste removal parameters are detailed in Table 3-6.

Table 3-6. Mixed Waste Removal Parameters

Parameter	Value	Units
Total Bakken oilfield waste mass	1.17×10^{6}	kg
Total mixed waste mass to be excavated, 25% fluff factor[a]	3.50×10^{6}	kg
Total volume to be removed, including 15% fluff factor[a]	3.80×10^{6}	kg
Total volume to be removed, including 50% fluff factor[a]	2.91×10^{6}	kg

a. Waste expands when removed from the landfill, so the total volume trucked off-site is greater than that excavated. A 25% fluff factor is assumed here. A sensitivity analysis was conducted assuming the fluff factor was 15% and 50%.

Applying the dilution factor to both the maximum and average source terms yields the radionuclide concentrations used for computing doses and risks for the excavate and redispose alternative (Table 3-7).

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Table 3-7. Radionuclide Concentrations for the Excavate and Redispose Alternative[a]

Radionuclide	Maximum radionuclide concentration (pCi g^{-1})	Weighted-average radionuclide concentration (pCi g^{-1})
U-238	3.93×10^{-1}	9.45×10^{-3}
U-234	6.70×10^{-1}	3.22×10^{-2}
Th-230	2.66×10^{-1}	1.29×10^{-2}
Ra-226	4.78×10^{1}	2.98×10^{1}
Pb-210	2.71×10^{2}	1.66×10^{2}
Th-232	1.58×10^{-1}	4.36
Ra-228	2.06×10^{-1}	1.37×10^{1}
Th-228	2.80	1.65

a. 25% fluff factor.

4. Exposure Scenarios Considered in the Dose and Risk Assessment

Exposure to radiation from radionuclides present in the Bakken oilfield waste depends on the types of radiation emitted, the environmental media where they may be present currently or in the future, and the location and activities of individuals in the vicinity of the waste. For Bakken oilfield waste individuals may be exposed from inhaling waste particulates released into the atmosphere during disposal or excavation and give a radiation dose to the lung and other tissues. This exposure decreases with distance from the disposal or excavation location due to atmospheric dilution and dispersion. Particles may be deposited on soil and be ingested in tiny quantities, but only if the individual is near the material. Individuals can also be exposed externally if they are very near the waste material. The waste also generates radon gas that can be inhaled and give a dose to the lung and other tissues. Over exceptionally long time periods (i.e., tens of thousands of years), radionuclides may migrate to groundwater and be ingested in drinking water. However, the likelihood that radionuclides from the Bakken oilfield waste would make their way to a potable aquifer for any time in the future is extremely remote.

Pertinent exposure scenarios to identified receptors were examined to develop radiation doses and risks associated with each scenario. Exposure scenarios that were considered include:

- During disposal;
- Closure-in-Place, and
- Excavate and redispose.

Receptors include waste handlers, landfill workers, hypothetical excavation workers, a hypothetical supervisor, the nearest current resident (Figure 4-1), and potential future residents.

4.1. During Disposal

The Bakken oilfield waste was disposed of at CWMNW Arlington over approximately a three-year period between May 2, 2016, and September 16, 2019. The waste was received in a total of 64 shipments. For the exposure assessment, it is assumed that the waste was disposed of entirely by a single individual without the benefit of personal protective equipment (PPE), which was not what is known to actually have occurred but was analyzed to estimate the highest possible risk.

This hypothetical individual in almost all cases was not a CWMNW employee but was employed by CWMNW's customer who transported the waste to the landfill. They are referred to as the waste handler in this report. The CWMNW employee with potential exposure during the disposal process is the landfill inspector who escorts the waste handler to the designated disposal area. This employee's exposure is less than the waste handler's as the landfill inspector maintains at least 4.6 m (15 ft) of distance from the waste handler's vehicle and remains inside the escort vehicle while wearing full PPE. All personnel entering the active disposal area are required to wear PPE, including respirators at all times due to the hazardous chemical nature of the wastes disposed. For these reasons, the dose to the landfill worker will be less than the dose to the waste handler and is not calculated explicitly.

The only other potentially exposed receptor during disposal operations is the current off-site resident, who occupies the home nearest to the CWMNW Arlington landfill, which is 3,260 m (10,700 ft or approximately 2 miles) away (Figure 4-1). Input parameters for each receptor are detailed in Table 4-1, and a detailed discussion is provided in Sections 4.1.1 and 4.1.2.

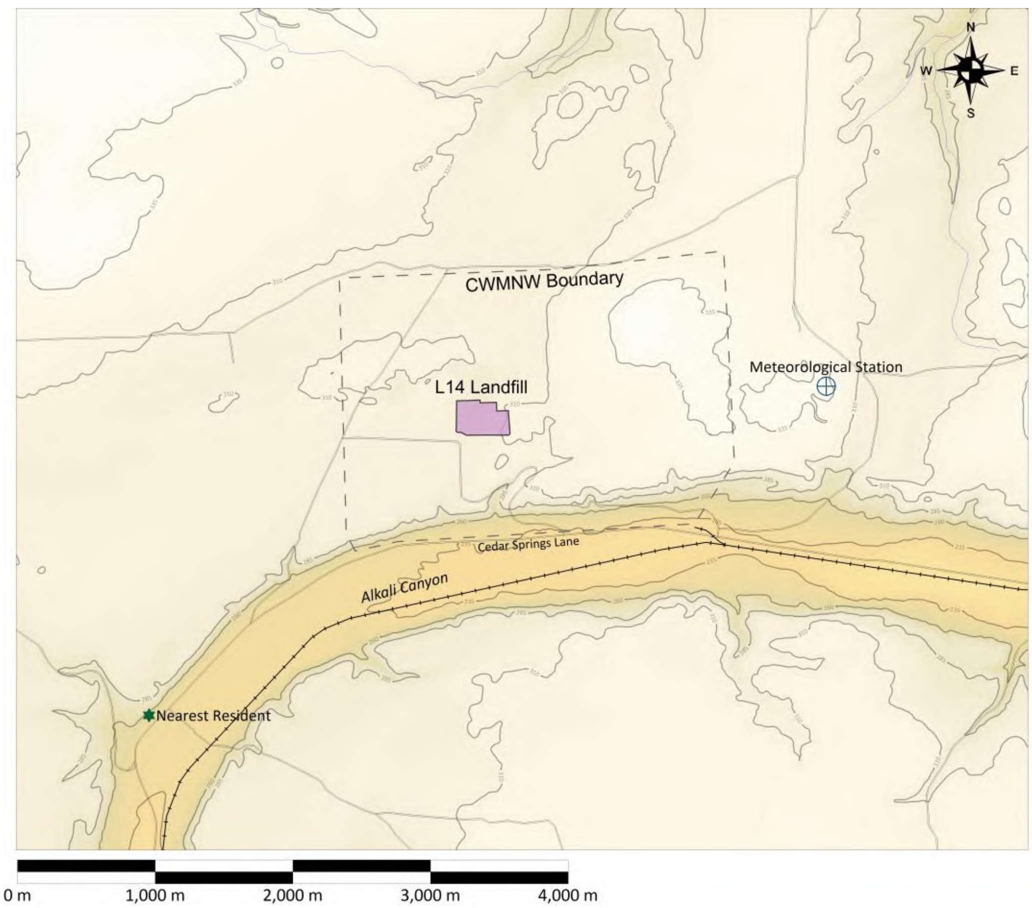

Figure 4-1. Location of nearest resident relative to CWMNW Arlington.

4.1.1. Waste Handler

The waste handler is the person who drives the waste delivery vehicle from the point of origin to the CWMNW Arlington landfill. Once at the designated disposal location inside of Landfill Unit

L-14, they operate the offloading controls outside the truck that allow the waste to be physically deposited into the landfill. This individual is the maximally exposed individual during the disposals as they are outside their truck in full PPE. For the purposes of this analysis, the exposure to the waste handler does not consider the required PPE, and thus the calculated doses represent overestimates of the actual exposures.

Relevant pathways of exposure for the waste handler are:

- Inhalation of particulates
- Inadvertent ingestion of soil
- External exposure.

As noted previously, it is assumed that the same individual is the waste handler for all the Bakken oilfield waste. This in fact was not the case; therefore, the calculated doses and risks are overestimates of the actual doses.

4.1.2. Current Off-site Resident

The current off-site resident occupies the closest home to the CWMNW Arlington landfill. This is in Alkali Canyon, approximately 3,260 m (10,700 ft or approximately 2 miles) southwest from Landfill Unit L-14 where the Bakken oilfield waste is located. This receptor is located upwind of the facility operations to the southwest. The only potentially complete pathway of exposure is inhalation of fugitive particulates, and the analysis does not consider the decrease in air concentrations inside the residence which would lower the resulting dose and risk. This receptor is included in the analysis as the nearest off-site human receptor.

Table 4-1. Exposure Parameters for Disposal Operations

Parameter	Value	Units	Reference
Daily inhalation rate – waste handler	43.2	m^3	EPA (2011)[a]
Daily inhalation rate – current off-site resident	20.0	m^3	EPA (1991)[b]
Soil ingestion rate	4.81	mg per disposal	EPA (2016)[c]
Minutes per disposal	7	minutes	Per CWMNW
Number of disposals	64	unitless	Per CWMNW
Distance to current off-site resident	3261.20	m	Per CWMNW

a. Represents a weighted-average calculated using short-term inhalation rates for construction workers assuming two hours light intensity, four hours moderate intensity, and two hours heavy intensity.
b. Default exposure factor for estimating the reasonable maximum exposure for a resident per EPA 1991 guidance.
c. Total soil ingestion is 330 mg per day.

4.2. Alternative 1: Closure-in-Place Scenario

This alternative assumes that the Bakken oilfield waste material is left in place and regular landfill operations continue to cover the material until the landfill is closed after 30 years and capped in compliance with the approved closure plan in the facility’s permit. Both the weighted-average and maximum source terms were analyzed for this alternative. Receptors and exposure pathways are detailed in the sections that follow. Additional details on this alternative can be found in the CAP (Gradient 2020). Input parameters are listed in Table 4-2.

4.2.1. Landfill Worker

The landfill worker represents individuals who currently operate equipment or perform other tasks within the landfill footprint on a regular basis. The analysis estimates their risk based on an assumption of a 30-year career continuing to work at the landfill. These individuals are in enclosed cabs of equipment while wearing full PPE, including respirators, while working in the landfill. No credit has been taken in the dose calculations for either the respirator or the shielding provided by the heavy equipment. Both of these factors serve to overestimate the calculated doses. For this scenario, the only complete pathway of exposure is inhalation of outdoor radon. Because radon is a long-term exposure concern, doses are reported assuming 30 years of exposure.

4.2.2. Current Off-site Resident

The current off-site resident occupies the closest residence to the CWMNW Arlington landfill. The resident is located approximately 3,261 m (10,700 ft) to the southwest from Landfill Unit L-14 where the Bakken oilfield waste was disposed. For this scenario, the only complete pathway of exposure is inhalation of outdoor radon. Because radon is a long-term exposure concern, doses are reported assuming 30 years of exposure.

4.2.3. Future Off-site Resident

The future off-site resident is assumed to live at the same location as the current off-site resident, but far into the future. Complete pathways of potential exposure include:

- Inhalation of outdoor radon, which includes 30 years of exposure
- Ingestion of groundwater; the model is run to maximum concentration and dose.

4.2.4. Future On-site Resident

The hypothetical future resident is assumed to live on Landfill Unit L-14, which is a highly unlikely case included to understand the possible risk if land use restrictions placed on the landfill following closure were to fail or be forgotten in the future. A groundwater well is located at the immediate downgradient edge of Landfill Unit L-14 (see Section 5 for details). Complete pathways for these individuals include:

- Inhalation of outdoor radon, which includes 30 years of exposure
- Ingestion of groundwater; the model is run to maximum concentration and dose.

Table 4-2. Exposure Parameters for Alternative 1

Parameter	Value	Units	Reference
Dose factor for radon	760	mrem WLM^{-1}	Yu et al. (2001)
Hours exposed, landfill worker	2,040	hours	[a]
Hours exposed, current off-site resident	6,760	hours	[b]
Hours exposed, future off-site resident	8,400	hours	[c]

Parameter	Value	Units	Reference
Hours exposed, future on-site resident	8,400	hours	c
χ/Q, landfill worker	3.03×10^{-4}	s m^{-3}	d
χ/Q, future on-site resident	3.03×10^{-4}	s m^{-3}	d
χ/Q, current off-site resident	2.71×10^{-7}	s m^{-3}	d
χ/Q, future off-site resident	2.71×10^{-7}	s m^{-3}	d

a. Assumed 170 hours per month for 12 months.
b. Assumed total hours per year – 2,000 working hours per year.
c. Assumed 350 days per year, 24 hours per day.
d. Annual averages based on AERMOD calculations See Section 5.1.4 for details. The landfill worker and future on-site resident are assumed to be located at the Bakken oilfield waste in Landfill Unit L-14. The current off-site resident is located 3,261 m (10,700 ft) from the Bakken oilfield waste. The future off-site resident is assumed to be located at the same place as the current off-site resident.

4.3. Alternative 2: Excavate and Redispose Bakken Oilfield Waste

This analysis is limited to the radiological risks associated with this alternative. Physical risks, such as transport risks, are discussed in detail in the Corrective Action Plan (Gradient 2020). This alternative assumes that the Bakken oilfield waste is excavated using heavy equipment and loaded into trucks for off-site disposal via public roads. Details of the excavation, trucking, and redisposal process can be found in the CAP as well (Gradient 2020). Input parameters for the dose calculations are the same as those for the disposal operations (Table 4-1) with two exceptions. First, the calculated time per removal load is approximately 66 minutes (Gradient 2020) rather than the 7 minutes for disposal. Second, the volume of waste to be removed differs from that disposed of due to mixing with other landfill wastes as described in Section 0. The waste is assumed to be removed using 20-yard dumpsters that hold 6.2 cubic meters of material each. Thus, the total number of truck loads required for removal operations is 322 (see Gradient [2020] for details). Inhalation and soil ingestion rates are the same as those used for disposal operations.

4.3.1. Excavation Worker

The excavation worker represents workers who are involved in the hypothetical excavation process. They are not landfill employees. The same individual is assumed to be present for all 322 loads, which for calculation purposes are assumed to occur in a single year. In reality, the excavation would occur over a period of approximately 10 years. As with the other receptors, no credit is taken for PPE worn by the worker, meaning that the dose to the worker is overestimated. Some shielding from the cab of the heavy equipment is accounted for in the external dose calculations. Complete pathways of exposure include:

- Inhalation of particulates
- Ingestion of soil
- External exposure.

4.3.2. Supervisor

The supervisor monitors the hypothetical excavation process and ensures it is conducted safely. The same individual is assumed to be present for all 322 loads, which for calculation purposes are assumed to occur in a single year. In reality, the excavation would occur over a period of approximately 10 years. As with the other receptors, no credit is taken for PPE worn by the worker, meaning that the supervisor's dose is overestimated. Complete pathways of exposure include:

- Inhalation of particulates
- Ingestion of soil
- External exposure.

4.3.3. Current Off-site Resident

This individual currently occupies the closest home to the CWMNW Arlington landfill. The current off-site resident is located approximately 3,261 m (10,700 ft) to the southwest from Landfill Unit L-14 where the Bakken oilfield waste is located. The complete pathway of potential exposure is inhalation of particulates.

5. Dose and Risk Calculation Methodology

This section provides the details of the methodology used to calculate the doses and risks from radiological exposures, distinguishing between the air pathway and the groundwater pathway.

5.1. Atmospheric Pathway Modeling Methods

Radionuclide emissions during disposal and hypothetical removal operations are based on the EPA emission model for aggregate handling and storage piles during drop loading operations as described in AP 42 *Compilation of Air Pollutant Emission Factors* (EPA 1995). Aggregate material is typically much drier, and particulate aggregate is more easily dispersed in air than any material that is attached to a filter sock. Modeling using aggregate material results in a worst-case inhalation scenario. The exposure scenarios are illustrated in Figure 5-1 and Figure 5-2. Full details of the calculations can be found in Appendix C.

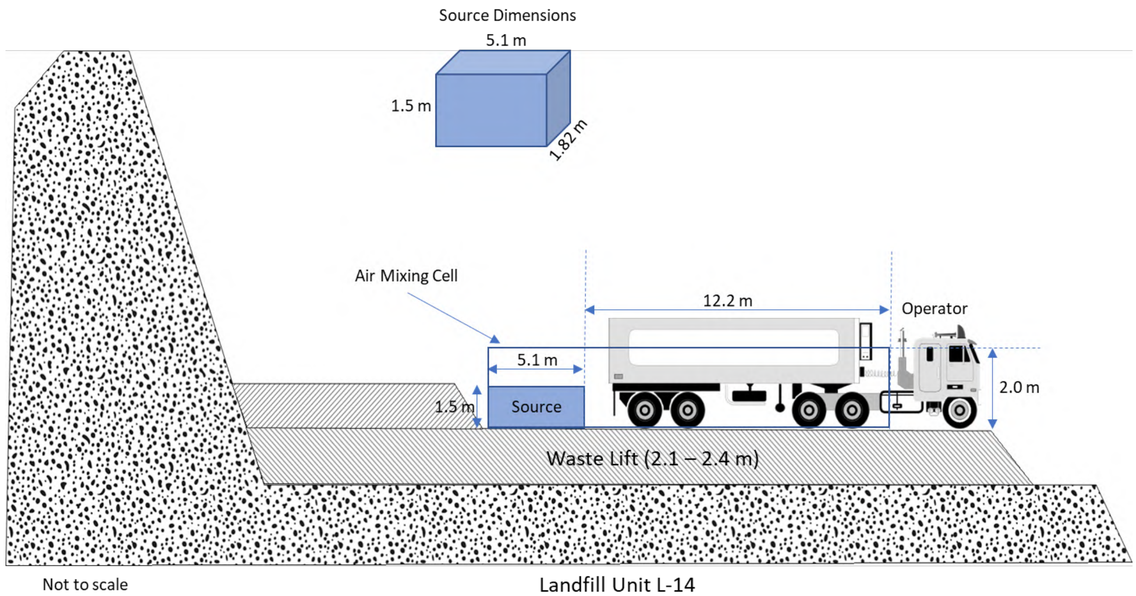

Figure 5-1. Conceptual model of exposure for the waste handler during disposal of the Bakken oilfield waste, which is indicated as "Source" in the figure.

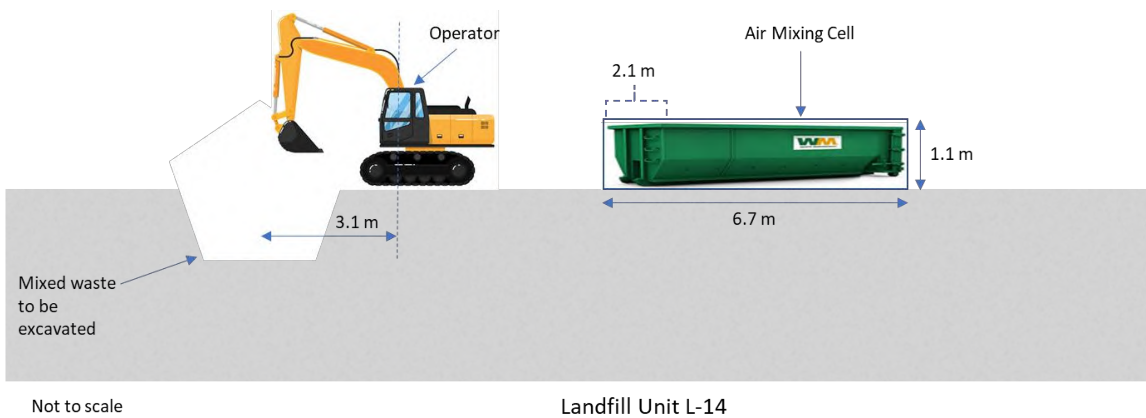

Figure 5-2. Conceptual model of exposure for the excavation worker during hypothetical removal of the Bakken oilfield waste.

The emission factor is calculated as:

$$E = k(0.0016)\frac{\left(U/2.2\right)^{1.3}}{\left(MC/2\right)^{1.4}} \tag{5-1}$$

where

E	=	emission factor (kg released to air per Mg of material handled)
U	=	wind speed (m s^{-1})
MC	=	% moisture content
k	=	particle size multiplier.

The product of the mass of Bakken oilfield waste in a load and the emission factor yields the mass of material that is available for suspension in air. The quantity of radionuclides released to the air is the product of the mass released to air and the representative radionuclide concentration:

$$Q = E \times M \times C \times y \tag{5-2}$$

where

Q	=	activity released to air (pCi)
M	=	mass of one TENORM disposal (Mg)
C	=	representative radionuclide concentration in Bakken oilfield waste (pCi g^{-1})
y	=	unit conversion factor, 1,000 g kg^{-1}.

The air concentration is then calculated by assuming the entire mass that is suspended is mixed in a volume of air (defined later as the mixing cell). The radionuclide concentration in air is then *Q/V*, where *V* is the volume of the mixing cell. The exposure scenario assumes the worker is exposed continuously until the material in air dissipates. The rate of removal from the mixing cell is described by the removal rate constant defined by:

$$K = \frac{U}{L} \tag{5-3}$$

where

K	=	removal rate constant (s^{-1})
U	=	wind speed (m s^{-1})
L	=	length of the mixing cell that lies parallel to the direction of wind (m).

Assuming a square area source, the value of *L* is given by $(A)^{1/2}$, where *A* is the surface area of the mixing cell. The change in concentration over time is described by the differential equation and solution:

$$\begin{aligned} \frac{dQ}{dt} &= -KQ \\ Q(t) &= Q_0 e^{-Kt} \end{aligned} \tag{5-4}$$

where Q_o is the initial activity in the mixing cell defined by Equation (5-2). The time-integrated air concentration that the worker is exposed to is calculated by:

$$TIC = \frac{Q_o}{V}\int_0^\infty e^{-kt}\,dt = \left(\frac{Q_o}{V}\right)\left(-\frac{1}{K}\right)e^{-kt}\Big|_0^\infty = -\frac{Q_o}{V\,K}(0-1) = \frac{Q_o}{V\,K} \tag{5-5}$$

where

TIC	=	time-integrated concentration (pCi-s m^{-3})
V	=	volume of the mixing cell (m^3).

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The area of the mixing cell for disposals was assumed to be the surface area of the disposal plus a buffer distance that accounts for the length of the trailer (12.2 m, see Figure 5-1). For hypothetical removal operations, no buffer is assumed beyond the 20-yard container (Figure 5-2). The surface area of the disposal is the disposal volume divided by the assumed average height of the pile. The mixing cell volume for disposals is the surface area (including buffer) × the difference between the height of the mixing cell and the average height of the pile. The mixing cell volume for hypothetical removal operations is the volume of the 20-yard dumpster.

$$L = \sqrt{\frac{V_{load}}{H_{load}}} + l$$
$$V = L^2 \left(H_{mc} - H_{load}\right) \qquad (5\text{-}6)$$

where

V_{load}	=	volume of the load (m^3)
H_{load}	=	height of the load after disposal (m)
l	=	buffer distance (m)
H_{mc}	=	height of mixing cell (m).

Source dimensions for disposal operations are depicted in Figure 5-1, and model parameters are listed in Table 5-1. Parameters that differ for hypothetical removal operations are given in Table 5-2.

Table 5-1. Parameters for Emission Model during Disposal and Transport in Air

Parameter	Value	Units	Notes
Average wind speed, *U*	4.839	m s^{-1}	From on-site met data
Moisture percent, *MC*	10.00	percent	Table 13.2.4-1 in Section 13.2.4, mean value for clay in municipal landfills (EPA 1995)
Particle size multiplier, *k*	0.48	unitless	AP-42 (EPA 1995) – assumes particles ≤15 μm are respirable
Volume of Bakken oilfield waste per disposal, V_{load}	1.03×10^1	m^3	Calculation
Bulk density, ρ_b	1.76×10^3	kg m^{-3}	Geosyntec Consultants (2020)
Buffer distance, *l*	12.2	m	Assumed distance from edge of disposal pile to waste handler. Per CWMNW, waste was brought in using ~40-ft trailers
Disposal pile height, H_{load}	1.5	m	Assumed average height of disposed load before compaction
Mixing cell height, H_{mc}	2.0	m	Assumed height of air mixing cell
Length of air mixing cell, *L*	17.3	m	Calculated from Equation (5-6)
Volume of mixing cell, *V*	36.87	m^3	Calculated from Equation (5-6)
Removal rate constant, *K*	0.3	s^{-1}	Calculated from Equation (5-3)

Parameter	Value	Units	Notes
Emission rate, *E*	4.09×10^{-3}	kg released to air per disposal	Calculated using Equation 2 from AP-42 (EPA 1995)

Table 5-2. Parameters for Emission Model during Hypothetical Removal Operations and Transport in Air

Parameter	Value	Units	Notes
Mass of Bakken oilfield waste per removal, m_{load}	1.09×10^{4}	kg per load	Calculation
Air mixing cell height, H_{mc}	1.1	m	Dimensions of a 20-yard dumpster[a]
Air mixing cell length, *L*	6.7	m	Dimensions of a 20-yard dumpster[a]
Air mixing cell width, *W*	2.1	m	Dimensions of a 20-yard dumpster[a]
Volume of mixing cell, *V*	1.57×10^{1}	m^3	Calculated as length×width×height
Removal rate constant, *K*	0.7	s^{-1}	Calculated from Equation (5-3)
Emission rate, *E*	2.45×10^{-3}	kg released to air per disposal	Calculated using Equation 2 from AP-42 (EPA 1995)

a. Dumpster dimensions taken from: https://www.wm.com/us/en/cpn/temp-dumpster.

5.1.1. Inhalation and Ingestion Dose Calculations

This section describes how inhalation and ingestion doses from the emissions described above are calculated. Inhalation doses to on-site receptors are calculated as:

$$DINH = IR \times \sum_{j=1}^{n} TIC_j \times DCINH_j \tag{5-7}$$

where

$DINH$ = inhalation effective dose for a Bakken oilfield waste disposal (mrem)
IR = inhalation rate ($m^3\ s^{-1}$)
TIC_j = time-integrated concentration for radionuclide *j* (pCi-s m^{-3})
$DCINH_j$ = inhalation effective dose coefficient for radionuclide *j* (mrem pCi^{-1})
n = number of radionuclides.

Inhalation doses to off-site receptors are calculated using the amount of activity suspended into the air and a dispersion factor calculated using AERMOD (see Section 5.1.4).

Ingestion effective doses during disposal or removal operations for on-site receptors assume that a given amount of the Bakken oilfield waste is ingested via adherence to skin and hand, and later transferred to mouth. The nominal value for soil ingestion per day for a worker is adjusted for the worker's exposure time during disposal or removal of the Bakken oilfield waste, which is 7 minutes and 66 minutes, respectively. The ingestion effective dose is simply the product of the effective dose coefficient and the amount of activity ingested. The amount of activity ingested is the soil ingestion rate adjusted for exposure time × the activity concentration of the Bakken oilfield waste. The amount of Bakken oilfield waste ingested is calculated by:

$$D_{ing} = SIR \times y \times ET \times \sum_{j=1}^{n} \mathrm{CA}_{j} DCING_{j} \quad (5\text{-}8)$$

where

- SIR = soil ingestion rate, 330 mg day^{-1}
- y = unit conversion factor: 1 g 1,000 mg^{-1}; 1 day 8 hours^{-1}
- ET = exposure time (hours)
- D_{ing} = effective dose from ingestion (mrem)
- CA_j = weighted-average concentration in Bakken oilfield waste for radionuclide j (pCi g^{-1})
- $DCING_j$ = ingestion effective dose coefficient (mrem pCi^{-1}).

Ingestion of contaminated soils is not a complete exposure pathway for off-site individuals.

The dose coefficients for a reference individual were taken from the U.S. Department of Energy Standard 1196 (hereafter DOEStd-1196) (DOE 2011), which are provided in the RESRAD code. Ingestion and inhalation dose coefficients are based on the default values provided in the RESRAD code for a given solubility class and gut absorption factor, and a 1-µm particle size for inhalation. Dose coefficients in DOEStd-1196 use the methodology described in Federal Guidance Report 13 (EPA 1999b) and International Commission on Radiation Protection (ICRP) Reports 68 and 72 (ICRP 1994, 1996). Inhalation and ingestion dose coefficients are given in Table 5-3.

Table 5-3. Inhalation and Ingestion Dose Coefficients

Radionuclide	Inhalation dose coefficient (mrem pCi^{-1})	Ingestion dose coefficient (mrem pCi^{-1})
U-238	3.21×10^{-2}	2.13×10^{-4}
U-234	3.74×10^{-2}	2.15×10^{-4}
Th-230	3.85×10^{-1}	9.36×10^{-4}
Ra-226	3.82×10^{-2}	1.68×10^{-3}
Pb-210	4.01×10^{-2}	1.03×10^{-2}
Th-232	4.26×10^{-1}	1.03×10^{-3}
Ra-228	6.34×10^{-2}	5.92×10^{-3}
Th-228	1.75×10^{-1}	9.34×10^{-4}

5.1.2. External Dose Calculations

External doses for the waste handler during disposals and the excavation worker and supervisor during hypothetical removal operations were calculated using a dose factor (Table 5-4) computed using the MicroShield code (Grove Engineering, Inc. 2013). The source-receptor geometry is as shown in Figure 5-1 and Figure 5-2. The source for the waste handler during disposals is represented by a rectangular volume having the dimensions illustrated in Figure 5-1 and a material with the chemical composition of cement (limestone and clay) and aggregate (silica sand) having a density of 1.3 g cm^{-3}. No shielding from the truck was assumed. The same source geometry and material was assumed for the excavation worker, but this worker is separated by 3.05 m of air and 0.095 cm of steel representing the cab of an excavator. The dose rate included photon buildup in the source. The external doses are computed as:

$$D = ET \times \sum_{i=1}^{n} DF_i \times C_i \qquad (5\text{-}9)$$

where

ET = exposure time (hours)

DF_i = dose factor for radionuclide i computed using the MicroShield code (mrad hr^{-1} per pCi g^{-1})

C_i = concentration of radionuclide i.

Table 5-4. External Dose Factors Computed Using MicroShield

Radionuclide	Dose factor for waste handler and excavation worker (mrad hr^{-1} per pCi g^{-1})	Dose factor for supervisor (mrad hr^{-1} per pCi g^{-1})
Ra-226	4.49×10^{-6}	5.65×10^{-5}
Ra-228	6.67×10^{-6}	8.32×10^{-5}

5.1.3. Radon Exposure and Dose

Radon-222 emissions from the landfill resulting from the Bakken oilfield waste disposals were calculated using U.S. Nuclear Regulatory Commission models and methods for assessment of uranium mill tailings (Rogers et al. 1984). A diffusion model is used to first calculate radon flux from the surface of uncovered compacted waste containing the Bakken oilfield waste and the other chemical and hazardous wastes (hereafter referred to as mixed waste). The flux from the bare surface is given by:

$$J_t = 10^4 C \rho_b E \sqrt{\lambda D_t}\, \tanh\left(\sqrt{\frac{\lambda}{D_t}}\, x_t\right) \qquad (5\text{-}10)$$

where

J_t = flux from the surface of the Bakken oilfield waste layer in the disposal cell (pCi m^{-2} s^{-1})

C = Ra-226 concentration in the mixed waste (pCi g^{-1})

D_t = radon diffusion coefficient in the mixed waste (m^2 s^{-1})

λ = radon decay constant (2.1×10^{-6} s^{-1})

ρ_b = bulk density of the mixed waste (g cm^{-3})

E = Rn-222 emanation coefficient (unitless)

x_t = thickness of compacted mixed waste (cm), calculated as shown in section 5.2.5.

Both the maximum and weighted-average Ra-226 concentrations were used. This waste is then covered with soil and other chemical/hazardous wastes, and ultimately the Unit will be capped in compliance with the facility's closure plan contained in CWMNW's permit. The radon flux after burying and covering the waste is given by:

$$J_c = \frac{2J_t e^{-b_c x_c}}{\left(1+\sqrt{a_t/a_c}\tanh(b_t x_t)\right)+\left(1-\sqrt{a_t/a_c}\tanh(b_t x_t)\right)e^{-2b_c x_c}}$$

$$b_i = \sqrt{\lambda/D_i}\,,\ i = c \text{ or } t \qquad (5\text{-}11)$$

$$a_i = \phi D_i\left(1-(1-k)m_i\right)^2$$

$$m_i = 10^{-2}MP\left(\frac{1}{\rho_b}-\frac{1}{\rho_s}\right)$$

where

J_c	=	radon flux from the disposal cell surface (pCi m^{-2} s^{-1})
ρ_s	=	particle density (g cm^{-3})
ϕ	=	porosity (unitless)
MP	=	dry-weight percent moisture (g of water g^{-1} of dry soil × 100)
k	=	0.26 pCi cm^{-3} in water per pCi cm^{-3} in air
m_i	=	moisture saturation fraction for waste (i=t) or cover (i=c).

The radon diffusion coefficient is given by:

$$D_i = 0.07\exp\left[-4\left(m - m\phi^2 - m^5\right)\right] \qquad (5\text{-}12)$$

The flux at the surface can be compared to the limit of 20 pCi m^{-2} s^{-1} applied to uranium mill tailings disposal cells.

Doses from outdoor radon are dependent on the radon progeny concentrations in outdoor air that exist in various levels of equilibrium with radon. Doses were estimated using the working level (WL) and a conversion of 760 mrem per working-level month (Yu et al. 2001). The WL is defined as any combination of short-lived radon progeny in one liter of air that will result in the emission of 1.3×10^5 MeV of potential alpha energy. One WL equals 100 pCi L^{-1} of radon in air with all short-lived progeny in equilibrium. The WL is related to the equilibrium equivalent concentration (EEC) and given by NCRP (1988):

$$EEC = 0.105A + 0.516B + 0.379C \qquad (5\text{-}13)$$

where *A*, *B*, and *C* are the concentrations of Po-218, Pb-214, and Bi-214, respectively. For these calculations, we assume worst-case conditions where radon progeny are in equilibrium with radon. If *A*, *B*, and *C* are measured in pCi L^{-1}, then 1 WL = EEC/100. Assuming progeny are in equilibrium with radon (a worst-case assumption) and 1 pCi L^{-1} radon concentration, then the EEC is 1 EEC per pCi L^{-1}. The working level month (WLM) and dose from radon is given by:

$$WLM = WL \frac{\text{hours exposed}}{170 \text{ hours}}$$
$$D = 760 \ \frac{\text{mrem}}{\text{WLM}} \times WLM \qquad (5\text{-}14)$$

Radon model parameters are given in Table 5-5.

Table 5-5. Radon Model Parameters

Parameter	Value	Units	Notes
Waste thickness, x_t	0.18	m	Assumes each disposal is spread out over a single 25'×25' disposal cell
Cover thickness, x_c	32.84	m	Average waste depth from final grade as calculated from data provided by CWMNW
Dry-weight percent moisture, waste, *MP*	5.20	percent	Calculation
Dry-weight percent moisture, cover, *MP*	5.20	percent	Calculation
Bulk density, waste, ρ_b	1.76	g cm^{-3}	2,970 lb yd^{-3} per Geosyntec Consultants (2020)
Bulk density, cover, ρ_b	1.76	g cm^{-3}	2,970 lb yd^{-3} per Geosyntec Consultants (2020)
Porosity, waste, ϕ	0.41	unitless	Assumption based on waste material type, sandy loam[3]
Porosity, cover, ϕ	0.41	unitless	CWMNW Updated Hydrogeologic Conceptual Site Model Report (2008)
Particle density, waste, ρ_s	2.98	g cm^{-3}	Calculated using $\rho s = \rho b/(1-\phi)$
Particle density, cover, ρ_s	2.98	g cm^{-3}	Calculated using $\rho s = \rho b/(1-\phi)$
Radon emanation coefficient, *E*	0.2	unitless	Typical value for uranium mill tailings
Max Ra-226 concentration, *C*	1.43×10^2	pCi g^{-1}	See section 3
Weighted-average Ra-226 concentration, *C*	8.93×10^1	pCi g^{-1}	See section 3
Total area of Bakken oilfield waste disposals, *A*	3.72×10^3	m^2	Total area for all 64 disposals

Waste thickness was calculated using the average volume of the waste and assuming each load was spread out over a single 25'×25' disposal cell. Cover thickness was calculated using CWMNW

[3] Sandy loam was chosen for the groundwater assessment as it transmits water more readily. It was used for the radon assessment for consistency.

estimates on the depth from final grade. Radium-226 (the radon source) was assumed to be uniformly distributed within this thickness. Worst-case Ra-226 concentrations were estimated by placing the entire Ra-226 inventory for both the maximum and weighted-average source terms in one disposal cell and applying the bulk density of compacted waste. Radon flux generally increases with waste thickness until the radon diffusion time is sufficient to result in decay of radon generated in the lower levels before exiting the top.

The waste is relatively dry with a calculated dry-weight percent moisture of 5.20%, calculated assuming an infiltration rate of 1 mm per year. Rogers et al. (1984) showed that radon diffusion coefficients decrease with moisture saturation. A doubling of the moisture saturation results in a decrease in the radon diffusion coefficient by a factor of 2 or more (see Figure 12 in Rogers et al. [1984]). Typical mill tailing covers have moisture contents ranging from 6% to 11%. Thus, a dry-weight percent moisture of ~5% is considered worst-case as it maximizes fluxes.

The radon emanation coefficient was assumed similar to uranium mill tailings, and a value of 0.2 was selected based on Figure 15 in Rogers et al. (1984). This value is likely a worst-case assumption because, again, the material in question was primarily associated with filter socks. However, as no data exists for estimating emanation coefficients from filter socks, the value for uranium mill tailings was deemed appropriate.

Radon concentrations for off-site receptors were calculated using χ/Q values derived from AERMOD as described in Section 5.1.4.

5.1.4. AERMOD Atmospheric Transport Modeling

Dispersion in air was calculated using the U.S. Environmental Protection Agency model AERMOD v19191 (EPA 2004) and one year of site-specific meteorological data (2010) obtained from the nearby meteorological tower (see Figure 2-1) operated by CWMNW. The meteorological data was processed with AERMET v12345, and the processed surface and upper air files were provided by CWMNW. For dispersion calculations, no deposition or plume depletion was assumed, which maximizes the air concentration. An area source (254 m east-west, 149 m north-south) located in the center of the landfill was used to calculate annual dispersion factors. This area represents the area in which the Bakken oilfield waste was disposed. The nearest resident was placed at UTM (zone 10) coordinates 711495E, 5053538N, and the future resident and landfill worker were placed at the center of the source (UTM 713932E, 5055692N). Air concentrations were calculated at 1 m above ground level.

AERMOD was used to calculate the dispersion factor or χ/Q (concentration [pCi m^{-3}] divided by release rate [pCi s^{-1}]). The χ/Q value has units of s m^{-3} and was calculated assuming a unit release rate from the source (1 pCi s^{-1}). Thus, the AERMOD concentration at either the future resident or nearest resident divided by the source release rate (1 pCi s^{-1}) yields the χ/Q value. The concentration for the actual release is found by multiplying the χ/Q value by the actual source release rate. Annual average χ/Q values were 3.03×10^{-4} s m^{-3} for the nearest future resident and landfill worker and 2.71×10^{-7} s m^{-3} for the nearest resident. For excavation and removal of waste, a 95% 1-hour average χ/Q value at the nearest resident was used. The 95% percentile is the 95th highest 1-hr χ/Q value calculated over the entire year (8,760 hours) of meteorological record. The 95% 1-hour χ/Q value for the nearest resident was 2.83×10^{-7} s m^{-3}. In this case, the χ/Q value is multiplied by the total activity released, instead of by the release rate, to yield the time-integrated concentration (pCi-s m^{-3}).

5.2. Groundwater Pathway Modeling

As discussed in Section 2.2.2, the Selah member of the Ellensburg formation underlies Landfill Unit L-14. To assess potential exposures via the groundwater pathway, unsaturated zone transport modeling was performed, which assumed leachate can migrate through the landfill's engineered double geomembrane and geosynthetic liner system and through its primary, secondary, and tertiary leachate collection and detection systems, through the unsaturated portion of the Selah to the saturated portion of the Selah (upper Selah aquifer). In this section, a conceptual and mathematical unsaturated and saturated zone transport model is presented to determine radionuclide travel times and pore water concentrations in the unsaturated and saturated zone, and potential maximum radiation doses and carcinogenic risks from ingesting water from a well in the upper Selah aquifer downgradient of Landfill Unit L-14, assuming liquid migration can occur. Note that the upper Selah aquifer is not used for drinking water or irrigation, and pore water in the unsaturated zone is not available for consumption as there is an insufficient amount to allow it to be pumped. Water balance calculations in CH2M HILL (2008) indicates groundwater does not discharge from the Selah south into Alkali Canyon but is lost through evapotranspiration.

5.2.1. Previous Modeling Efforts

Burns & McDonnell, Inc. (1998) developed a flow and transport model for Landfill Unit L-14 using the semi-analytical model MULTIMED for unsaturated transport and MODFLOW for the saturated portion. The unsaturated flow and transport portion of the MULTIMED model assumes steady-state infiltration and initial tracer concentrations in a source zone, and thereby provides tracer fluxes and concentrations as a function of time that may be input to MODFLOW as an upper boundary condition. The MODFLOW simulation was discretized into four layers that included the upper Selah water-bearing unit, the Intermediate Grey Clay, the lower Selah water-bearing unit, and the underlying water-bearing units of the Priest Rapids Member. The model included leakage from the upper Selah through the Grey Clay and into the lower Selah, and leakage from the lower Selah into the saturated portion of the Priest Rapids Basalt. The purpose of the model was to evaluate the effectiveness of a proposed groundwater monitoring network for early warning of a potential release of materials from the landfill. Concentrations were expressed in terms of the normalized concentration. The normalized concentration is the concentration in the aquifer divided by the concentration in the source. Based on modeling from a sump source that drained into the upper Selah, normalized concentrations in the upper Selah, Grey Clay, lower Selah, and underlying Priest Rapids were approximately 0.0019, 0.0003, <0.0001, and 0.0001, respectively. Thus, concentrations in the saturated portions of the Priest Rapids Basalt were predicted to be a factor of ~19 less than concentrations in the upper Selah (0.0019/0.0001 = 19).

This model was considered a "worst case" model because the vertical leakage rates from the upper Selah to the Priest Rapids was based on vertical hydraulic conductivities ranging from 5.0×10^{-9} to 4.6×10^{-7} cm s^{-1}. Recent analysis of leakage between the upper Selah aquifer to underlying saturated zones in the Priest Rapids Basalt (CH2M Hill 2008) indicated vertical hydraulic conductivities were unlikely to be greater than 5×10^{-10} cm s^{-1} and may be less than 1×10^{-10} cm s^{-1} Thus, movement of water from the upper Selah to the underlying Priest Rapids Basalt is much lower than what was assumed in the Burns & McDonnell, Inc. (1998) model. Consequently, concentrations in the saturated portions of the Priest Rapids Basalt would be substantially less than predicted by Burns & McDonnell, Inc. (1998), and likely zero. For these reasons, we used the upper Selah aquifer as a means of bounding any potential impacts in saturated zones in the Priest Rapids Basalt. It should also be noted that the regional aquifer used for domestic sources and irrigation lies huntress of feet below the Priest Rapids Basalt. Any impacts to the saturated portion of the Priest Rapids Basalt will be at least a factor of 19 less than in the upper Selah aquifer.

5.2.2. Conceptual Model for Flow and Transport to the Upper Selah Aquifer

A generalized conceptual model for assessment of the groundwater pathway is illustrated in Figure 5-3. The Bakken oilfield waste is represented by a rectangular area source of fixed thickness. Radionuclide concentrations are assumed to be uniform throughout the source. Radionuclides associated with the Bakken oilfield waste partition into the infiltrating water and move downward through Landfill Unit L-14.

During active facility operations, leachate moves through the waste mass, is captured by the primary geomembrane liner system, and conveyed via the geosynthetic leachate collection layer on top of the primary geomembrane liner at the bottom of the landfill. The primary leachate collection layer channels the leachate to the primary sump, where it is removed as needed from the primary sump. Landfill L-14 has a geomembrane-lined secondary leachate detection layer underneath the primary geomembrane that conveys any potential leaks to the secondary leak detection sump. Additionally, Landfill Unit L-14 has a geomembrane-lined tertiary sump acting as a redundant leak detection and protection system for potential leachate leaks in the secondary sump. Notwithstanding the multiple redundant leak protection systems, a small fraction of leachate is assumed to pass through all three liner systems during operations. During closure of Landfill Unit L-14 an evapotranspiration cap will be installed over the entire waste footprint in compliance with the facility’s closure plan. The evapotranspiration cap is designed to exclude infiltrating waters from entering the waste cell, thus discontinuing the addition of liquids into the landfill. The leachate collection system will remain in operation until the end of the post closure period, at which point all leachate is expected to be drained from the landfill waste mass.

For purposes of modeling, a worst-case scenario is assumed for the time after site closure, where the leachate collection system is assumed to cease operation and the engineered liner system is assumed to fail hydrologically, allowing any infiltrating precipitation to pass through the landfill and into the underlying vadose zone (or unsaturated zone). Over time, the hydrologic effectiveness of the engineered cap is assumed to degrade, resulting in infiltration through the engineered landfill cover system equivalent to natural background infiltration. In this assumed failure mode, leachate travels downward vertically through the vadose zone and enters the aquifer over a footprint area equivalent to the simulated Bakken oilfield waste block in Landfill Unit L-14. Radionuclides that enter the aquifer mix vertically within a defined region and migrate downgradient to a receptor well assumed to be (1) 100 m downgradient from the downgradient edge to the source (POC 1 in Figure 5-3) and (2) on the downgradient edge of the source footprint (POC 2 in Figure 5-3).

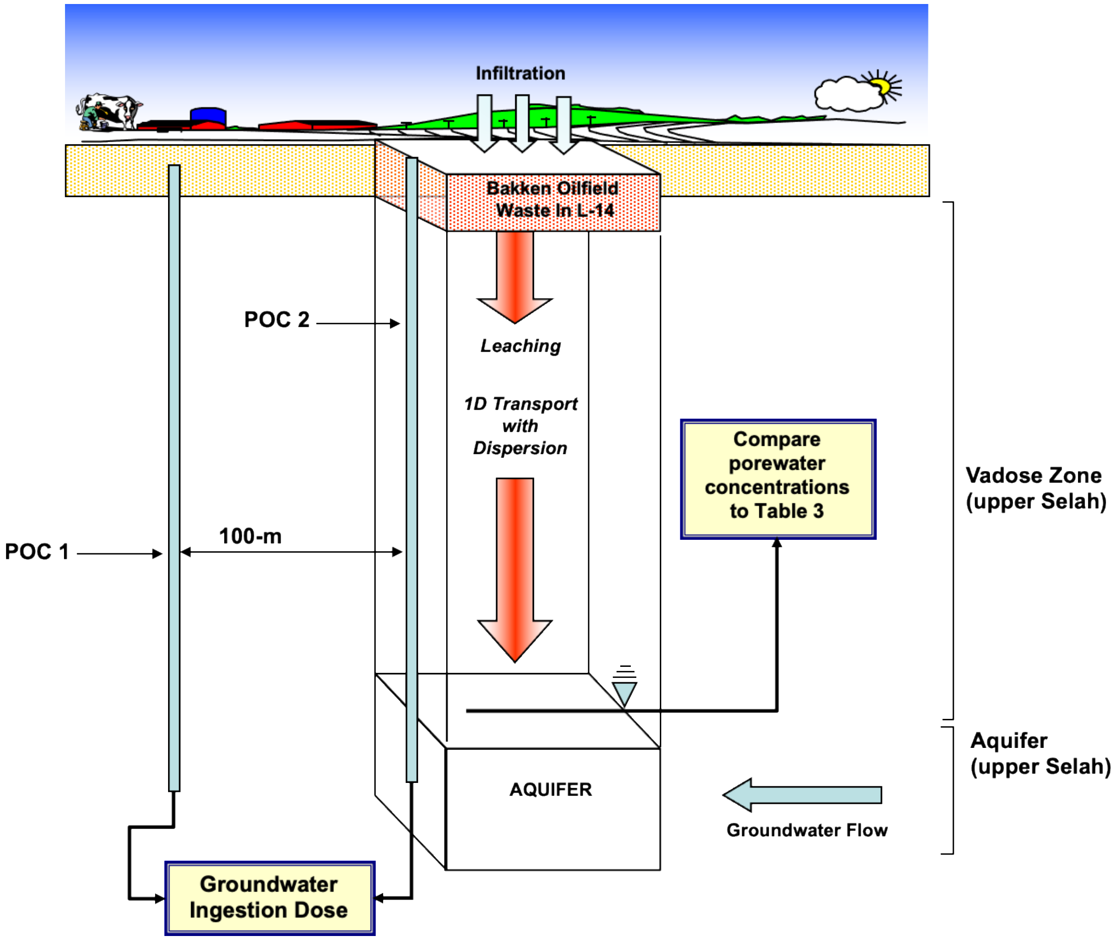

Figure 5-3. Generalized conceptual model for assessment of the groundwater pathway.

5.2.3. Mathematical Model and Code Selection

The conceptual model is typically represented mathematically by established equations for water flow in a porous medium and contaminant transport via advection, dispersion, and diffusion. For water flow in the unsaturated zone, the general one-dimensional equation is given by:

$$q = K\left(\frac{\partial H}{\partial z} + \frac{\partial \psi}{\partial z}\right) \qquad (5\text{-}15)$$

where

q	=	specific discharge or Darcy flux (m yr^{-1})
θ	=	volumetric moisture content (m^3 m^{-3})
H	=	elevation head (m)
ψ	=	suction or pressure head from capillary forces (m)
K	=	unsaturated hydraulic conductivity (m yr^{-1})
z	=	distance positive downward from the top of the column (m).

The general equation for one-dimensional transport in the vadose zone under transient flow conditions is given by:

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$$Rd\,A\,\theta\frac{\partial C}{\partial t}=A\frac{\partial}{\partial z}\left(\theta D\frac{\partial C}{\partial z}\right)-A\frac{\partial qC}{\partial z}-\left(Rd\,\theta\,\lambda+Rd\frac{\partial\theta}{\partial t}\right)AC \tag{5-16}$$

where

C	=	radionuclide solute concentration (pCi m^{-3})
D	=	dispersion coefficient (m^2 yr^{-1})
A	=	cross-sectional area perpendicular to flow (m^2)
Rd	=	retardation coefficient (unitless)
λ	=	first order decay constant (yr^{-1}).

The retardation coefficient (*Rd*) is given by:

$$Rd=1+\frac{K_d\rho_b}{\theta} \tag{5-17}$$

where

K_d	=	soil-water partitioning coefficient (cm^3 g^{-1})
ρ_b	=	bulk density (g cm^{-3}).

For steady-state saturated conditions, these equations greatly simplify in that the terms $\partial\theta/dt$, $\partial\theta/\partial z$, and $\partial q/\partial z$ are zero in Equation (5-16). Solutions to these equations for different boundary and initial conditions range from simple semi-analytical assessment models like RESRAD ONSITE (Kamboj et al. 2018) to detailed numerical research-grade models like HYDRUS (Simunek et al. 2013) for unsaturated modeling and MODFLOW/MT3D for saturated zone modeling.

For this problem, the system was represented mathematically through a series of mixing cells that are connected via rate constants. This modeling approach is implemented in the GoldSim®[4] modeling software that has become an industry standard for low-level radioactive waste (LLRW) performance assessment (PA) models, but is equally applicable to any system involving long-term performance of engineered disposal cells.

This model is quantitatively represented in the Mixing Cell Model (MCM) code (Rood 2004b, 2005). MCM is an established model for evaluating performance of engineered disposal facilities. It is used at Idaho National Laboratory (DOE-ID 2007, 2008, 2011, 2012, 2018) and was also applied to the U.S. Ecology Site on the Hanford Reservation (Rood 2004a) and was used in the TENORM analysis at the Blue Ridge Landfill (RAC 2016). The MCM model has been benchmarked with HYDRUS and has shown comparable results. Furthermore, the model has been used to abstract complex three-dimensional vadose zone models into a simpler formulation that incorporates the salient features of the system (DOE-ID 2007).

MCM is a one-dimensional unsaturated flow and transport model but can also be used for saturated conditions. The model domain is discretized into a series of mixing cells where the model calculates water and solute balance. Unit gradient conditions (i.e., $\partial\psi/\partial z=0$, $\partial H/\partial z=1$) are assumed for each cell in the unsaturated zone. The continuity equation states:

$$\frac{\partial\theta}{\partial t}=-\frac{\partial q}{\partial z} \tag{5-18}$$

[4] https://www.goldsim.com

Combining Equations (5-15) and (5-18) with the unit gradient assumption gives the water balance equation in MCM.

$$\frac{\partial \theta}{\partial t} = -\frac{\partial K(\theta)}{\partial z} \tag{5-19}$$

Water balance is based on the constituent relationships of hydraulic conductivity [$K(\theta)$], pressure, and moisture content as described by van Genuchten (1980). Solute transport is based on a linearization of the advection-dispersion into fully mixed cells. One-dimensional dispersion and diffusion are addressed through either the dispersion implicit in model discretization or explicitly. The model addresses transient as well as steady-state water infiltration and is thus well-suited for assessments involving landfills with engineered covers that may degrade over time. Transient infiltration occurs because infiltration-reducing covers do not last indefinitely, resulting in infiltration through the waste and into the vadose zone that changes over time. The MCM model was used to compute water fluxes and solute transport in the vadose zone.

For the aquifer, the GWSCREEN code is typically used (Rood 1994, 2002) because it interfaces with output from MCM. The GWSCREEN model is an application of the U.S. NRC semi-analytical groundwater models for time-variable solute fluxes (Codell et al. 1981). The semi-analytical model assumes one-dimensional flow and three-dimensional dispersion in an aquifer of infinite lateral extent and finite thickness. However, for this application, a saturated MCM simulation was used instead because GWSCREEN does not perform differential transport among radioactive progeny. When flow velocities in the aquifer are rapid compared to unsaturated flow, this limitation in GWSCREEN makes little difference. However, horizontal flow velocities in the upper Selah aquifer are slow, allowing substantial ingrowth of radioactive progeny during transport across the source region. For this reason, a saturated MCM model was used instead of GWSCREEN because MCM addresses differential transport of radioactive progeny. Differential transport occurs because each radionuclide has element-specific soil water partitioning coefficients that determine the speed at which the radionuclide travels in groundwater. Output from GWSCREEN and saturated MCM were compared to provide confidence in the MCM saturated simulation.

The conceptual model for unsaturated flow and transport in MCM is illustrated in Figure 5-4. The upper-boundary condition for the flow model was the infiltration rate through the waste cell and into vadose zone, and the lower boundary is free drainage flow into the aquifer. The infiltration into the waste cell accounts for the presence of a geosynthetic engineered cover system. For transport, a zero-flux boundary condition was applied at the top and initial inventories assigned to the first layer.

For the saturated zone, the hydraulic conductivity and moisture content were fixed in each cell at the Darcy velocity and saturated aquifer porosity, respectively. Thus, a water flow simulation was not necessary (i.e., Darcy velocity is assigned). The upper-boundary condition for transport in the aquifer was the radionuclide fluxes from the MCM unsaturated simulation.

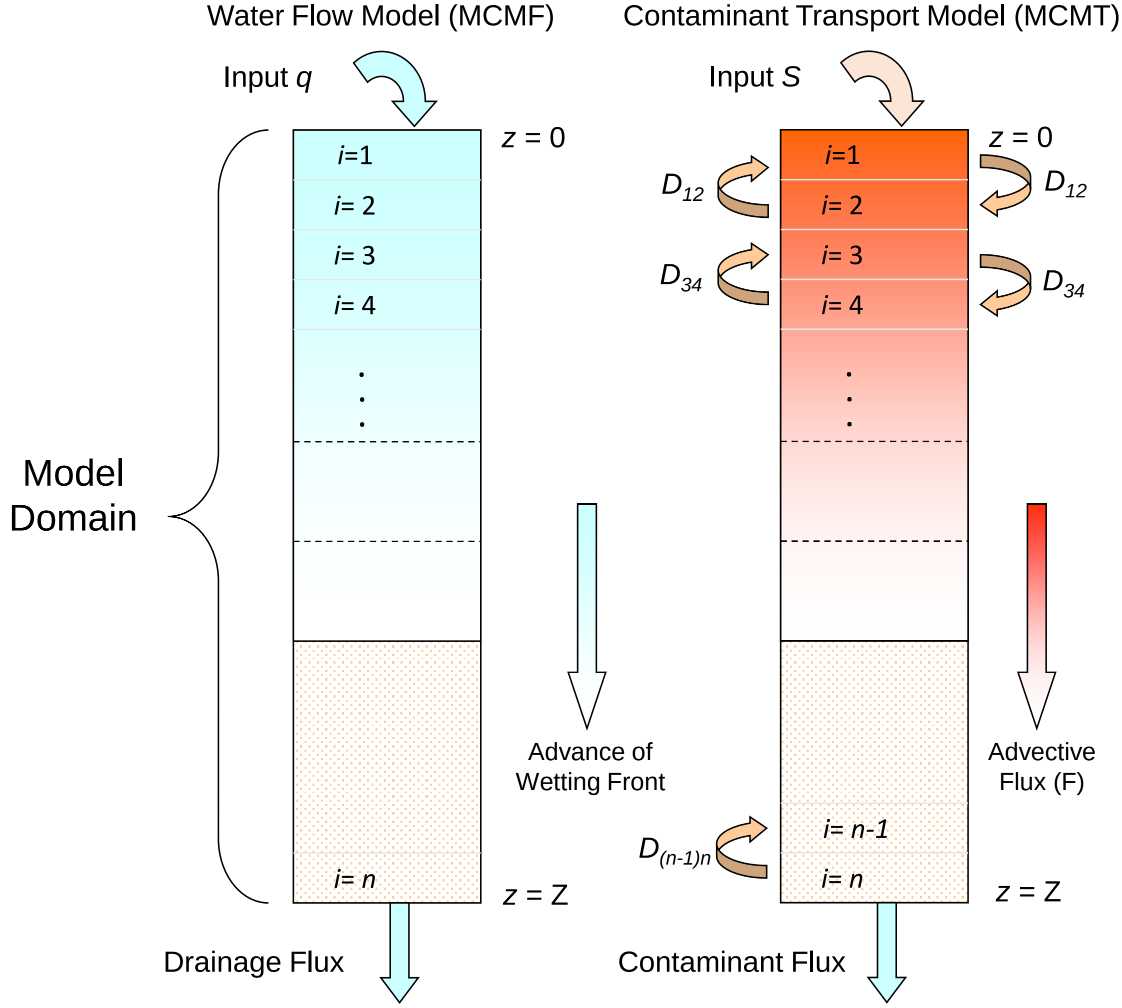

Figure 5-4. The MCM conceptual model for water flow (left) and contaminant transport (right). The model domain is discretized into *n* cells and extends to a depth of *z* = *Z*. Interchange between cells is indicated by the variable $D_{i,j}$, where *i* is the index of the donor cell and *j* is the index of the receiving cell. The variable *q* is the water flux, and *S* is the source or radionuclide flux (Rood 2005).

5.2.4. Modeled Decay Series

The two decay series modeled, which were described in Section 3, were ^{238}U (see Figure 3-1) and ^{232}Th (see Figure 3-2). The long simulation times that are encountered in groundwater modeling require that decay and ingrowth be accounted for in the modeling. However, many of the decay chain members in both decay series are short-lived and do not occur in the environment without the presence of their parent. These short-lived members do not require explicit treatment and can be assumed to be in secular equilibrium with their parent. Radiological doses and risks from these short-lived members are not ignored because the dose and risk coefficients of the short-lived progeny are added to their parent such that ingestion of the parent also assumes ingestion of the progeny in the environment. Thus, instead of modeling the full decay series, an abbreviated decay series is modeled. The abbreviated ^{238}U decay series is given by:

$$^{238}\text{U}\rightarrow{}^{234}\text{U}\rightarrow{}^{230}\text{Th}\rightarrow{}^{226}\text{Ra}\rightarrow{}^{210}\text{Pb}\rightarrow{}^{206}\text{Pb (stable)}.$$

The abbreviated ^{232}Th decay series is given by:

$$^{232}\text{Th}\rightarrow{}^{228}\text{Ra}\rightarrow{}^{228}\text{Th}\rightarrow{}^{208}\text{Pb (stable)}.$$

5.2.5. Source Configuration and Receptor Locations

Based on landfill manifests, there were 64 shipments of Bakken oilfield waste that were disposed in Landfill Unit L-14. The total waste mass was reported to be 1,285 tons (2,569,320 lbs or 1,167,873 kg). After disposal and burial, the bulk density of the disposal material was reported to be 1,770 kg m^{-3}. Assuming each disposal load was spread across the 25 ft × 25 ft (58 m^2) grid block, the total area of disposal was 64 × 58 m^2 = 3,716 m^2. In reality, the individual disposal loads of Bakken oilfield waste in Landfill Unit L-14 are estimated to have been spread over an area of 28,883 m^2 based on Figure 5-5. Thus, the compressed source assumed for modeling results in a bounding estimate of radionuclide pore water concentrations because the activity is compressed into a smaller volume than what actually occurred.

The thickness of the waste in the model is calculated as:

$$T = \frac{1{,}167{,}873 \text{ kg}}{1{,}770 \text{ kg/m}^3} \times \frac{1}{3{,}716 \text{ m}^2} = 0.178 \text{ m}$$

For the model, the source is assumed to represent a square area source with the length of a side equal to $(3{,}716)^{1/2}$ = 60.96 m and a waste thickness of 0.178 m.

Figure 5-5 illustrates the actual and modeled areal extent of the source region and the location of the hypothetical receptor wells where groundwater impacts (concentrations, doses, and risks) are evaluated. Receptor wells are assumed to be in the upper Selah aquifer and placed on the downgradient edge of the source where maximum concentrations occur. A 100-m downgradient receptor is also added based on U.S. DOE performance assessments allowing a 100-m receptor well for comparing predicted concentrations and doses with DOE and NRC LLRW performance objectives.

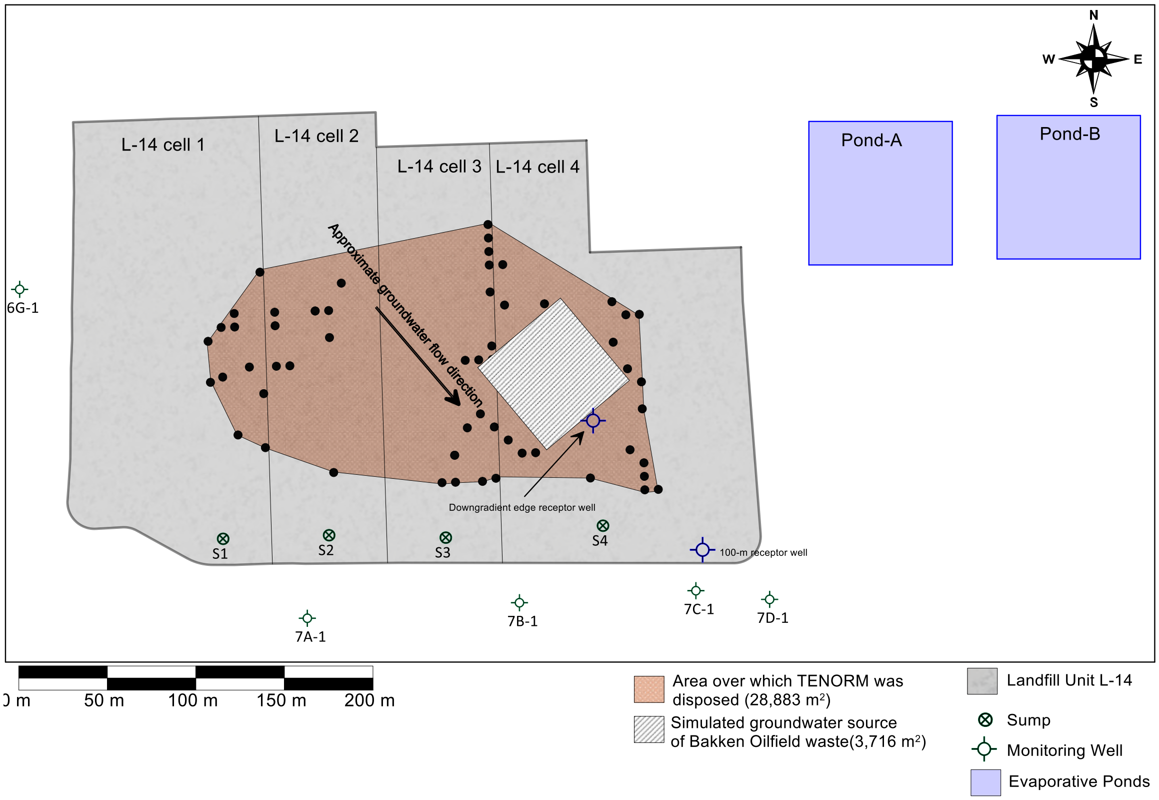

Figure 5-5. Landfill Unit L-14, the area over which the Bakken oilfield waste disposals (dots) were reported, the simulated groundwater Bakken oilfield source, and the receptor well locations.

The source configuration described here was intended to address the Bakken oilfield waste disposals in question in a pessimistic manner only (i.e., it does not underestimate the concentrations and resultant doses).

5.2.6. Summary of Groundwater Pathway Modeling Assumptions

The assumptions for the unsaturated and saturated zone transport model are summarized below:

- Bakken oilfield waste inventory assumes maximum radionuclide concentrations from the available data for all shipments and therefore overestimates the actual radionuclide inventory in Landfill Unit L-14.
- Bakken oilfield waste is compressed into a single source cell measuring 60.96 m on each side. This assumption results in higher predicted (modeled) concentrations in the upper Selah aquifer (i.e., minimizes radionuclide dilution if material is assumed to be spread over a larger area).
- Radionuclide fluxes to the upper Selah aquifer are distributed across an area equal to the modeled source area in Landfill Unit L-14.
- The model assumes releases of leachate through the entire engineered liner system and leachate detection systems after the site has been capped and no leachate is being generated. Thus, it represents an extremely pessimistic scenario.

- Concentrations, doses, and risks are evaluated at the downgradient edge of the source within the upper Selah aquifer, which is where the highest results are encountered. Results at this receptor location represent a pessimistic estimate.
- Results at a well 100 m downgradient from the source are also presented because this is the compliance point for DOE and NRC LLRW performance assessments.
- Results are presented in the upper Selah aquifer, which is the first occurrence of groundwater. This aquifer is highly confined to the north of the landfill with very low flow to the south, has no receptors, and dissipates in the Alkali Canyon face. Concentrations, doses, and risks in the underlying aquifers will be significantly less than concentrations in the Selah based on hydrogeologic conditions.

It is noted that the results of the modeling effort represent a pessimistic estimate of impacts for groundwater at the Arlington site and is presented as an absolute worst-case scenario that is highly unlikely. Modeling of actual conditions would incorporate the spatial distribution of the Bakken oilfield waste disposals, minimal infiltration of water through the final engineered landfill cap, and minimal movement of liquids through the engineered triple-liner and leachate collection system.

5.2.7. Groundwater Parameters

Groundwater model parameters include infiltration, material properties, dispersion coefficients, and element-specific soil-water partitioning coefficients (K_d). Radionuclide-independent properties are provided in Table 5-6 followed by a discussion of some of the parameters.

Table 5-6. Radionuclide-Independent Groundwater Modeling Parameters

Parameter	Value	Reference/comments
Infiltration		
Infiltration, natural (mm yr^{-1})	3.5	DOE (2018) – see discussion
Infiltration, cover (mm yr^{-1})	1.0	Bounding assumption for an engineered cover
Infiltration, leakage from liner (mm yr^{-1})	0.5	Bounding assumption
Engineered cover		
Cover longevity (years)	200	Assumed cover lifetime in RAC (2016)
Cover failure time (years)	100	Assumed time from the onset of cover failure to complete failure and when infiltration returns to a natural state RAC (2016)
Source properties		
Length and width (m)	60.96	Calculated
Thickness of TENORM (m)	0.178	Calculated
Bulk density (g cm^{-3})	1.77	email from J. Denson to E. Caffrey, May 6, 2020
Porosity	0.46	Carsel and Parrish (1988)
Saturated hydraulic conductivity (m yr^{-1})	387.2	Carsel and Parrish (1988)
Residual moisture	0.145	Carsel and Parrish (1988)

Parameter	Value	Reference/comments
van Genuchten α (m^{-1})	1.6	Carsel and Parrish (1988)
van Genuchten *n*	1.37	Carsel and Parrish (1988)
Free water diffusion coefficient (m^2 yr^{-1})	0.0158	DOE (2018)
Vadose zone		
Vadose zone thickness (m)	24.0	Burns & McDonnell, Inc. (1998)
Vertical hydraulic conductivity in Selah (m yr^{-1})	0.145	Maximum value in Table 6-1 of Burns & McDonnell, Inc. (1998)
Porosity	0.46	Carsel and Parrish (1988) and Burns & McDonnell, Inc. (1998)
Residual moisture	0.037	Carsel and Parrish (1988) and Burns & McDonnell, Inc. (1998)
van Genuchten α (m^{-1})	1.6	Carsel and Parrish (1988) and Burns & McDonnell, Inc. (1998)
van Genuchten *n*	1.37	Carsel and Parrish (1988) and Burns & McDonnell, Inc. (1998)
Bulk density (g cm^{-3})	1.15	Table 4-2 in CH2M Hill (2008)
Saturated zone		
Saturated horizontal hydraulic conductivity (m yr^{-1})	6.28	Geometric mean from values in Table 4-4 in CH2M Hill (2008)
Hydraulic gradient (m/m)	0.029	Figure 4-7 in CH2M Hill (2008)
Porosity	0.46	Carsel and Parrish (1988)
Bulk density (g cm^{-3})	1.15	Table 4-2 in CH2M Hill (2008)
Longitudinal dispersivity (m)	6.096	See discussion
Transverse dispersivity (m)	3.05	See discussion
Vertical dispersivity (m)	0.6096	See discussion
Saturated thickness (m)	15.24	Figure 4-2 in CH2M Hill (2008)
Well screen (mixing) thickness (m)	5	Assumed – see discussion
Exposure scenario		
Water ingestion (L yr^{-1})	730	Water ingestion rate for determining maximum contaminant limits in 40 CFR 141 (2 L day^{-1})
Exposure duration, effective dose (years)	1	One-year for annual effective dose
Exposure duration, carcinogenic risk (years)	30	Assumed the individual resides at same location for 30 years

5.2.7.1. Infiltration

The transport of radionuclides from to the landfill to the aquifer is driven by the infiltration of precipitation from the landfill surface. A good estimate of the amount of infiltration through Landfill Unit L-14 was made by taking the annual amount of liquids collected in the leachate collection system divided by the area of the landfill. This overstates the leachate generation as newer cells in the landfill transmit precipitation to the leachate system much faster than older cells. Volumes of leachate collected in each of the four disposal cells vary with the area of the cell and volume of waste in place (see Table 5-7). The oldest cells (L-14 cells 1 and 2) have the greatest waste mass and cover soils and no exposed liner. The newest cell (L-14 cell 4) has an exposed liner in the eastern portion of the cell. Water that falls as precipitation on L-14 cell 4 contacts the exposed liner and is transmitted to the leachate collection system with minimal evaporation. Consequently, this cell collected the most leachate during 2019. A thin layer of waste over the liner (L-14 cell 3) will also transmit water at a higher rate to the sump compared to cells 1 and 2 because as soon as water hits the impermeable liner it is channeled to the sump. Liquids that fall on the surface of the older cells infiltrates into thicker soil covers and waste mass and is held in the pore spaces where evaporation removes a substantial fraction. Note that the infiltration for L-14 cells 1 and 2 are about the same (~2.2 mm yr^{-1}), while L-14 cell 3 is slightly greater (3.67 mm yr^{-1}). These infiltration rates are comparable to those estimated at the Hanford reservation (DOE 2018) of 3.5 mm yr^{-1} and provide a good estimate of natural infiltration in the Arlington environment.

Table 5-7. Volume of Water Collected in Each of the L-14 Landfill Cells in 2019, Area of Each Cell, and Estimated Infiltration

Cell	Volume (gal yr^{-1})[a]	Volume (m^3 yr^{-1})	Area of cell (m^2)[b]	Infiltration (m yr^{-1})
L-14 cell 1	15,361	58.148	26,331.5	0.00221
L-14 cell 2	9,538	36.105	16,651.3	0.00217
L-14 cell 3	147,402	557.98	15,202.1	0.0367
L-14 cell 4	730,884	2,766.7	28,605.1	0.0967
Total	903,185	3,418.9	86,790	0.0394
Total, L-14 cell 1 through L-14 cell 3	---	---	58,185	0.0588

a. From J. Denson email dated May 5, 2020.

b. Calculated from the GIS coverages provided by Waste Management.

For this assessment, the Hanford estimate of 3.5 mm yr^{-1} is used to represent natural background infiltration. It is slightly greater than the site-specific value for 2019 from the Arlington results but provides a reasonable long-term average for the region. The model assumes operation of the landfill continues for the next 30 years and the leachate collection system will continue to operate during this time. This is a pessimistic assumption as the landfill will continue to operate for several decades. Although the leachate collection systems and liner preclude infiltration from the waste cells entering the vadose zone, a leakage rate of 0.5 mm yr^{-1} through the liner system into the vadose zone was assumed for modeling purposes.

Upon closure of the landfill, an engineered evapotranspiration cover will be placed over the entire landfill surface and the leachate collection system will continue to operate until no further leachate accumulates in the sumps. The evapotranspiration cover will be designed for zero infiltration. Drainage of moisture from the waste is modeled to continue for 30 years. The model assumes during this period that all three leachate collection systems are breached and moisture in the waste at the time of closure is allowed to drain into the vadose zone. The engineered cover is assumed to limit infiltration to 1 mm yr^{-1} based on preliminary cover designs assumed for performance assessments at the Idaho National Laboratory (DOE-ID 2018). This is a pessimistic assumption because the cover will be designed to prevent infiltration (i.e., zero infiltration) that will overestimate the leachate flux from the closed landfill to the vadose zone. Recent studies of geosynthetic covers and liners in low-level waste facilities (Benson 2016; Tian et al. 2017) suggest minimum cover service life is in the range of 730–1,400 years.

The model assumes the hydrologic integrity of the evapotranspiration cover lasts 200 years. The actual cover system is designed to last significantly longer. The 200-year cover lifetime and 1 mm yr^{-1} infiltration is considered a pessimistic scenario that will overestimate radionuclide releases to the vadose zone from the closed landfill. The model assumes over the next 100 years (year 200 through 300), the cover degrades, and infiltration linearly increases its natural level (3.5 mm yr^{-1}) at 300 years and continues at that rate indefinitely. The actual and modeled infiltration conditions are summarized in Table 5-8.

Table 5-8. Summary of Actual and Modeled Infiltration Conditions

Time period from presen	Actual/expected conditions	Modeled conditions
0 to 30 years	Landfill continues operations, and no leachate water is released to vadose zone.	Landfill continues to operate, and 0.5 mm yr^{-1} of leachate water is released to vadose zone.
30 to 60 years	Evapotranspiration cover with zero infiltration is placed over the landfill at closure, and the leachate collection system operates until no further leachate is available to be collected.	Evapotranspiration cover with 1 mm yr^{-1} infiltration is placed over landfill at closure. No leachate collection occurs and liner fails, allowing leachate in waste to drain into the vadose zone.
60 to 230 years	Evapotranspiration cover with zero infiltration continues to operate, resulting in no leachate generation.	Evapotranspiration cover with 1 mm yr^{-1} infiltration continues to operate, allowing leachate to enter vadose zone.
230 to 330 years	Evapotranspiration cover with zero infiltration continues to operate, resulting in no leachate generation.	Evapotranspiration cover degrades hydrologically, allowing infiltration to increase linearly from 1 mm yr^{-1} in year 230 to 3.5 mm yr^{-1} in year 330.
>330	Evapotranspiration cover with zero infiltration may continue to operate up to 1,400 years or longer. If the cover fails hydrologically, infiltration is not expected to be greater than natural infiltration.	Infiltration through closed landfill is fixed at the natural rate of 3.5 mm yr^{-1}.

5.2.7.2. Unsaturated Hydrologic Parameters

Unsaturated parameters include the unsaturated thickness van Genuchten fitting parameters that describe the relationship between unsaturated hydraulic conductivity, pressure, and moisture content, and the bulk density. The unsaturated thickness below landfill unit L-14 was estimated to be between ~23 m (75 ft) in the northwest to ~34 m (112 ft) in the southeast (Figure 4-6 in CH2M

Hill [2008]). For the model, the value used by Burns & McDonnell, Inc. (1998) of 24 m (rounded from 24.4 m) was chosen.

There are no site-specific hydrologic parameters for waste materials or the Selah formation, so literature values were used for the van Genuchten α and n, the residual moisture content, and the total porosity as described below. Based on review of the lithology and measurements of vertical saturated hydraulic conductivity of the Selah Member, previous modeling (Burns & McDonnell, Inc. 1998) assumed the van Genuchten fitting parameters α, *n*, and total porosity of silt as described in Carsel and Parrish (1988), and these parameters were retained for this simulation. The vertical saturated hydraulic conductivity was the maximum reported in Burns & McDonnell, Inc. (1998). For the waste, a material with a higher saturated hydraulic conductivity was used (sandy loam) with van Genuchten parameters and saturated hydraulic conductivity from Carsel and Parrish (1988).

Bulk density for the Selah in both the saturated and unsaturated zones were from Table 4-2 in CH2M Hill (2008). For the waste, the bulk density of 2,970 lbs yd^{-3} (1.77 g cm^{-3}) was provided by CWMNW[5].

5.2.7.3. Aquifer Parameters

The aquifer properties include total porosity, saturated hydraulic conductivity, thickness of the saturated zone, and the hydrologic gradient. The bulk density and total porosity of the unsaturated Selah were assumed for the saturated portion. The horizontal saturated hydraulic conductivity was taken from Table 4-4 in CH2M Hill (2008) and represented the geometric mean of the six minimum and maximum values reported by Dames and Moore (1987) and the three values measured by RUST Environmental & Infrastructure (RUST 1998a) (2.0×10^{-5} cm s^{-1}). The hydraulic gradient (0.029 m/m) was taken from Figure 4-7 in CH2M Hill (2008). The calculated Darcy velocity in the aquifer is then:

$$v = K_{sat}\frac{dh}{dx} = 2.0\times10^{-5}\ \text{cm/s}\ \times 0.029\ \text{m/m}\ \times\ 3.1536\times10^{7}\ \text{s/yr} = 0.182\ \text{m/yr}$$

and the pore velocity would be (0.182 m/yr)/0.46 = 0.396 m/yr. This value is lower than the horizontal flow velocity estimated in CH2M Hill (2008) of 2 ft yr^{-1} (0.61 m yr^{-1}) and overestimates radionuclide concentrations in the aquifer. Higher Darcy velocities result in greater dilution and dispersion and thereby reduced predicted concentrations in the aquifer.

The saturated zone thickness of the of the upper Selah aquifer underlying Landfill Unit L-14 ranges from 9.1 m (30 ft) in the northeastern portion to 18.3 m (60 ft) in the southwestern portion (Figure 4-2 in CH2M Hill [2008]). A value of 15.24 m (50 ft) was chosen because it represents the largest area in Figure 4-2 of CH2M Hill (2008) underling Landfill Unit L-14.

5.2.7.4. Dispersion Coefficients

Dispersion in groundwater is the sum of mechanical dispersion and molecular diffusion, although in advective-dominated systems, molecular diffusion is negligible. Mechanical dispersion is calculated as the product of the dispersivity and the pore water velocity. The dispersion coefficients are calculated by:

[5] Email from J. Denson to E. Caffrey, dated May 6, 2020.

$$D_x = \alpha_L u + D_e$$
$$D_y = \alpha_T u + D_e \qquad (5\text{-}20)$$
$$D_z = \alpha_V u + D_e$$

where

D_x, D_y, D_z = longitudinal, transverse, and vertical dispersion coefficient, respectively ($m^2\ s^{-1}$)
α_L, α_T, α_V, = longitudinal, transverse, and vertical dispersivity, respectively (m)
u = pore water velocity ($m\ s^{-1}$)
D_e = effective molecular diffusion coefficient ($m^2\ s^{-1}$).

The dispersivity is an empirically derived parameter that varies with scale length. Xu and Eckstein (1995) developed regression equations that described the longitudinal dispersivity (spreading parallel the flow) to scale length, which can be approximated by the scale length divided by 10. The scale length in the aquifer is the length of the source parallel to groundwater flow (60.69 m). Thus, α_L, = 60.96 m/10 = 6.096 m. The transverse and vertical dispersivity are approximated by data in Gelhar et al. (1992), which show that the transverse dispersivity is approximately one-half the longitudinal dispersivity and the vertical dispersivity is $1/10^{th}$ the longitudinal dispersivity. For the vadose, zone, the longitudinal dispersivity was assigned $1/10^{th}$ the unsaturated thickness.

Molecular diffusion was considered for the unsaturated zone where unsaturated pore velocities are on the order of 0.0091 m yr^{-1} (2.9×10^{-8} cm s^{-1}). The measured effective diffusion coefficient for a non-sorbing specie in grout reported in DOE (2018) was 2.9×10^{-8} $cm^2\ s^{-1}$. The free water diffusion coefficient is defined as the effective diffusion coefficient divided by the tortuosity, which was given as 5.8×10^{-3}. Thus, the free-water diffusion coefficient (which is input in MCM) was $2.9\times10^{-8}\ cm^2\ s^{-1}/5.8\times10^{-3}\ m^2/10^4\ cm^2 \times 3.1536\times10^7\ s\ yr^{-1} = 0.0158\ m^2\ s^{-1}$. The free-water diffusion coefficient is modified by the porosity and saturation of the media in MCM using the formulation in Millington and Quirk (1961) and only applied to radionuclides to the aqueous phase.

$$D_e = D_m \frac{\theta^{10/3}}{\theta_s^2} \qquad (5\text{-}21)$$

where

D_e = effective diffusion coefficient in water ($m^2\ s^{-1}$)
D_m = free-water molecular diffusion coefficient ($m^2\ s^{-1}$).

The MCM model is one-dimensional; thus, only longitudinal dispersivity is considered. Using the dispersivity parameters and the GWSCREEN code, which embodies the three-dimensional semi-analytical groundwater model developed by the NRC (Codell et al. 1981), a comparison was made between the one- and three-dimensional solution to confirm it provided comparable results (See Section 5.2.7.9).

5.2.7.5. Well Screen Thickness

The well screen thickness is the depth in the saturated zone where radionuclides are mixed vertically and thereby averaged over the vertical column of water. The conceptual model assumes leachate enters the top of the aquifer and is mixed vertically within this thickness. The conceptual model does not account for water withdrawn from the well, which maximizes concentrations because it does not take credit for additional dilution from clean water drawn downgradient and laterally from the source. The well screen thickness for performance assessments at the Idaho National Laboratory (DOE-ID 2007, 2011, 2018) was 15 m and assumes no effects from pumping. For this assessment, a screen thickness of 5 m was assumed to account for the narrow saturated-zone thickness.

To check the validity of this assumption, RESRAD OFFSITE v4 (NRC 2020) was run using the CWMNW conceptual model and model parameters (assuming a steady-state infiltration of 3.5 mm yr^{-1}), and the U-238 inventory assuming a zero K_d. The zero K_d was necessary because maximum concentrations with the base case uranium K_d are achieved after 10,000 years and RESRAD limits the maximum simulation time to 10,000 years. The well water concentration in RESRAD OFFSITE is dependent on the water usage requirements, assumed well pumping rate, and the depth of the aquifer contributing to the well. If the aquifer is not able to provide the water usage requirements, then radionuclide concentrations are diluted by the additional makeup water necessary to meet the water usage requirements. For example, if the depth in the aquifer is shallow and the aquifer is low yielding, then the well will not be able to produce enough water to meet the water usage requirements and makeup water will be added. The upper Selah aquifer is a very low-yielding aquifer and is not capable of supporting withdrawal for use as a drinking water source. The default RESRAD value for the depth in the aquifer contributing to the well is 10 m. Using the RESRAD OFFSITE default pumping rate of 5,100 m^3 yr^{-1}, the maximum well water concentration for a well located on the downgradient edge of the source was 0.15 pCi L^{-1}; using 1 m^3 yr^{-1} pumping rate (the minimum value allowed) gave a maximum concentration of 3.76 pCi L^{-1}. The corresponding concentration calculated with MCM and a 5-m mixing thickness was 3.61 pCi L^{-1}, which matches reasonably well with the RESRAD value assuming minimal pumping. Also, under the low pumping rate scenario, RESRAD radionuclide concentrations in the aquifer are almost uniform with depth, ranging from 3.76 pCi L^{-1} at the surface to 3.4 pCi L^{-1} near the bottom of the aquifer. Thus, the aquifer is well mixed vertically. Ignoring well drawdown from pumping results in higher well water concentrations. Furthermore, assuming a 5-m well screen thickness provides results that are consistent with the RESRAD modeling assuming no drawdown.

5.2.7.6. Equilibrium Soil-Water Partitioning Coefficients (K_d)

The equilibrium soil-water partitioning coefficient or K_d (mL g^{-1}) is defined by:

$$K_d = \frac{C_s}{C_a} \tag{5-22}$$

where

C_s = concentration in soil at equilibrium (pCi g^{-1})
C_a = concentration in aqueous solution at equilibrium (pCi mL^{-1}).

The K_d is important because it defines how fast the radionuclide moves in groundwater. If the K_d is zero, then all of the radionuclides are in the aqueous phase and they move at the same velocity as the water. A K_d greater than zero indicates some fraction of the radionuclide is sorbed to soil or solids and therefore retards its movement. The amount of retardation is quantified by the retardation factor (R_d) given by:

$$R_d = 1 + \frac{K_d \rho_b}{\theta} \tag{5-23}$$

where

ρ_b	=	bulk density (g cm^{-3})
θ	=	moisture content (m^3 m^{-3}).

Note that R_d has no units; for a K_d value of zero, the R_d is 1.0. The K_d value is element-specific, highly variable, and depends on the chemical forms and geochemistry of the soil and water. Table 5.9 lists K_d values from the literature for the elements of interest for various lithologies and default or recommended values used in assessment models. The values for Hanford reflect sorption in material containing gravel, which reduces the K_d.

Table 5-9. Linear Sorption Coefficients (K_d) from the Literature and their Geometric Mean (GM)

Element	Sand (mL g^{-1})[a]	Clay (mL g^{-1})[a]	RESRAD (mL g^{-1})[b]	Hanford (mL g^{-1})[c]	INL (mL g^{-1})[d]	NRC (1992)[e]	Geometric mean (mL g^{-1})
U	35	1,600	50	1	10	15	27
Th	3,200	5,800	60,000	1,000	500	3,200	3,482
Ra	500	9,100	70	14	500	500	322
Pb	270	550	100	--	270	270	255

a. Sheppard and Thibault (1990).
b. Kamboj et al. (2018); Yu et al. (2001); NRC (2020).
c. DOE (2018).
d. Sondrup et al. (2018).
e. Kennedy and Strenge (1992).

The geometric mean (GM) values in Table 5-9 were used in the groundwater transport model. Generally, higher K_d values result in lower pore water concentrations and longer radionuclide transit times, which would correspond to lower doses farther out in time. The use of the GM as the central tendency will overestimate impacts (i.e., shorter transit times and higher pore water concentrations) because the GM is always lower than the arithmetic average in lognormally distributed data. The GM values listed in Table 5-9 were compared to the range of values in EPA (1999a), shown in Table 5-10, for a pH of 7.6, which is the reported pH of Selah porewater (Table 4-5 in CH2M Hill [2008]). The GM values are generally within the lower range of the values given in Table 5-10, except for lead, where the GM value of 255 L g^{-1} is less than the lowest lead value of 710 mL g^{-1}. In contrast, the values in Table 5-9 for Hanford reflect sorption in soils containing gravel. In general, little sorption occurs in pure gravel because of the lack of sorption sites. In material containing gravel, sorption mainly occurs in the interstitial silts and clays. For Hanford, K_d values were reduced based on the percentage of gravel in the lithology.

Table 5-10. Ranges of K_d values in EPA (1999a) for a pH of ~7.6

Element	Minimum K_d (mL g^{-1})	Maximum K_d (mL g^{-1})	Comments
U	63	630,000	Table 5.17 in EPA (1999a) for a pH=7
U	0.4	250,000	Table 5.17 in EPA (1999a) for a pH=8
Th	1,700	17,000	Table 5.15 in EPA (1999a) for an assumed dissolved Th content of <1×10^{-9} Molar
Th	300,000	300,000	Table 5.15 in EPA (1999a) for an assumed dissolved Th content of >1×10^{-1} Molar
Pb	4,360	23,270	Table 5.9 in EPA (1999a) for an assumed equilibrium lead concentration of 0.1-0.9 µg L^{-1}
Pb	710	2,300	Table 5.9 in EPA (1999a) for an assumed equilibrium lead concentration of 100-200 µg L^{-1}

5.2.7.7. Model Discretization

The MCM model contains two modules, a flow module (MCMF) and a contaminant transport module (MCMT) (see Figure 5-4). Water fluxes and moisture content as a function of time calculated with MCMF are read by MCMT. Thus, the discretization of the flow and transport modules must be identical. For the vadose zone, the first cell in the MCM model domain is in the landfill and represents the region where the Bakken oilfield waste was disposed. The thickness of this cell (0.178 m) was derived in Section 5.2.5 and is composed of material having higher hydraulic conductivity than the Selah Formation. The remainder of the vadose zone was discretized in the 30, 1-m-thick cells all having the hydrologic properties of the Selah Formation. Radionuclide fluxes were extracted at cell 25 (24.178 m) and input to the aquifer model. The vadose zone model domain was extended because the lower-boundary condition in MCMT does not include diffusive fluxes. Thus, by extending the domain past the aquifer and extracting fluxes at the 24.178 m depth allowed for fluxes entering the aquifer to represent the sum of advective and diffusive components.

In the aquifer model, the Darcy velocity and saturated porosity are specified and thus a MCMF simulation is not necessary. The first cell in the aquifer model represents the region in the aquifer that receives fluxes from the vadose zone. Consequently, the thickness of this cell is the length of the source projected into the aquifer. Although MCMT is one-dimensional, the model allows input of a length and width that is applied to all cells. These parameters are important for determining initial concentrations and whether solubility limits are exceeded. For the aquifer model, the width dimension was 60.96 m (width of the source) and the length dimension was the 5-m mixing thickness. The saturated porosity of the aquifer is 0.46; thus, fluxes entering the aquifer in a 60.96 m × 60.96 m area are mixed in 60.96 m × 60.96 m × 5 m × 0.46 = 8,547 m^3 volume of water. The remainder of the aquifer was composed of 50, 2-m-thick cells such that the last cell would represent a receptor 100 m downgradient from the downgradient edge of the source.

5.2.7.8. Initial Conditions and Modeled Water Fluxes

The initial condition for water flow in the vadose zone is the moisture content in each layer. The initial moisture content at the start of the simulation (the year of disposal of the Bakken oilfield waste) was established with a MCMF flow simulation assuming natural background infiltration rates for times prior to construction of the facility, followed by a 30-year operational period of a liner-leachate collection system that represents the construction and operation of the facility up to the disposal of the Bakken oilfield waste. The initial moisture profile reflects the drainage of water from the infiltration shadow after 30 years of operation of the facility. The initial condition for radionuclide transport was the radionuclide inventories in the 0.178-m-thick source zone and zero concentration everywhere else (Table 5-11). Radionuclide inventories were calculated from the maximum and weighted-average radionuclide concentrations reported in Table 3-5 and Table 3-4, respectively. The inventory is given by:

$$Q = C_w \times M_w \qquad (5\text{-}24)$$

where

Q	=	radionuclide inventory (Ci)
Cw	=	radionuclide concentration (Ci kg^{-1})
Mw	=	mass of Bakken oilfield waste 1.17×10^6 kg.

Table 5-11. Initial Radionuclide Concentrations and Inventories in the Source Layer

Radionuclide	Maximum inventory (Ci)	Weighted-average inventory (Ci)
U-238	1.38E-03	3.31E-05
U-234	2.35E-03	1.13E-04
Th-230	9.33E-04	4.52E-05
Ra-226	1.67E-01	1.04E-01
Pb-210	9.51E-01	5.82E-03
Th-232	5.54E-04	1.53E-03
Ra-228	7.21E-02	4.79E-03
Th-228	9.81E-03	5.79E-03

Water fluxes and the saturation ratio (defined as the moisture content divided by the total porosity) in the vadose (Figure 5-6 and Figure 5-7) vary in time and space because:

- Placement of the landfill liner with a leachate collection system creates an infiltration shadow while the facility is operating,
- Placement of an infiltration-limiting cover over the facility at closure and concurrently the assumed failure of the landfill leachate liner,
- Finally, subsequent failure of the engineered cover over time results in a return of infiltration to its natural state.

The facility is assumed to continue operating for another 30 years following disposal of the Bakken oilfield waste after which an engineered cover is installed and the leachate liner is assumed to then concurrently fail. As explained in Table 5-8, the leachate collection system will continue to operate after closure of Landfill Unit L-14 and installation of the cover. Leachate collection will continue until no further leachate accumulates in the sumps. The model assumption that the liner system, leachate collection system, and redundant detection systems fail at closure and the moisture in the waste is allowed to drain into the vadose zone. This significantly overestimates the release of radionuclides from the landfill in real world scenarios and is considered a highly pessimistic modeling scenario. The model also assumes the lower levels in the vadose zone continue to drain from the previous natural infiltration until about 400 years after the present. This is followed by an increase in infiltration to natural background conditions as the engineered barrier (cover) fails. The water fluxes nearest the bottom of the landfill reflect the changes in infiltration most directly. Water fluxes in deeper layers reflect the attenuation of infiltration changes at the surface. The saturation ratio (see Figure 5-7) in the landfill materials where the Bakken oilfield waste was disposed reflects the higher hydraulic conductivity compared to the low conductivity materials of the Selah Formation. The higher hydraulic conductivity results in greater drainage of water and lower saturation ratios.

A rough estimate of the vadose zone water travel time (*VZWTT*) can be calculated by:

$$VZWTT = \frac{T}{q/\left(SR\,\theta_s\right)} \tag{5-25}$$

where

T	=	vadose zone thickness (24 m)
q	=	Darcy velocity in the vadose zone (m yr^{-1})
SR	=	saturation ratio (unitless)
θ_s	=	saturated porosity (m^3 m^{-3}).

Assuming a Darcy velocity equal to the natural infiltration of 3.5 mm yr^{-1}, a saturation ratio of 0.84 (see Figure 5-7), and the total porosity of the Selah Formation of 0.46, the *VZWTT* is 2,650 years. This value is within the range of estimated water travel times based on groundwater age dating of 1,000 to 5,000 years (Section 4.1.2.1 in CH2M Hill [2008]). Radionuclide travel times would be the *VZWTT* times the R_d for the radionuclide (Equation [5-8]).

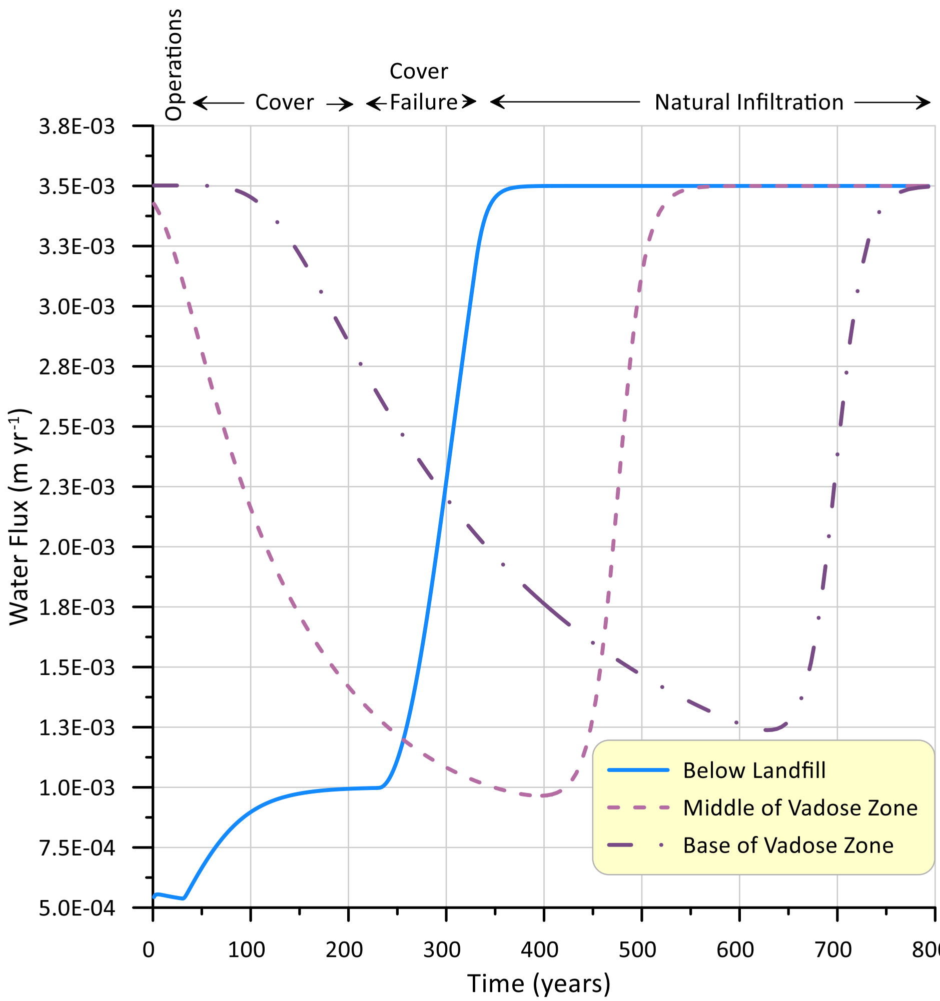

Figure 5-6. Vadose zone water fluxes as a function of time staring at the time when the Bakken oilfield waste was disposed.

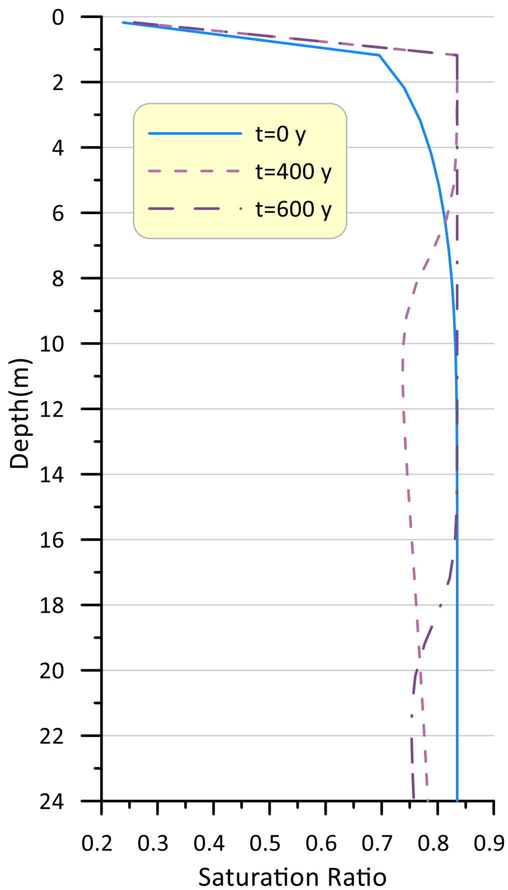

Figure 5-7. Saturation ratio depth profiles for initial condition (t=0 y), and 400 years and 600 years after the start of the simulation.

5.2.7.9. Comparison of 1-D Dispersion to 2-D and 3-D Dispersion

A three-dimensional transport simulation was made using GWSCREEN and aquifer parameters inTable 5-6 (Figure 5-8) using U-238 as a tracer. The radionuclide flux to the aquifer was computed using MCMT unsaturated simulation. The cross section shows that maximum concentration occurs on the downgradient edge of the source and concentrations exhibit little variation with depth to the 5-m level.

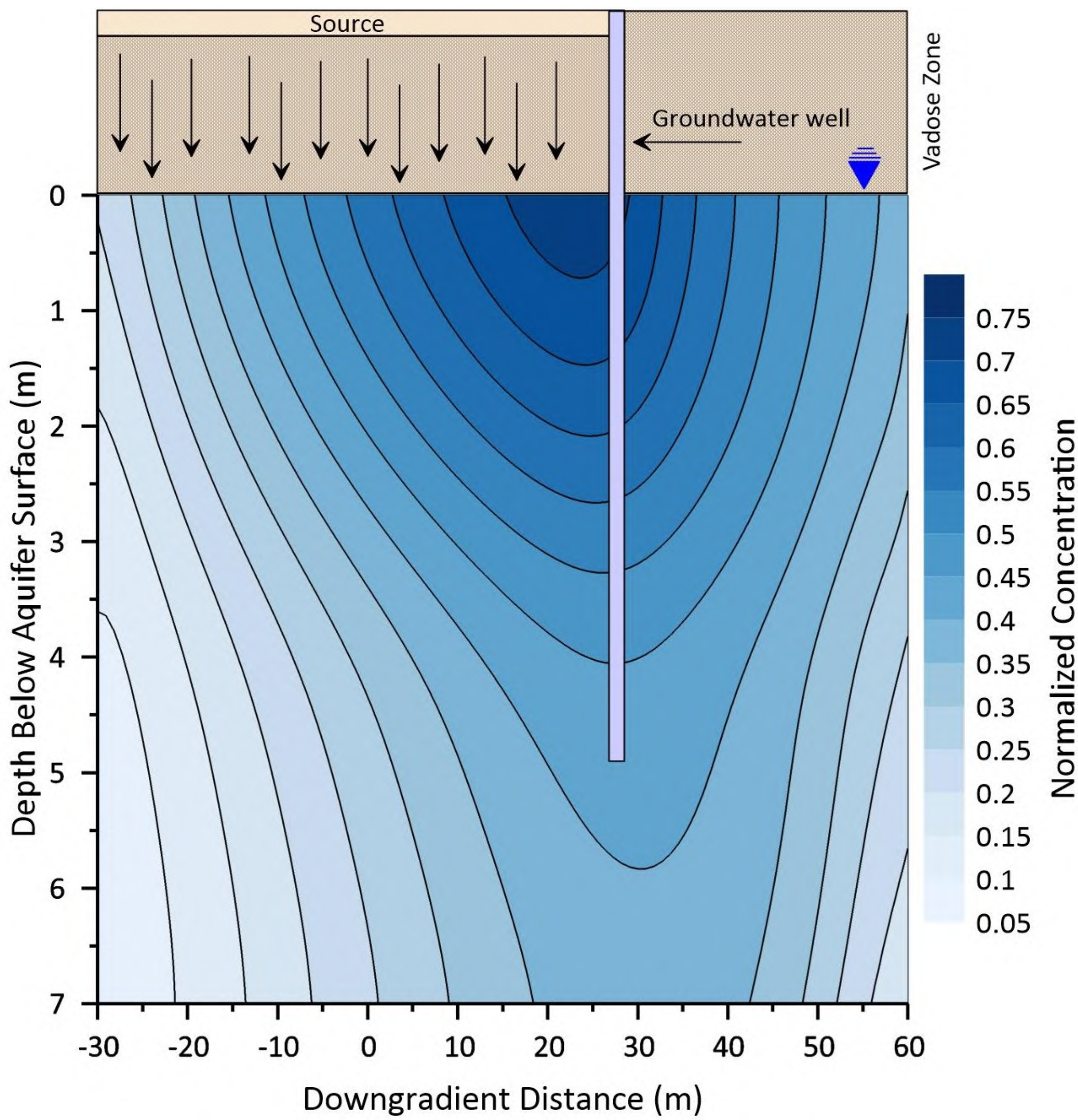

Figure 5-8. Cross section of U-238 aquifer concentration calculated with GWSCREEN with MCMT fluxes from the unsaturated zone.

A second GWSCREEN simulation was performed using the 2-D vertically averaged solution and an averaging thickness of 5 m. Concentrations were output at the downgradient edge of the source and at a well 100 m downgradient and compared with the MCMT output for the same unsaturated flux. The results (Figure 5-9) show that peak concentrations at the downgradient well from both models were in general agreement. The peak time for GWSCREEN was earlier than MCMT; this is attributed to the source region in MCMT treated as one cell instead of discretized into a series of cells. At the well 100 m downgradient, GWSCREEN concentrations were lower that the MCMT concentrations because of transverse dispersion in GWSCREEN. The MCMT concentration at the well 100 m downgradient was effectively the same as the concentration at the downgradient edge because pore velocities in the aquifer are low, resulting in little longitudinal dispersion compared to advective flow. Only the time to peak concentration was longer.

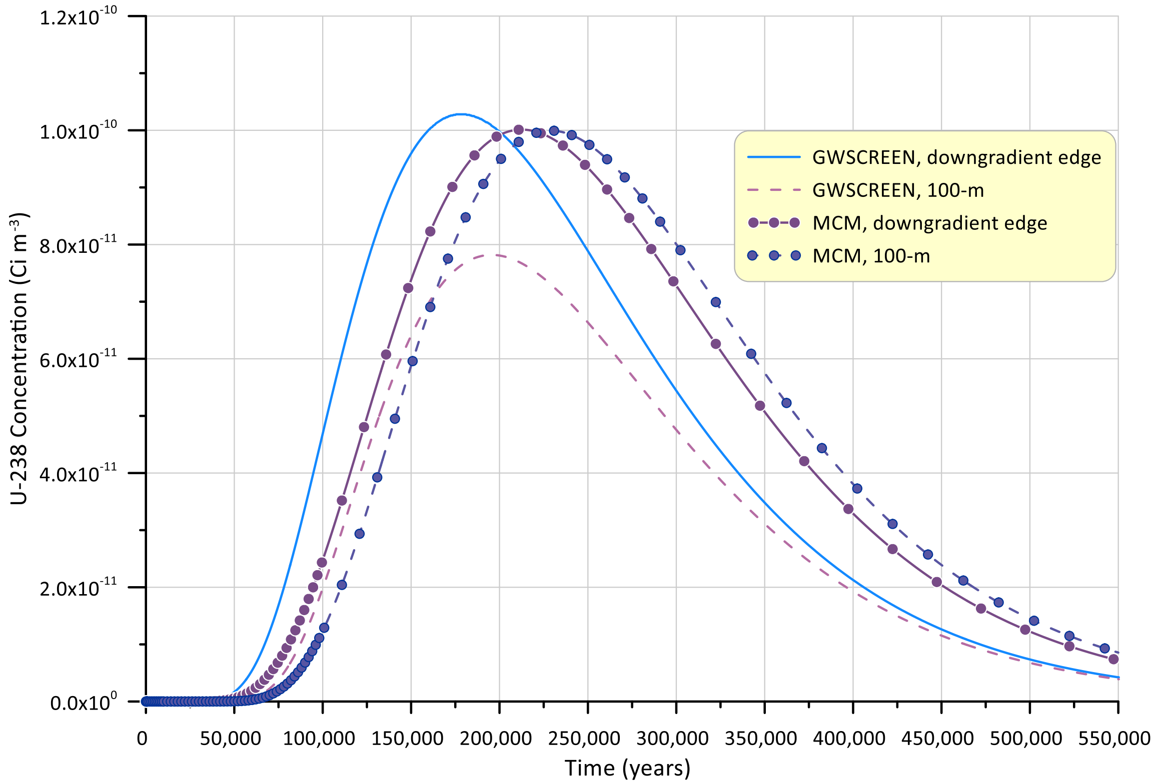

Figure 5-9. Comparison of U-238 concentration calculated with a 2-D GWSCREEN simulation and the MCMT aquifer model at the downgradient edge of the source and the 100-m well.

5.2.8. Dose and Risk Calculations for Groundwater Assessment

The effective dose coefficients and carcinogenic risk coefficients for morbidity (Table 5-12) were from DOE-Std-1196 (DOE 2011) and Federal Guidance Report 13 (EPA 1999b). These data were obtained from RESRAD ONSITE v7.2 (Kamboj et al. 2018) code. The "+D" designation indicates the dose coefficient includes short-lived progeny assumed to be in secular equilibrium with their parent in the environment. The half-life cutoff time for inclusion was 180 days.

Table 5-12. Effective Dose Coefficients and Cancer Morbidity Risk Coefficients

Radionuclide (progeny)	Dose coefficient for ingestion (rem Ci^{-1})	Cancer morbidity risk coefficient for water ingestion (risk Ci^{-1})
U-238+D (Th-234, Pa-234)	2.11×10^{5}	8.71×10^{1}
U-234	2.15×10^{5}	7.07×10^{1}
Th-230	9.36×10^{5}	9.14×10^{1}
Ra-226+D (Po-218, Pb-214, Bi-214, Po-214)	1.68×10^{6}	3.85×10^{2}
Pb-210+D (Bi-210, Po-210)	1.03×10^{7}	2.67×10^{3}
Th-232	1.03×10^{7}	1.01×10^{2}
Ra-228+D (Ac-228)	5.92×10^{7}	1.04×10^{3}

FINAL

Radionuclide (progeny)	Dose coefficient for ingestion (rem Ci^{-1})	Cancer morbidity risk coefficient for water ingestion (risk Ci^{-1})
Th-228+D (Ra-224, Po-216, Pb-212, Bi-212, Tl-208, Po-212)	9.35×10^{5}	3.00×10^{2}

The annual effective dose from groundwater ingestion is given by:

$$D_{GWING} = C_a \times IR \times DC \times ED \tag{5-26}$$

where

- D_{GWING} = annual effective dose from groundwater ingestion (mrem)
- C_a = aqueous-phase radionuclide concentration in aquifer (pCi L^{-1})
- IR = annual water ingestion rate (L yr^{-1})
- DC = effective dose coefficient for ingestion (mrem pCi^{-1})
- ED = exposure duration (1 yr).

The cancer morbidity risk from groundwater ingestion is given by:

$$R_{GWING} = C_{a30} \times IR \times RC \times ED \tag{5-27}$$

where

- R_{GWING} = carcinogenic morbidity risk from groundwater ingestion (unitless)
- C_{a30} = aqueous-phase radionuclide concentration in aquifer averaged over exposure duration (pCi L^{-1})
- IR = annual water ingestion rate (L yr^{-1})
- RC = morbidity risk coefficient for water ingestion (risk pCi^{-1}).
- ED = exposure duration (30 yrs).

5.3. Surface Water Assessment

As described in Section 2.2.3, surface water from the site is not connected hydraulically to any regional surface water body. Any stormwater falling on the facility during the operational period and the post closure period is conveyed to on-site stormwater retention ponds that do not discharge to the nearby water bodies.

6. Dose and Risk Estimates during Disposal of the Bakken Oilfield Waste at the CWMNW Landfill

The calculated radiation doses and cancer morbidity risks for the exposure scenarios described in Section 4 are presented and discussed here. Full details of the calculations and complete results, including cancer mortality risks, are available in Appendix C.

6.1. Doses and Risks during Disposal

This section summarizes the doses and cancer morbidity risks for the receptors described above during the original disposal of the Bakken oilfield waste. The waste handler represents the maximally exposed individual for the disposals of the Bakken oilfield waste, as the handler is physically the closest to the material. No credit is taken in the calculations for the required PPE; therefore, actual exposures would have been significantly lower. Landfill workers located in the lead truck or in the office/laboratory will have lower exposures as they do not exit the vehicle during disposal and are physically far removed from the disposals. The nearest off-site receptor is farther removed from the disposals.

6.1.1. Waste Handlers

As described above, the waste handler is the person who drives the waste delivery vehicle from the point of origin to the CWMNW Arlington landfill. Once at the designated disposal location inside of Landfill Unit L-14, the waste handler operates the offloading controls outside the truck that allow the waste to be physically deposited into the landfill. This individual is the maximally exposed individual during the disposals because the waste handler is outside the truck in full PPE. For the purposes of this analysis, no credit is taken for the PPE. The effective doses in Table 6-1 and Table 6-2 are annual averages and assume all disposals occurred in a single year.

Table 6-1. Annual Effective Dose for the Waste Handler, Maximum Source Term

Radionuclide	Inhalation dose (mrem)	Ingestion dose (mrem)	Total dose (mrem)
U-238	4.81×10^{-4}	7.76×10^{-5}	5.59×10^{-4}
U-234	9.54×10^{-4}	1.33×10^{-4}	1.09×10^{-3}
Th-230	3.91×10^{-3}	2.30×10^{-4}	4.14×10^{-3}
Ra-226	6.95×10^{-2}	7.42×10^{-2}	1.44×10^{-1}
Pb-210	4.15×10^{-1}	2.57	2.99
Th-232	2.56×10^{-3}	1.50×10^{-4}	2.71×10^{-3}
Ra-228	4.96×10^{-2}	1.13×10^{-1}	1.62×10^{-1}
Th-228	1.87×10^{-2}	2.42×10^{-3}	2.11×10^{-2}
Total	**5.6×10^{-1}**	**2.8**	**3.3**

For the maximum source term, the external dose was 7.9×10^{-3} mrem, again assuming the same individual attended all disposals.

Table 6-2. Annual Effective Dose for the Waste Handler, Weighted-average Source Term

Radionuclide	Inhalation dose (mrem)	Ingestion dose (mrem)	Total dose (mrem)
U-238	1.16×10^{-5}	1.86×10^{-6}	1.34×10^{-5}
U-234	4.59×10^{-5}	6.40×10^{-6}	5.23×10^{-5}
Th-230	1.89×10^{-4}	1.11×10^{-5}	2.00×10^{-4}
Ra-226	4.33×10^{-2}	4.62×10^{-2}	8.96×10^{-2}
Pb-210	2.54×10^{-1}	1.57	1.83

Radionuclide	Inhalation dose (mrem)	Ingestion dose (mrem)	Total dose (mrem)
Th-232	7.08×10^{-2}	4.15×10^{-3}	7.49×10^{-2}
Ra-228	3.30×10^{-2}	7.47×10^{-2}	1.08×10^{-1}
Th-228	1.10×10^{-2}	1.43×10^{-3}	1.25×10^{-2}
Total	**4.1×10^{-1}**	**1.7**	**2.1**

For the weighted-average source term, the external dose was 5.0×10^{-3} mrem, again assuming the same individual attended all disposals.

The dominant pathway of exposure for the waste handler was ingestion. Again, no credit is taken for the required PPE that is worn by all persons in the active areas of the landfill. Thus, these doses represent bounding, or worst-case scenarios. The maximum total dose was 3.3 mrem for the waste handler, which is a tiny fraction of the dose received from exposure to natural background in the United States.

Cancer risks are expressed as a unitless probability (*e.g.*, 1 in 1 million, or 1×10^{-6}) and represent the incremental probability of an individual developing cancer over a lifetime as a result of exposures related to the Bakken oilfield wastes. The risk is incremental because it refers to the probability of cancer above and beyond the background rate of cancer in the general population, which on average is approximately 40 out of 100 for men and 39 out of 100 for women (American Cancer Society 2020)

Cancer morbidity risks for each source term are presented in Table 6-3 and Table 6-4. Even for the most exposed receptor, the waste handler, cancer morbidity risks are all at the extreme lower end of EPA's guidance range of 1×10^{-6} to 1×10^{-4}. The maximum morbidity risk for the most exposed individual, the waste handler, was 2.4×10^{-6}, which is at the very low end of the EPA's acceptable risk range. This analysis demonstrates that no adverse effects are likely from the original disposal of the Bakken oilfield waste.

Table 6-3. Cancer Morbidity Risk for the Waste Handler, Maximum Source Term

Radionuclide	Total inhalation morbidity risk	Total ingestion morbidity risk	Total external morbidity risk
U-238	1.40×10^{-10}	4.52×10^{-11}	8.77×10^{-9}
U-234	2.91×10^{-10}	5.91×10^{-11}	4.32×10^{-13}
Th-230	2.89×10^{-10}	2.93×10^{-11}	5.57×10^{-13}
Ra-226	2.10×10^{-8}	2.27×10^{-8}	1.04×10^{-6}
Pb-210	1.45×10^{-7}	8.63×10^{-7}	2.92×10^{-9}
Th-232	2.61×10^{-10}	1.94×10^{-11}	1.38×10^{-13}
Ra-228	4.10×10^{-9}	2.72×10^{-8}	2.38×10^{-7}
Th-228	1.53×10^{-8}	1.09×10^{-9}	1.03×10^{-8}
Pathway totals	1.87×10^{-7}	9.15×10^{-7}	1.30×10^{-6}
Total			**2.4×10^{-6}**

Table 6-4. Cancer Morbidity Risk for the Waste Handler, Weighted-average Source Term

Radionuclide	Total inhalation morbidity risk	Total ingestion morbidity risk	Total external morbidity risk
U-238	3.37×10^{-12}	1.08×10^{-12}	2.11×10^{-10}
U-234	1.40×10^{-11}	2.84×10^{-12}	2.08×10^{-14}
Th-230	1.40×10^{-11}	1.42×10^{-12}	2.70×10^{-14}
Ra-226	1.31×10^{-8}	1.42×10^{-8}	6.46×10^{-7}
Pb-210	8.89×10^{-8}	5.28×10^{-7}	1.78×10^{-9}
Th-232	7.19×10^{-9}	5.37×10^{-10}	3.81×10^{-12}
Ra-228	2.72×10^{-9}	1.81×10^{-8}	1.58×10^{-7}
Th-228	9.02×10^{-9}	6.44×10^{-10}	6.08×10^{-9}
Pathway totals	1.21×10^{-7}	5.61×10^{-7}	8.12×10^{-7}
Total			**1.5×10^{-6}**

6.1.2. Current Off-site Residents

The nearest current off-site resident is located about 3,260 m (10,700 ft or roughly 2 miles) from the disposal facility. The only complete pathway of exposure for the current off-site resident is inhalation of particulates that may have been blown off-site. The calculated doses and cancer morbidity risks for the off-site resident during disposal are summarized in Table 6-5.

Table 6-5. Doses and Risks for the Current Off-site Resident, during Disposal

Radionuclide	Inhalation dose, max source term (mrem)	Inhalation dose, weighted-avg source term (mrem)	Total morbidity risk, max source term	Total morbidity risk, weighted-avg source term
U-238	6.50×10^{-10}	1.56×10^{-11}	1.81×10^{-16}	4.35×10^{-18}
U-234	1.29×10^{-9}	6.20×10^{-11}	3.76×10^{-16}	1.81×10^{-17}
Th-230	5.28×10^{-9}	2.55×10^{-10}	3.74×10^{-16}	1.81×10^{-17}
Ra-226	9.40×10^{-8}	5.85×10^{-8}	2.72×10^{-14}	1.69×10^{-14}
Pb-210	5.61×10^{-7}	3.43×10^{-7}	1.88×10^{-13}	1.15×10^{-13}
Th-232	3.46×10^{-9}	9.56×10^{-8}	3.37×10^{-16}	9.30×10^{-15}
Ra-228	6.71×10^{-8}	4.45×10^{-8}	5.30×10^{-15}	3.52×10^{-15}
Th-228	2.53×10^{-8}	1.49×10^{-8}	1.97×10^{-14}	1.17×10^{-14}
Total	**7.6×10^{-7} mrem**	**5.6×10^{-7} mrem**	**2.4×10^{-13}**	**1.6×10^{-13}**

These doses are extremely low, and the cancer morbidity risks are effectively zero. This analysis demonstrates that no adverse effects are likely from the original disposal of the Bakken oilfield waste.

7. Dose and Risk Estimates for Remediation Alternatives

The calculated doses and risks for the exposure scenarios for the two remediation alternatives described in Section 4 are presented here. Full details of the calculations and complete results are available in Appendix C.

7.1. Alternative 1: Closure-in-Place

As described above and in detail in the CAP (Gradient 2020), this alternative assumes the Bakken oilfield waste is left in place and covered with other chemical/hazardous wastes accepted by the landfill.

This section summarizes the doses and cancer morbidity risks for the relevant receptors assuming the Bakken oilfield waste is left in place. For the closure-in-place alternative, viable exposure pathways include inhalation of outdoor radon, which represents a long-term exposure hazard, and thus risks are presented assuming 30 years of exposure (see Table 7-1 and Table 7-2), and ingestion of groundwater. The maximum dose that is calculated to occur is 0.12 mrem for a future on-site resident at 260,000 years into the future and results primarily from ingestion of groundwater (section 7.1.1). This dose corresponds to a risk of getting cancer of $1×10^{-6}$, or a one in a million.

In addition to the doses and risks, the radon flux calculated at the surface of the Landfill Unit L-14 is also of interest. The radon flux for the maximum source term was $3.0×10^{-11}$ pCi m^{-2} s^{-1}; for the weighted-average source term, the radon flux was $1.9×10^{-11}$ pCi m^{-2} s^{-1}, substantially below the limit for uranium mill tailings disposal cells and the Department of Energy (DOE) performance criteria for low-level radioactive waste disposal sites of 20 pCi m^{-2} s^{-1} (DOE 2007; EPA 1998).

Table 7-1. Radon Results[a], Maximum Source Term

Receptor	Radon concentration (pCi L^{-1})	WLM[b]	Radon dose (mrem)	Cancer morbidity risk – 30 years
Landfill worker	$3.40×10^{-14}$	$4.08×10^{-15}$	$3.1×10^{-12}$	$2.0×10^{-16}$
Current off-site resident	$3.03×10^{-17}$	$1.21×10^{-17}$	$9.2×10^{-15}$	$5.9×10^{-19}$
Future off-site resident	$3.03×10^{-17}$	$1.50×10^{-17}$	$1.1×10^{-14}$	$7.3×10^{-19}$
Future on-site resident	$3.40×10^{-14}$	$1.68×10^{-14}$	$1.3×10^{-11}$	$8.2×10^{-16}$

a. Represents outdoor radon concentration, dose, and risk.
b. Assuming equilibrium factor is unity.

Table 7-2. Radon Results[a], Weighted-average Source Term

Receptor	Radon concentration (pCi L^{-1})	WLM[b]	Radon dose (mrem)	Cancer morbidity risk – 30 years
Landfill worker	2.12×10^{-14}	2.54×10^{-15}	1.9×10^{-12}	1.2×10^{-16}
Current off-site resident	1.89×10^{-17}	7.52×10^{-18}	5.7×10^{-15}	3.7×10^{-19}
Future off-site resident	1.89×10^{-17}	9.34×10^{-18}	7.1×10^{-15}	4.6×10^{-19}
Future on-site resident	2.12×10^{-14}	1.05×10^{-14}	7.9×10^{-12}	5.1×10^{-16}

a. Represents outdoor radon concentration, dose, and risk.
b. Assuming equilibrium factor is unity.

Exposures for all receptors are several orders of magnitude below the EPA's acceptable risk level of 1×10^{-6} and are effectively zero. This analysis demonstrates that no adverse effects are likely from the original disposal of the Bakken oilfield waste.

7.1.1. Groundwater Pathway Results

Any potential exposures associated with the groundwater pathway occur at substantially longer times than any of the other exposure pathways. This is a result of the long unsaturated water travel times and radionuclide sorption in the landfill, unsaturated zone, and aquifer. Results presented for the groundwater pathway include porewater concentrations in the unsaturated zone, annual effective doses assuming groundwater ingestion, and cancer morbidity risk from groundwater ingestion. In summary, no appreciable concentrations, effective doses, and cancer morbidity risks occur before 60,000 years from present. Maximum radionuclide concentrations, effective doses, and cancer morbidity risks occur ~260,000 years from the present and are well below applicable limits.

The radionuclide flux from the unsaturated zone to the aquifer, shown in Figure 7-1, demonstrates that no appreciable radionuclide fluxes occur before 60,000 years. Lead-210 has the highest flux and is not a result of the initial Pb-210 inventory, but rather is from ingrowth from parents (U-234, Th-230, and Ra-226). After 10,000 years, Th-230, Ra-226, and Pb-210 are about 50% of the initial U-234 activity. The lower K_d value for lead relative to radium and thorium results in higher porewater concentrations and greater transport speeds.

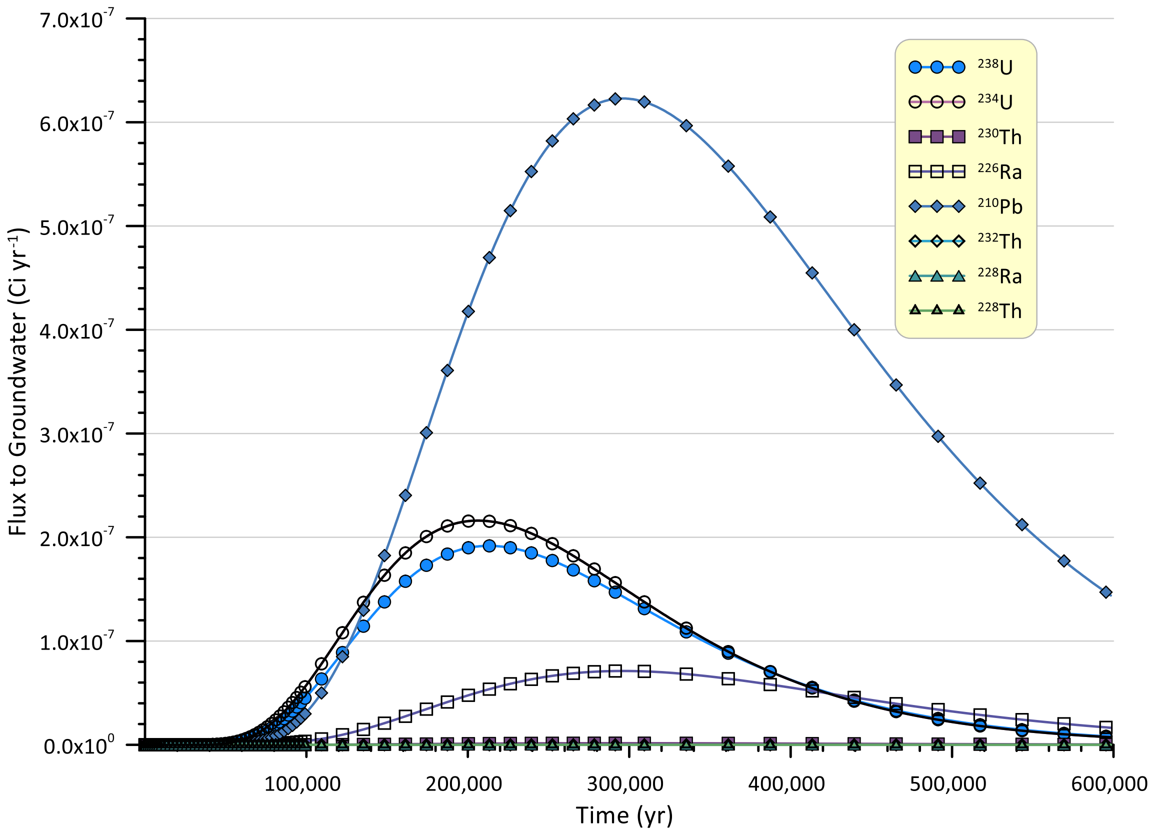

Figure 7-1. Radionuclide flux from the unsaturated zone to the aquifer for the maximum radionuclide inventory.

Radionuclide concentration limits in water are specified in ODOE 345-050-0035 (Table 7-3). These concentrations were compared against unsaturated porewater concentrations at the unsaturated/saturated interface. Table 7-4 shows the unsaturated porewater concentration at the unsaturated/saturated interface and compares these concentrations to those in Table 3 of ODOE-050-0035 for the maximum inventory and the weighted-average inventory. For multiple radionuclides, the sum of ratios (SOR) must be less than 1.0. For the maximum inventory, the maximum SOR was 0.00182; for the weighted-average inventory, the maximum SOR was 7.5×10^{-5}. Thus, unsaturated pore water concentrations are substantially lower than the Table 3 values in ODOE-050-0035.

Additionally, unsaturated pore water concentrations were also less than the federal maximum contaminant limits (MCLs) for drinking water stated in 40 CFR 141. The MCL for Ra-226 and Ra-228 combined is 5 pCi L^{-1}, 15 pCi L^{-1} for Th-228, Th-230 and Th-232, and a uranium mass concentration of 30 µg L^{-1}. Uranium mass is dominated by U-238 and the activity concentration of U-238 that corresponds to 30 µg L^{-1} is about 10 pCi L^{-1}. Although MCLs do not apply to unsaturated pore water and only apply to drinking water at the tap, this comparison shows that the pore water concentrations in the unsaturated zone meet the drinking water MCLs and concentrations at any seep or discharge point in the Selah will also meet federal MCLs.

Maximum groundwater ingestion effective dose (Table 7-5 and Figure 7-2) was 0.12 mrem yr^{-1} for the maximum inventory and 0.0046 mrem yr^{-1} for the weighted-average inventory for the receptor located on the downgradient edge of the source. Doses and risks at the 100-m receptor were ~78% of the doses at the downgradient edge. These doses are substantially below the annual effective dose limit of 25 mrem in 10 CFR Part 61, DOE Order 435.1, and recommended in the American National Standards Institute (ANSI) standard for TENORM (ANSI/HPS 2009). Maximum doses occur well after the 10,000-year and 1,000-year time of compliance for NRC and DOE, respectively. The corresponding cancer morbidity risk was 1.0×10^{-6} and 3.8×10^{-8} for the maximum and weighted-average inventory, respectively. These risks are less than the target EPA cancer risk range of 10^{-6} to 10^{-4}. Maximum doses and risks occurred ~260,000 years from the present, and ^{210}Pb, ^{234}U, and ^{226}Ra were the primary dose/risk contributors.

Table 7-3. Radionuclide Concentration Limits in Table 3 of ODOE 345-050-0035 and Federal Maximum Contaminant Limits (MCLs)

Radionuclide	Table 3 Value (µCi mL^{-1})	Federal MCL (pCi L^{-1})
U-238a	4.00×10^{-5}	10.1
U-234a	3.00×10^{-5}	186,750
Th-230	2.00×10^{-6}	15
Ra-226	3.00×10^{-8}	5
Pb-210	1.00×10^{-7}	b
Th-232	2.00×10^{-6}	15
Ra-228	3.00×10^{-8}	5
Th-228	7.00×10^{-6}	15

a. The MCL for uranium is 30 µg L^{-1}. This value was converted to an activity concentration using specific activities from Browne and Firestone (1986) of 3.36E-7 Ci g^{-1} for U-238 and 6.23E-3 Ci g^{-1} for U-234.
b. No MCL for Pb-210

Table 7-4. Radionuclide Unsaturated Pore Water Concentrations at the Unsaturated/Saturated Interface and Comparison to Table 3 Values

Time window (years)	U-238	U-234	Th-230	Ra-226	Pb-210	Th-232	Ra-228	Th-228	SOR[a]
Radionuclide concentration in unsaturated pore water for maximum inventory (pCi L^{-1})									
<250y	2.89E-53	4.92E-53	5.52E-59	3.98E-60	1.61E-60	0.00E+00	0.00E+00	0.00E+00	N/A
250-500y	3.18E-49	5.41E-49	1.45E-54	2.46E-55	1.65E-55	0.00E+00	0.00E+00	0.00E+00	N/A
500-1000y	1.26E-35	2.15E-35	4.56E-41	6.39E-42	3.93E-42	2.32E-88	1.14E-82	1.06E-83	N/A
1000-5000y	9.56E-18	1.62E-17	2.58E-22	2.52E-22	2.80E-22	3.31E-69	5.92E-68	5.48E-69	N/A
5000,10,000y	9.27E-12	1.56E-11	5.74E-16	1.15E-15	1.38E-15	7.99E-62	1.08E-60	9.96E-62	N/A
10,000-100,000y	2.45E-01	3.74E-01	5.23E-04	5.17E-03	6.52E-03	8.62E-38	9.49E-37	8.78E-38	N/A
100,000-400,000y	4.80E-01	6.90E-01	3.62E-03	3.92E-02	4.94E-02	7.02E-27	7.63E-26	7.06E-27	N/A
>400,000y	2.34E-01	3.05E-01	3.38E-03	3.67E-02	4.63E-02	1.99E-20	2.15E-19	1.99E-20	N/A
Ratio of unsaturated pore water concentrations to Table 3 values for maximum inventory									
<250y	7.23E-58	1.64E-57	2.76E-62	1.33E-61	1.61E-62	0.00E+00	0.00E+00	0.00E+00	2.36E-57
250-500y	7.95E-54	1.80E-53	7.25E-58	8.20E-57	1.65E-57	0.00E+00	0.00E+00	0.00E+00	2.60E-53
500-1000y	3.16E-40	7.17E-40	2.28E-44	2.13E-43	3.93E-44	1.16E-91	3.80E-84	1.51E-87	1.03E-39
1000-5000y	2.39E-22	5.39E-22	1.29E-25	8.40E-24	2.80E-24	1.65E-72	1.97E-69	7.83E-73	7.90E-22
5000,10,000y	2.32E-16	5.20E-16	2.87E-19	3.85E-17	1.38E-17	4.00E-65	3.59E-62	1.42E-65	8.05E-16
10,000-100,000y	6.12E-06	1.25E-05	2.62E-07	1.72E-04	6.52E-05	4.31E-41	3.16E-38	1.25E-41	2.56E-04
100,000-400,000y	1.20E-05	2.30E-05	1.81E-06	1.31E-03	4.94E-04	3.51E-30	2.54E-27	1.01E-30	1.82E-03
>400,000y	5.86E-06	1.02E-05	1.69E-06	1.22E-03	4.63E-04	9.93E-24	7.17E-21	2.84E-24	1.70E-03
Radionuclide concentration in pore water for weighted-average inventory (pCi L^{-1})									
<250y	6.93E-55	2.37E-54	2.65E-60	1.91E-61	7.75E-62	0.00E+00	0.00E+00	0.00E+00	N/A
250-500y	7.63E-51	2.60E-50	6.97E-56	1.18E-56	7.94E-57	0.00E+00	0.00E+00	0.00E+00	N/A
500-1000y	3.03E-37	1.03E-36	2.19E-42	3.07E-43	1.89E-43	6.41E-88	3.15E-82	2.91E-83	N/A
1000-5000y	2.29E-19	7.75E-19	1.24E-23	1.21E-23	1.34E-23	9.12E-69	1.63E-67	1.51E-68	N/A
5000,10,000y	2.22E-13	7.44E-13	2.74E-17	5.51E-17	6.56E-17	2.20E-61	2.97E-60	2.75E-61	N/A
10,000-100,000y	5.87E-03	1.65E-02	2.34E-05	2.32E-04	2.92E-04	2.38E-37	2.62E-36	2.42E-37	N/A
100,000-400,000y	1.15E-02	2.89E-02	1.49E-04	1.61E-03	2.03E-03	1.93E-26	2.10E-25	1.95E-26	N/A
>400,000y	5.62E-03	1.14E-02	1.36E-04	1.48E-03	1.86E-03	5.47E-20	5.93E-19	5.49E-20	N/A
Ratio of pore water concentrations to Table 3 values for weighted-average inventory									
<250y	1.73E-59	7.89E-59	1.33E-63	6.38E-63	7.75E-64	0.00E+00	0.00E+00	0.00E+00	9.62E-59
250-500y	1.91E-55	8.67E-55	3.48E-59	3.94E-58	7.94E-59	0.00E+00	0.00E+00	0.00E+00	1.06E-54
500-1000y	7.58E-42	3.44E-41	1.09E-45	1.02E-44	1.89E-45	3.20E-91	1.05E-83	4.16E-87	4.20E-41
1000-5000y	5.73E-24	2.58E-23	6.18E-27	4.02E-25	1.34E-25	4.56E-72	5.44E-69	2.16E-72	3.21E-23
5000,10,000y	5.56E-18	2.48E-17	1.37E-20	1.84E-18	6.56E-19	1.10E-64	9.89E-62	3.92E-65	3.29E-17
10,000-100,000y	1.47E-07	5.52E-07	1.17E-08	7.72E-06	2.92E-06	1.19E-40	8.72E-38	3.46E-41	1.13E-05
100,000-400,000y	2.88E-07	9.63E-07	7.46E-08	5.37E-05	2.03E-05	9.67E-30	7.01E-27	2.78E-30	7.50E-05
>400,000y	1.41E-07	3.80E-07	6.79E-08	4.92E-05	1.86E-05	2.74E-23	1.98E-20	7.84E-24	6.84E-05

a. Sum of ratios.

N/A Not Applicable.

Table 7-5. Groundwater Ingestion Effective Dose and Carcinogenic Morbidity Risk for the Maximum and Weighted-Average Inventory

Time window (years)	U-238	U-234	Th-230	Ra-226	Pb-210	Th-232	Ra-228	Th-228	Total
Radionuclide effective dose for the maximum inventory at the downgradient edge of the source (mrem)									
<250y	2.33E-56	4.05E-56	1.87E-61	2.30E-62	5.55E-62	0.00E+00	0.00E+00	0.00E+00	6.38E-56
250-500y	4.87E-52	8.45E-52	9.34E-57	2.72E-57	1.10E-56	0.00E+00	0.00E+00	0.00E+00	1.33E-51
500-1000y	1.59E-38	2.76E-38	2.47E-43	6.00E-44	2.23E-43	0.00E+00	1.27E-85	1.85E-87	4.35E-38
1000-5000y	3.36E-20	5.80E-20	3.97E-24	6.85E-24	4.66E-23	1.49E-72	1.58E-70	1.20E-52	9.17E-20
5000,10,000y	4.11E-14	7.06E-14	1.12E-17	3.98E-17	2.90E-16	7.14E-65	5.58E-63	3.12E-53	1.12E-13
10,000-100,000y	3.80E-03	5.92E-03	3.05E-05	5.31E-04	4.10E-03	5.64E-40	3.57E-38	5.22E-40	1.44E-02
100,000-400,000y	1.55E-02	2.19E-02	5.34E-04	1.04E-02	8.01E-02	8.86E-29	5.53E-27	8.09E-29	1.20E-01
>400,000y	1.12E-02	1.48E-02	5.33E-04	1.03E-02	8.00E-02	3.38E-22	2.11E-20	3.08E-22	1.17E-01
Radionuclide effective dose for the weighted-average inventory at the downgradient edge of the source (mrem)									
<250y	5.60E-58	1.95E-57	8.97E-63	1.11E-63	2.67E-63	0.00E+00	0.00E+00	0.00E+00	2.51E-57
250-500y	1.17E-53	4.06E-53	4.49E-58	1.31E-58	5.27E-58	0.00E+00	0.00E+00	0.00E+00	5.23E-53
500-1000y	3.82E-40	1.33E-39	1.18E-44	2.88E-45	1.07E-44	0.00E+00	3.49E-85	5.11E-87	1.71E-39
1000-5000y	8.06E-22	2.78E-21	1.90E-25	3.28E-25	2.23E-24	4.12E-72	4.35E-70	5.29E-53	3.59E-21
5000,10,000y	9.87E-16	3.37E-15	5.32E-19	1.90E-18	1.39E-17	1.97E-64	1.54E-62	3.12E-53	4.37E-15
10,000-100,000y	9.11E-05	2.61E-04	1.36E-06	2.38E-05	1.84E-04	1.56E-39	9.85E-38	1.44E-39	5.61E-04
100,000-400,000y	3.71E-04	8.88E-04	2.13E-05	4.13E-04	3.20E-03	2.44E-28	1.53E-26	2.23E-28	4.61E-03
>400,000y	2.68E-04	5.54E-04	2.12E-05	4.11E-04	3.18E-03	9.32E-22	5.81E-20	8.49E-22	4.44E-03
Radionuclide carcinogenic morbidity risk for the maximum inventory at the downgradient edge of the source									
<250y	2.89E-61	4.00E-61	5.47E-67	1.58E-67	4.31E-67	0.00E+00	0.00E+00	0.00E+00	6.89E-61
250-500y	6.03E-57	8.33E-57	2.74E-62	1.87E-62	8.53E-62	0.00E+00	0.00E+00	0.00E+00	1.44E-56
500-1000y	1.97E-43	2.72E-43	7.22E-49	4.13E-49	1.73E-48	0.00E+00	6.68E-91	1.78E-92	4.69E-43
1000-5000y	4.16E-25	5.72E-25	1.16E-29	4.71E-29	3.62E-28	4.40E-78	8.31E-76	1.15E-57	9.89E-25
5000,10,000y	5.09E-19	6.96E-19	3.27E-23	2.73E-22	2.26E-21	2.10E-70	2.94E-68	3.00E-58	1.21E-18
10,000-100,000y	4.70E-08	5.84E-08	8.94E-11	3.65E-09	3.19E-08	1.66E-45	1.88E-43	5.03E-45	1.41E-07
100,000-400,000y	1.92E-07	2.16E-07	1.56E-09	7.12E-08	6.23E-07	2.61E-34	2.92E-32	7.79E-34	1.03E-06
>400,000y	1.38E-07	1.46E-07	1.56E-09	7.11E-08	6.22E-07	9.95E-28	1.11E-25	2.96E-27	9.79E-07
Radionuclide carcinogenic morbidity risk for the weighted-average inventory at the downgradient edge of the source									
<250y	6.93E-63	1.92E-62	2.63E-68	7.60E-69	2.07E-68	0.00E+00	0.00E+00	0.00E+00	2.61E-62
250-500y	1.45E-58	4.01E-58	1.32E-63	8.98E-64	4.10E-63	0.00E+00	0.00E+00	0.00E+00	5.45E-58
500-1000y	4.73E-45	1.31E-44	3.47E-50	1.98E-50	8.32E-50	0.00E+00	1.84E-90	4.92E-92	1.78E-44
1000-5000y	9.99E-27	2.74E-26	5.57E-31	2.26E-30	1.74E-29	1.21E-77	2.29E-75	5.10E-58	3.74E-26
5000,10,000y	1.22E-20	3.32E-20	1.56E-24	1.31E-23	1.08E-22	5.79E-70	8.11E-68	3.00E-58	4.55E-20
10,000-100,000y	1.13E-09	2.58E-09	3.99E-12	1.63E-10	1.43E-09	4.57E-45	5.19E-43	1.39E-44	5.30E-09
100,000-400,000y	4.60E-09	8.76E-09	6.25E-11	2.84E-09	2.49E-08	7.18E-34	8.04E-32	2.15E-33	3.84E-08
>400,000y	3.32E-09	5.46E-09	6.20E-11	2.83E-09	2.47E-08	2.74E-27	3.06E-25	8.17E-27	3.64E-08

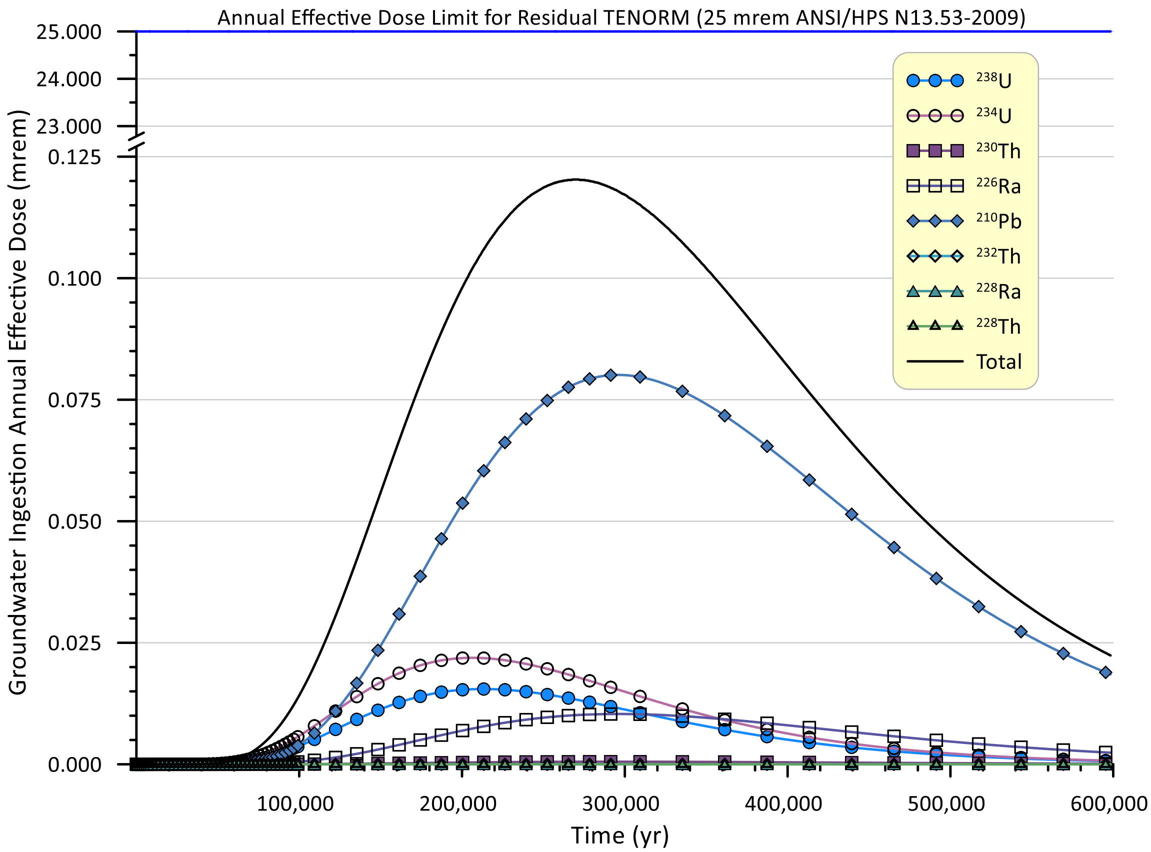

Figure 7-2. Effective dose from groundwater ingestion at the downgradient edge of the source as a function of time for the maximum inventory.

7.1.1.1. Sensitivity Case for Groundwater Assessment

A sensitivity case was run where the minimum K_d values in Table 5-10 were used instead of the geometric mean. The maximum inventory was used in the simulation and all other parameters remained the same. Thus, this sensitivity case represents the most improbable and extreme overstated estimate of the impacts from the groundwater pathway. The maximum annual effective dose (Table 7-6) was 0.87 mrem and occurred in the 10,000–100,000-year time window. Both ^{226}Ra and ^{210}Pb represented about 45% of the total dose. The maximum cancer morbidity risk was 9.4×10^{-6} and occurred in the 10,000–100,000-year time window. The ratio of the unsaturated pore water concentration to Table 3 values had a maximum SOR of 0.0046. Thus, even with minimum K_ds, maximum inventory, and worst-case assumptions regarding the performance of the Landfill Unit L-14 liner and cover, annual effective doses were more than an order of magnitude below the 25 mrem per year dose limit. The cancer morbidity risks were at the lower end of the EPA acceptable target risk range of 10^{-6} to 10^{-4}, and the SOR of unsaturated pore water concentrations was substantially lower than 1.0.

Table 7-6. Groundwater Ingestion Effective Dose, Cancer Morbidity Risk and Ratio of Unsaturated Pore Water Concentrations to Table 3 Values for the Maximum Inventory and Minimum K_d Values

Time window (years)	U-238	U-234	Th-230	Ra-226	Pb-210	Th-232	Ra-228	Th-228	Total
Radionuclide effective dose at the downgradient edge of the source for the maximum inventory and minimum K_d values (mrem)									
<250y	1.31E-23	2.26E-23	4.14E-29	1.84E-29	5.03E-30	9.13E-89	1.01E-57	4.67E-60	3.57E-23
250-500y	7.08E-20	1.23E-19	5.54E-25	5.93E-25	2.75E-25	2.45E-84	2.42E-59	1.32E-61	1.94E-19
500-1000y	2.04E-09	3.54E-09	1.63E-14	1.80E-14	8.45E-15	1.23E-70	6.26E-53	2.85E-55	5.58E-09
1000-5000y	6.98E-02	1.20E-01	1.14E-05	1.78E-04	1.49E-04	8.82E-51	9.11E-47	4.14E-49	1.91E-01
5000,10,000y	3.11E-01	5.33E-01	2.10E-04	7.34E-03	6.38E-03	3.14E-43	1.81E-40	8.23E-43	8.58E-01
10,000-100,000y	3.15E-01	5.40E-01	6.31E-04	3.89E-02	3.42E-02	5.72E-20	1.21E-17	5.51E-20	8.73E-01
100,000-400,000y	5.03E-10	7.83E-10	3.27E-04	2.08E-02	1.83E-02	2.80E-11	5.67E-09	2.58E-11	3.93E-02
>400,000y	5.29E-31	7.01E-31	5.11E-05	3.24E-03	2.85E-03	2.00E-07	4.01E-05	1.82E-07	6.14E-03
Ratio of unsaturated pore water concentrations to Table 3 values for maximum inventory and minimum K_d values									
<250y	8.38E-26	1.90E-25	1.16E-30	1.94E-29	2.62E-31	1.73E-88	1.61E-57	1.99E-61	2.74E-25
250-500y	3.82E-22	8.67E-22	1.28E-26	5.16E-25	1.17E-26	1.99E-84	2.12E-59	3.17E-63	1.25E-21
500-1000y	1.08E-11	2.44E-11	3.75E-16	1.57E-14	3.62E-16	1.31E-70	9.79E-53	1.20E-56	3.52E-11
1000-5000y	1.19E-04	2.69E-04	1.00E-07	6.41E-05	2.64E-06	1.60E-51	1.40E-46	1.72E-50	4.54E-04
5000,10,000y	2.46E-04	5.54E-04	9.59E-07	1.40E-03	5.93E-05	3.19E-44	2.04E-40	2.50E-44	2.22E-03
10,000-100,000y	2.33E-04	5.22E-04	1.89E-06	4.38E-03	1.88E-04	1.59E-21	3.92E-18	4.81E-22	4.61E-03
100,000-400,000y	1.83E-13	3.72E-13	9.64E-07	2.29E-03	9.81E-05	5.56E-13	1.31E-09	1.61E-13	2.39E-03
>400,000y	1.92E-34	3.32E-34	1.52E-07	3.61E-04	1.55E-05	3.17E-09	7.40E-06	9.09E-10	3.76E-04
Carcinogenic morbidity risk at the downgradient edge of the source for maximum inventory and minimum K_d values									
<250y	1.62E-28	2.23E-28	1.21E-34	1.26E-34	3.91E-35	2.69E-94	5.35E-63	4.50E-65	3.85E-28
250-500y	8.77E-25	1.21E-24	1.62E-30	4.08E-30	2.14E-30	7.22E-90	1.28E-64	1.27E-66	2.09E-24
500-1000y	2.53E-14	3.49E-14	4.77E-20	1.23E-19	6.57E-20	3.61E-76	3.30E-58	2.74E-60	6.02E-14
1000-5000y	8.65E-07	1.19E-06	3.35E-11	1.22E-09	1.16E-09	2.59E-56	4.80E-52	3.98E-54	2.06E-06
5000,10,000y	3.85E-06	5.26E-06	6.16E-10	5.05E-08	4.96E-08	9.23E-49	9.54E-46	7.92E-48	9.21E-06
10,000-100,000y	3.90E-06	5.33E-06	1.85E-09	2.68E-07	2.66E-07	1.68E-25	6.39E-23	5.31E-25	9.36E-06
100,000-400,000y	6.22E-15	7.72E-15	9.59E-10	1.43E-07	1.42E-07	8.23E-17	2.99E-14	2.48E-16	2.86E-07
>400,000y	6.55E-36	6.91E-36	1.50E-10	2.23E-08	2.22E-08	5.87E-13	2.11E-10	1.75E-12	4.46E-08

7.2. Alternative 2: Excavate and Redispose

As described above and in detail in the CAP (Gradient 2020), this alternative assumes the Bakken oilfield waste is excavated from the landfill and trucked off-site to an alternative disposal facility.

Beyond the scope of this analysis are the much greater and real risks posed by disturbing the hazardous wastes currently safely disposed in Landfill Unit L-14. Disturbing these wastes during the excavation of the Bakken oilfield wastes would create unknown mixtures of unidentifiable chemicals with the real risk of creating adverse reactions between the disturbed wastes, thus creating exposures to workers and the environment. The excavation of these wastes would present an unacceptable, if not extreme, risk to human health and the environment under this scenario. To a lesser extent, but equally as valid, the radiation doses and risks to transport drivers and receptors at the alternative disposal facility are not addressed by this assessment.

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Radon inhalation represents a long-term radiation exposure concern and is thus not considered for the excavation and re-disposal alternative. All doses and risks presented here assume that the same individual attends all 322 removal loads. Full details of the calculations and complete results are available in Appendix C.

7.2.1. Excavation Workers and Supervisor

During hypothetical retrieval and removal operations, both the excavation worker and supervisor would be exposed via inhalation of particulates, ingestion of soil, and external soil exposure. The excavation worker is assumed to operate the heavy equipment needed to excavate the waste. The supervisor is assumed to monitor the excavation operations on the ground. No credit is taken for the PPE worn by the excavation worker or supervisor. The excavation worker is assumed to be somewhat shielded from external radiation by the equipment (see Section 5.1.2). The supervisor is on the ground near the removal operations; thus, there is no shielding assumed for this receptor. Effective doses are shown in Table 7-7 for the maximum source term; in Table 7-8 for the weighted average source term.

Table 7-7. Effective Dose for the Excavation Worker and Supervisor, Maximum Source Term

Radionuclide	Inhalation dose (mrem)	Ingestion dose (mrem)	Total dose (mrem)
U-238	4.39×10^{-4}	1.23×10^{-3}	1.67×10^{-3}
U-234	8.70×10^{-4}	2.11×10^{-3}	2.97×10^{-3}
Th-230	3.56×10^{-3}	3.64×10^{-3}	7.20×10^{-3}
Ra-226	6.34×10^{-2}	1.17	1.24
Pb-210	3.78×10^{-1}	4.07×10^{1}	4.11×10^{1}
Th-232	2.34×10^{-3}	2.38×10^{-3}	4.71×10^{-3}
Ra-228	4.52×10^{-2}	1.78	1.83
Th-228	1.70×10^{-2}	3.82×10^{-2}	5.53×10^{-2}
Total	$\mathbf{5.11\times10^{-1}}$	$\mathbf{4.37\times10^{1}}$	$\mathbf{4.4\times10^{1}}$

Assuming the maximum source term, the external dose to the excavation worker in the equipment cab was 1.2×10^{-1} mrem; to the supervisor on the ground, it was 1.5 mrem.

Table 7-8. Effective Dose for the Excavation Worker and Supervisor, Weighted-average Source Term

Radionuclide	Inhalation dose (mrem)	Ingestion dose (mrem)	Total dose (mrem)
U-238	1.05×10^{-5}	2.95×10^{-5}	4.00×10^{-5}
U-234	4.18×10^{-5}	1.01×10^{-4}	1.43×10^{-4}
Th-230	1.72×10^{-4}	1.76×10^{-4}	3.49×10^{-4}
Ra-226	3.95×10^{-2}	7.31×10^{-1}	7.71×10^{-1}
Pb-210	2.31×10^{-1}	2.49×10^{1}	2.51×10^{1}
Th-232	6.45×10^{-2}	6.56×10^{-2}	1.30×10^{-1}
Ra-228	3.00×10^{-2}	1.18	1.21

Radionuclide	Inhalation dose (mrem)	Ingestion dose (mrem)	Total dose (mrem)
Th-228	1.01×10^{-2}	2.26×10^{-2}	3.27×10^{-2}
Total	$\mathbf{3.76\times10^{-1}}$	$\mathbf{2.69\times10^{1}}$	$\mathbf{2.7\times10^{1}}$

Assuming the weighted-average source term, the external dose to the excavation worker was 7.8×10^{-2} mrem; to the supervisor, it was 9.8×10^{-1} mrem. Cancer morbidity risks for each source term are presented in Table 7-97-9 and Table 7-10.

Table 7-9. Cancer Morbidity Risk for the Excavation Worker and Supervisor, Maximum Source Term

Radionuclide	Total inhalation morbidity risk	Total ingestion morbidity risk	Total external morbidity risk
U-238	1.28×10^{-10}	7.14×10^{-10}	1.39×10^{-7}
U-234	2.65×10^{-10}	9.35×10^{-10}	6.83×10^{-12}
Th-230	2.63×10^{-10}	4.64×10^{-10}	8.81×10^{-12}
Ra-226	1.91×10^{-8}	3.60×10^{-7}	1.64×10^{-5}
Pb-210	1.32×10^{-7}	1.37×10^{-5}	4.62×10^{-8}
Th-232	2.37×10^{-10}	3.08×10^{-10}	2.18×10^{-12}
Ra-228	3.73×10^{-9}	4.30×10^{-7}	3.77×10^{-6}
Th-228	1.39×10^{-8}	1.73×10^{-8}	1.63×10^{-7}
Pathway totals	1.70×10^{-7}	1.45×10^{-5}	2.05×10^{-5}
Total			$\mathbf{3.5\times10^{-5}}$

Table 7-10. Cancer Morbidity Risk for the Excavation Worker, Weighted-average Source Term

Radionuclide	Total inhalation morbidity risk	Total ingestion morbidity risk	Total external morbidity risk
U-238	3.07×10^{-12}	1.71×10^{-11}	3.33×10^{-9}
U-234	1.27×10^{-11}	4.50×10^{-11}	3.28×10^{-13}
Th-230	1.27×10^{-11}	2.24×10^{-11}	4.26×10^{-13}
Ra-226	1.19×10^{-8}	2.24×10^{-7}	1.02×10^{-5}
Pb-210	8.10×10^{-8}	8.35×10^{-6}	2.82×10^{-8}
Th-232	6.55×10^{-9}	8.49×10^{-9}	6.03×10^{-11}
Ra-228	2.48×10^{-9}	2.86×10^{-7}	2.50×10^{-6}
Th-228	8.21×10^{-9}	1.02×10^{-8}	9.62×10^{-8}
Pathway totals	1.10×10^{-7}	8.88×10^{-6}	1.28×10^{-5}
Total			$\mathbf{2.2\times10^{-5}}$

7.2.2. Current Off-site Resident

The nearest current off-site resident is located about 3,260 m (10,700 ft or roughly 2 miles) from the disposal facility. The only complete pathway of exposure for the current off-site resident is inhalation of particulates that may be blown off-site during hypothetical removal operations. The calculated doses and cancer morbidity risks for the off-site resident during hypothetical removal operations are summarized in Table 7-11.

Table 7-11. Doses and Risks for the Current Off-site Resident, Alternative 2

Radionuclide	Inhalation dose, max source term (mrem)	Inhalation dose, weighted-avg source term (mrem)	Total morbidity risk, max source term	Total morbidity risk, weighted-avg source term
U-238	6.52×10^{-10}	1.57×10^{-11}	1.90×10^{-16}	4.56×10^{-18}
U-234	1.29×10^{-9}	6.22×10^{-11}	3.94×10^{-16}	1.90×10^{-17}
Th-230	5.29×10^{-9}	2.56×10^{-10}	3.92×10^{-16}	1.90×10^{-17}
Ra-226	9.42×10^{-8}	5.87×10^{-8}	2.84×10^{-14}	1.77×10^{-14}
Pb-210	5.62×10^{-7}	3.44×10^{-7}	1.97×10^{-13}	1.20×10^{-13}
Th-232	3.47×10^{-9}	9.59×10^{-8}	3.53×10^{-16}	9.74×10^{-15}
Ra-228	6.72×10^{-8}	4.47×10^{-8}	5.55×10^{-15}	3.69×10^{-15}
Th-228	2.53×10^{-8}	1.50×10^{-8}	2.07×10^{-14}	1.22×10^{-14}
Total	**7.6×10^{-7} mrem**	**5.6×10^{-7} mrem**	**2.5×10^{-13}**	**1.6×10^{-13}**

8. Intruder Assessment

At the request of the Oregon Department of Energy, an intruder assessment was conducted. This assessment assumes that at some point in the future a hypothetical individual inadvertently drills through the Bakken oilfield waste while installing a water well. This person is then assumed to use the excavated materials produced while drilling the water well, including both the Bakken oilfield waste and other chemical and hazardous wastes, as a foundation for a home (see Figure 8-1).

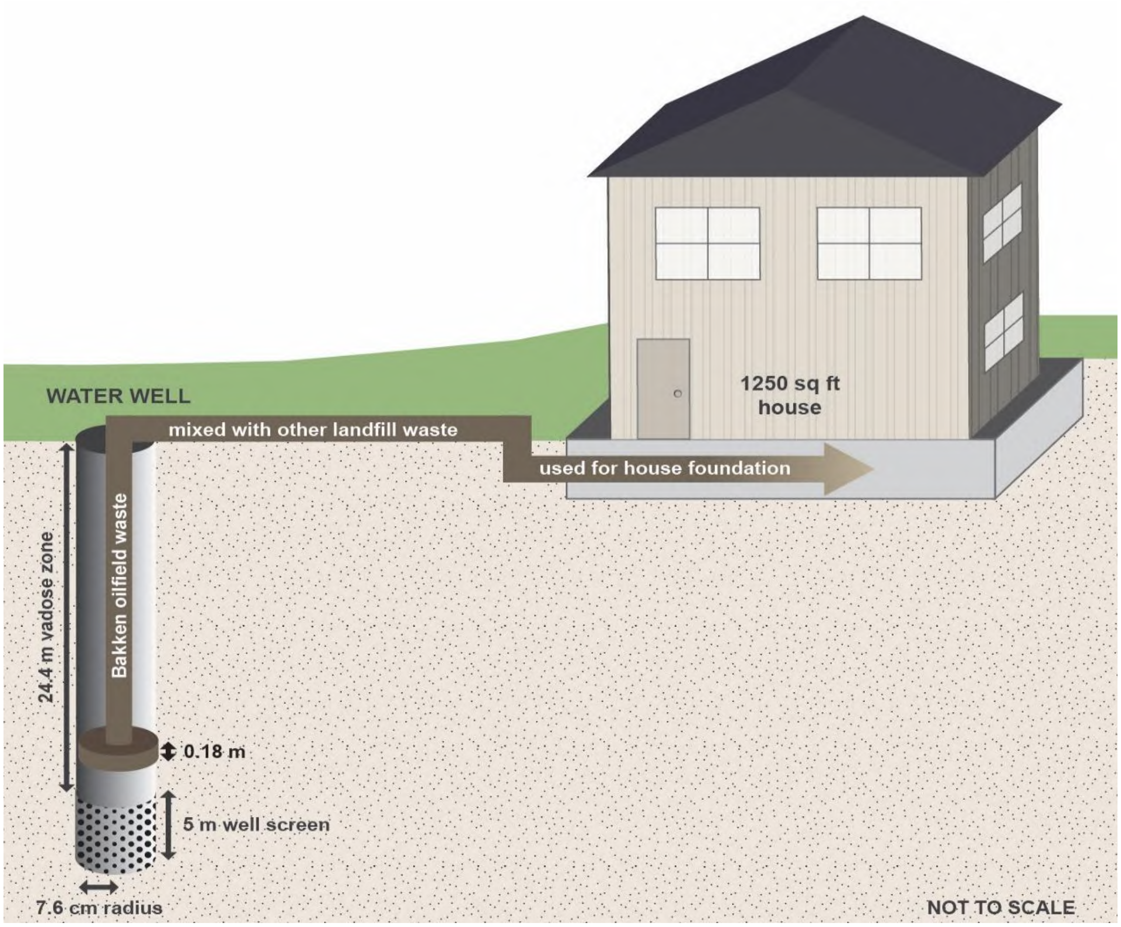

Figure 8-1. Conceptual model of exposure for the intruder.

RESRAD ONSITE v7.2 was used for this assessment. To assume the most pessimistic case for this scenario, no cover is assumed to exist over the hazardous waste before the house is placed. Further, the actual depth to the waste will be significantly greater than is assumed for this assessment, as materials are still being added to Landfill Unit L-14, which means that this assessment represents an extremely pessimistic scenario. Pathways of exposure examined for this assessment are indoor and outdoor radon inhalation and external exposure. Dose from groundwater ingestion is also considered here, with the calculations as described in Section 5.2. The intruder is assumed to draw water from the well located at the immediate downgradient edge of the source.

As with the remediation source term, the intruder source term is a diluted version of the disposal source term. The water well is assumed to be 24.4 m deep with a 5 m well screen. It is physically located within the landfill waste mass (see Section 5.2). According to the Oregon Water Resources Department[6], the nearest water well to the Arlington site is 6 inches in diameter. The source term paraments for this assessment are listed in Table 8-1.

[6] Well reports can be accessed here: https://www.oregon.gov/owrd/programs/GWWL/WCC/Pages/FindaWellLog.aspx.

Table 8-1. Intruder Assessment Source Term Parameters

Parameter	Value	Units	Notes
Total mass of Bakken oilfield waste	1.17×10^{6}	kg	Arlington landfill manifest data provided by CWMNW
Bulk density	1.76×10^{3}	kg m^{-3}	2970 lb yd^{-3} per Geosyntec Consultants (2020)
Total Bakken oilfield waste volume in dirt excavated from water well	3.29×10^{-3}	m^3	Calculation assuming 0.18 m thickness of TENORM. Calculation assumes 3 in (7.62 cm) well radius.
Total Bakken oilfield waste mass in dirt excavated from water well	5.80×10^{3}	g	Calculation using bulk density
Total volume of other landfill waste brought to surface during water well drilling	5.36×10^{-1}	m^3	Calculation assumes 3 in (7.62 cm) well radius, 24.4 m to water table plus 5 m well screen for a total depth of 29.4 m
Total mixed waste volume brought to surface	5.40×10^{-1}	m^3	Calculation assuming 1.15 g cm^{-3} bulk density of Selah

Given this, the dilution factor was calculated as:

$$Dilution\ Factor = \frac{Excavated\ Bakken\ Oilfield\ Waste\ Mass}{Total\ Mixed\ Waste\ Mass} = \frac{5.80\times10^{3}\,g}{6.21\times10^{5}\,g} = 0.01$$

The dilution factor was then applied to the maximum source term given in Table 3-5. Radionuclide concentrations used in the intruder assessment are given in Table 8-2. Input parameters that differ from RESRAD defaults are given in Table 8-3.

Table 8-2. Radionuclide Concentrations for the Intruder Assessment

Radionuclide	Radionuclide concentration (pCi g^{-1})
U-238	1.10×10^{-2}
U-234	1.88×10^{-2}
Th-230	7.46×10^{-3}
Ra-226	1.34
Pb-210	7.61
Th-232	4.43×10^{-3}
Ra-228	5.76×10^{-1}
Th-228	7.85×10^{-2}

Table 8-3. RESRAD-ONSITE Input Parameters for Intruder Assessment

Parameter	Value	Units	Notes
Area of contaminated zone	116.13	m^2	1,250 sq ft house, single story per 1987 Pathway Exemption Court Case[a]
Thickness of contaminated zone	0.0046	m	Volume of waste divided by square footage of home
Density of contaminated zone	1.76	g cm^{-3}	2,970 lb yd^{-3} per Geosyntec Consultants (2020)
Contaminated zone total porosity	0.41	unitless	Assumption based on waste material type – sandy loam
Average annual wind speed	4.839	m sec^{-1}	Extracted from meteorological data provided by CWMNW via email on 3/17/2020
Precipitation	0.235	m yr^{-1}	Reference: https://www.usclimatedata.com/climate/arlington/oregon/united-states/usor0013
Total porosity of the cover material	0.41	unitless	CWMNW Updated Hydrogeologic Conceptual Site Model Report (2008)
Average building air exchange rate	1.00	hr^{-1}	Per 1987 Pathway Exemption Court Case[a]
Height of the building (room)	2.44	m	Per 1987 Pathway Exemption Court Case[a]
Emanating power of Rn-222 gas	0.20	m^2	Assumption; value is typical of uranium mill tailings

a. Teledyne Wah Chang v. Energy Facility Siting Council, dated 5 March 1987.

8.1. Intruder Assessment Results

The doses and cancer morbidity risks are presented in Table 8-4. This analysis demonstrates that no adverse effects are likely should the Bakken oilfield waste be exhumed and used as the foundation for a home in the distant future.

Table 8-4. Intruder Assessment Results

Pathway	Dose (mrem)	Total cancer morbidity risk
Inhalation of indoor and outdoor radon	2.47×10^{-1}	1.89×10^{-6}
External exposure	6.49×10^{-1}	3.38×10^{-6}
Ingestion of groundwater	1.20×10^{-1}	1.03×10^{-6}
Total	**1.02 mrem**	**6.3×10^{-6}**

9. Ecological Assessment

For the closure-in-place alternative, an ecological assessment is provided to evaluate the radiological impacts to biota to ensure there are no deleterious effects. This assessment is in addition to the radiological assessment for human receptors evaluated in Section 7. The ecological assessment is conducted using the ERICA (Environmental Risk from Ionizing Contaminants: Assessment and Management) Tool (Brown et al. 2008; Larsson 2008), which combines data on environmental transfer of radionuclides and dosimetry to obtain a measure of exposure that is then compared to exposure levels defined by regulators or levels at which deleterious effects are known to occur. The ERICA tool has a hierarchical structure consisting of three tiers of impact assessment. After the first two tiers, the user is given a "stoplight" that is either red (further assessment recommended), yellow (potential concern, further assessment warranted), or green (negligible concern). The first tier is the most general and represents a worst-case scenario. Tier 1 is media-concentration-based and uses pre-calculated environmental media concentration limits to estimate risk quotients. If the calculated risk quotient is less than unity at the end of the Tier 1 assessment, no further calculations are necessary. Otherwise, a Tier 2 assessment is required. Tier 2 calculates dose rates and allows the user to examine and edit most of the parameters used in the calculation, including concentration ratios, distribution coefficients, percentage dry weight soil or sediment, dose conversion coefficients, radiation weighting factors, and occupancy factors. Tier 3 allows for a probabilistic assessment by assigning probability distribution functions to each underlying parameter value.

First a Tier 1 assessment was performed using the maximum activity concentrations provided in Table 3-5, and assigning a dose rate screening value of 40 µGy hr^{-1} for terrestrial mammals and 400 µGy hr^{-1} for birds and plants, consistent with U.S. Department of Energy and ICRP guidance (DOE 2002; ICRP 2014). The Tier 1 assessment exceeded these screening values for generic lichen and bryophyte receptors, so a Tier 2 assessment was conducted.

The Tier 2 assessment was performed for generic large mammals, generic burrowing mammals, birds, flying insects, reptiles, shrubs, and grasses. The maximum dose rate in the Tier 2 assessment was 2.5×10^{2} µGy hr^{-1} for shrubs. All dose rates were substantially less than the screening values; thus, the assessment was considered complete, and no deleterious ecological effects from radiation are likely to occur should the closure-in-place alternative be selected.

10. Summary

The calculated doses and risks for different pessimistic exposure scenarios and timeframes are compared to a selection of radiation doses and risks from other sources, including natural and anthropogenic background near the site. Risks are evaluated against the EPA's recommended acceptable risk level of one in 10,000 (10^{-4}) to one in one million (10^{-6}).

During the disposals, the maximally exposed individual—the waste handler—received a maximum dose of 3.3 mrem, assuming the maximum source term, taking no credit for the PPE required, and assuming the same individual attended all disposals. For these reasons, the actual dose was significantly lower. The maximum dose is 94 times lower than the U.S. average background radiation dose. The increased risk of cancer mortality for the waste handler is very low, at 0.0000017 (1.7×10^{-6}), well within the EPA's acceptable risk range. The current off-site resident received a negligible dose during the disposals, and their increased cancer risk is also essentially zero, at 0.00000000000023 (2.3×10^{-13}).

Two remediation alternatives were also examined, one in which the waste is left in place, and the other in which it is excavated and trucked to an off-site disposal location. For the leave- in-place option, exposures for all receptors are less than 1 mrem per year, including the worst-case scenario of an on-site resident far into the future who consumes the groundwater. The maximum cancer risk is for the future on-site receptor, at 0.000001 (1×10^{-6}), which is the bottom of the EPA's acceptable risk range. The risks for all other receptors are essentially zero. For the excavation alternative, the maximum dose is to the on-site supervisor, at approximately 46 mrem. The cancer mortality risk for the supervisor is within the EPA's acceptable risk range at 0.000025 (2.5×10^{-5}), but is substantially greater than the risk if the material is left in place.

Disregarding the physical risks and costs associated with removal operations, which are discussed in detail in the CAP (Gradient 2020), solely from a radiological dose and risk perspective, it is more protective of workers and the public to leave the materials in place. The Corrective Action Plan examines the remediation alternatives holistically (Gradient 2020). Figure 10-1 shows annual average U.S. radiation doses by source alongside the highest average annual receptor dose for each scenario considered for the Arlington facility. All doses are substantially lower than natural background.

This assessment, coupled with the gamma survey of the site, indicate that any impacts from the placement of Bakken oilfield wastes are minimal.

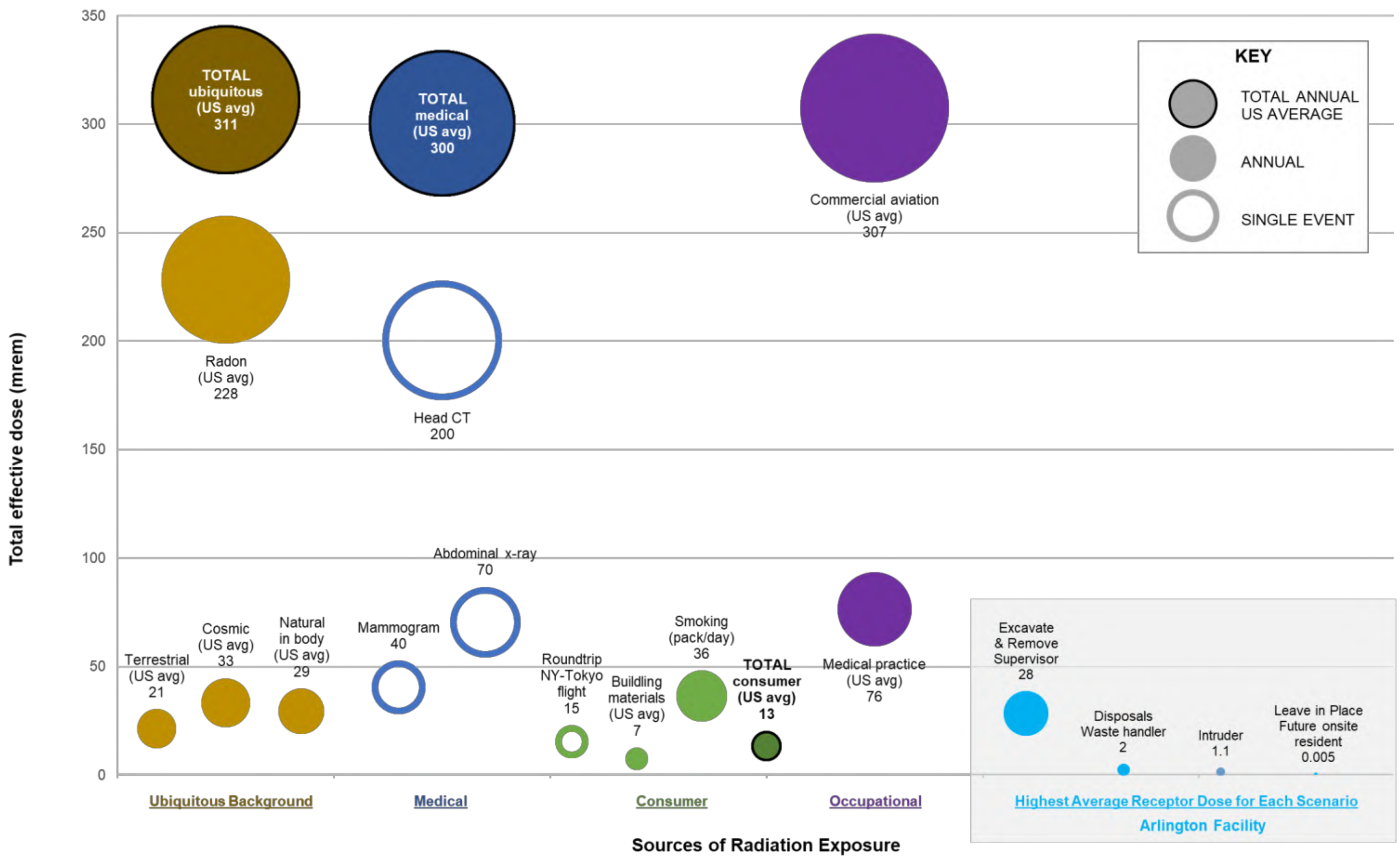

Figure 10-1. This figure shows average U.S. radiation doses by source (NCRP 2009; Mettler et al. 2008) and the highest average annual receptor dose for each scenario (mrem) considered for the Arlington facility. Note that the supervisor's estimated dose (28 mrem) is 11 times lower than the average U.S. ubiquitous background dose received by the public (311 mrem) and 179 times lower than the allowable dose limit to a worker in restricted areas (5,000 mrem).

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11. References

40 CFR 141. 2011. "National Primary Drinking Water Regulations" *Code of Federal Regulations*, Office of the Federal Register.

American Cancer Society. 2020. Cancer Facts & Figures 2020.

ANL (Argonne National Laboratory). 2014. Radiological Dose and Risk Assessment of Landfill Disposal of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in North Dakota. ANL/EVS-14/13.

ANSI/HPS (American National Standards Institute/Health Physics Society). 2009. Control and Release of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM). ANSI/HPS N13.53-2009. McLean, VA: Health Physics Society.

Benson, C.H. 2016. Predicting Service Life of Geomembranes in Low-Level and Mixed Waste Disposal Facilities. Performance & Risk Assessment Community of Practice Webinar Workshop 16 May 2016.

Brown, J.E. et al. 2008. "The ERICA Tool." *Journal of Environmental Radioactivity* 99 (9): 1371–1383.

Browne, E., and R.B. Firestone. 1986. *Table of Radioactive Isotopes*. John Wiley & Sons, New York.

Burns & McDonnell, Inc. 1998. L-14 Landfill Study: Data Analysis and Modeling CEMNW Arlington Facility, Arlington, Oregon. Burns & McDonnell, Inc., for WMI Mountain Group Inc., Arlington, OR.

Carsel, R.F., and R.S. Parrish. 1988. "Developing Joint Probability Distributions of Soil Water Retention Characteristics." *Water Resources Research* 25 (5): 311–314.

CH2M Hill (CH2M Hill Companies, Ltd.). 2008. Updated Hydrogeologic Conceptual Site Model Report. CH2M Hill, prepared for Waste Management, Inc., Arlington, OR.

Codell, R.B., K.T. Key, and G. Whelan. 1981. A Collection of Mathematical Models for Dispersion of Surface Water and Groundwater. NUREG-0868. U.S. Nuclear Regulatory Commission, Washington, D.C.

Dames and Moore. 1987. Geologic and Hydrogeologic Site Characterization Report: RCRA Part B Permit Application. Prepared for Chem-Security Systems, Inc., Arlington, OR. April.

DOE (U.S. Department of Energy). 2002. A Graded Approach for Evaluation Radiation Doses to Aquatic and Terrestrial Biota. DOE-STD-1153-2002. U.S. Department of Energy, Washington, D.C.

DOE. 2007. "Radioactive Waste Management." DOE O 435.1, Chg1. U.S. Department of Energy, Washington, D.C.

DOE. 2011. Derived Concentration Technical Standard. DOE-STD-1196-2011. U.S. Department of Energy, Washington, D.C.

DOE. 2018. Performance Assessment for the Integrated Disposal Facility. RPP-RPT-59958, Rev B. U.S. Department of Energy, Richland Operations Office, Richland, WA.

DOE-ID (U.S. Department of Energy, Idaho Operations Office). 2007. Performance Assessment for the RWMC Active Low-Level Waste Disposal Facility at the Idaho National Laboratory Site. DOE/NE-ID-11243. Idaho National Laboratory, Idaho Falls, ID.

DOE-ID. 2008. Composite Analysis for the RWMC Active Low-Level Waste Disposal Facility at the Idaho National Laboratory Site. DOE/NE-ID-11244. Idaho National Laboratory, Idaho Falls, ID.

DOE-ID. 2011. Performance Assessment for the Idaho CERCLA Disposal Facility Landfill. DOE/ID-10978. Idaho National Laboratory, Idaho Falls, ID.

DOE-ID. 2012. Performance Assessment for the Idaho National Laboratory Remote-Handled Low-Level Waste Disposal Facility. DOE/ID-11421. Idaho National Laboratory, Idaho Falls, ID.

DOE-ID. 2018. Performance Assessment for the Idaho National Laboratory Remote-Handled Low-Level Waste Disposal Facility. DOE/ID-11421, Rev 2. Idaho National Laboratory, Idaho Falls, ID.

EPA (U.S. Environmental Protection Agency). 1990. National Oil and Hazardous Substances Pollution Contingency Plan; Final rule. Fed. Reg. 55(46):8666-8865. March 8.

EPA. 1991. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance Standard Default Exposure Factors. Interim Final. OSWER Directive 9285.6-03.

EPA. 1991. Role of the baseline risk assessment in Superfund remedy selection decisions. Office of Solid Waste and Emergency Response (OSWER). National Technical Information Service (NTIS). OSWER Directive 9355.0-30, NTIS PB91-92139. April 22.

EPA. 1995. Compilation of Air Pollutant Emission Factors. AP-42. U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

EPA. 1998. Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings. 40 CFR Part 192.

EPA. 1999a. *Understanding Variation in Partitioning Coefficient*, K_d *Values*. EPA402-R-99 004a. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington DC.

EPA. 1999b. Cancer Risk Coefficients for Environmental Exposure to Radionuclides. Federal Guidance Report No. 13. EPA 402-R-99-001. Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

EPA. 2004a. User's Guide for the AMS/EPA Regulatory Model -AERMOD. EPA-454/B-03-001. U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

EPA. 2011. Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. EPA/600/R-090/052F. September.

EPA. 2016. Regional Screening Levels (RSLs) – Users Guide. U.S. Environmental Protection Agency. May. Available at https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide-may-2016.

ERG and K2 (Environmental Restoration Group, Inc., and K2 Environmental, LLC). 2020. Gamma Survey Report.

Gelhar, L.W., C. Welty, and K.R. Rehfeldt, 1992. "A Critical Review of Data on Field-Scale Dispersion in Aquifers." *Water Resources Research*. Vol. 28, No. 7, Pg. 1955.

Geosyntec Consultants (2020). Foundation Settlement Analysis. Chemical Waste Management of the Northwest, Inc. Arlington, Oregon.

Gradient. 2020. Corrective Action Plan (CAP) for the Chemical Waste Management of the Northwest Facility, Arlington, OR.

Grove Engineering, Inc. 2013. MicroShield Software Package. 4925 Boonsboro Road #257, Lynchburg, VA 24503. Available at http://radiationsoftware.com/MicroShield/.

ICRP (International Commission on Radiological Protection). 1994. Dose Coefficients for Intakes of Radionuclides by Workers. ICRP Publication 68. Ann. ICRP 24 (4). International Commission on Radiation Protection, Oxford.

ICRP 1996. Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients. ICRP Publication 72. Ann. ICRP 26 (1). International Commission on Radiation Protection, Oxford.

ICRP. 2014. Protection of the Environment under Different Exposure Situations. ICRP Publication 124. Ann. ICRP 43(1). International Commission on Radiation Protection, Oxford.

Kamboj. S. E. Gnanapragasam, and C. Yu. 2018. *User's Guide for RESRAD-ONSITE Code*. ANL/EVS/TM-18/1 Argonne National Laboratory, Argonne IL.

Kennedy, W.E. and D.L. Strenge. 1992. *Residual Radioactive Contamination from Decommissioning*. NUREG/CR-5512. Vol. 1. U.S. Nuclear Regulatory Commission, Washington DC.

Larsson, C.M. 2008. "An Overview of the ERICA Integrated Approach to the Assessment and Management of Environmental Risks from Ionising Contaminants." *Journal of Environmental Radioactivity* 99 (9): 1364–1370.

Mettler, F.A. Jr., W. Huda, T.T. Yoshizumi, and M. Mahesh. 2008. "Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog." Radiology 248 (1): 254–263.

Millington, R.J., and J.M. Quirk. 1961. "Permeability or Porous Solids". *Trans Faraday Soc*. 57: 1200-1207.

NRC (U.S. Nuclear Regulatory Commission). 2020. User's Manual for the RESRAD OFFSITE Code Version 4. NUREG/CR-7268 ANL/EVA/TM-19/2. U.S. Nuclear Regulatory Commission, Washington DC.

NCRP (National Council on Radiation Protection and Measurements). 1988. Measurements of Radon Daughters in Air. NCRP Report 97. NCRP, Bethesda, MD.

NCRP. 2009. Ionizing Radiation Exposure of the Population of the United States. Report No. 160. National Council on Radiation Protection and Measurements, Bethesda, Maryland. March.

ODOE (Oregon Dept. of Environmental Quality). 2020. Hazardous Substance Remedial Action Rules: Definitions. OAR 340-122-0115.

Risk Assessment Corp. (RAC). 2016. "Dose and Risk Assessment of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) Disposals at the Blue Ridge Landfill (Final)." Report to Advanced Disposal. October 11.

Rogers, V.C., K.K. Nielson, and R. Kalkwarf. 1984. Radon Attenuation Handbook for Uranium Mill Tailings Cover Design. NUREG/CR-3533. U.S. Nuclear Regulatory Commission, Washington, D.C.

Rood, A.S. 1994. "GWSCREEN: A Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination." *The Environmental Professional* 16 (3): 196–210.

Rood, A.S. 2002. GWSCREEN: A Semi-Analytical Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination: Theory and User's Manual, Version 2.5, Rev 1b. INEEL/EXT-98-00750. Idaho National Laboratory, Idaho Falls, ID. July.

Rood, A.S. 2004a. Groundwater Concentrations and Doses with Uncertainty for the U.S. Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington. K-Spar Inc., Idaho Falls, Idaho.

Rood, A.S. 2004b. "A Mixing-Cell Model for Assessment of Contaminant Transport in the Unsaturated Zone Under Steady-State and Transient Flow Conditions." *Environmental Engineering Science* 21 (6): 661–677.

Rood, A.S. 2005. Mixing Cell Model: A One-Dimensional Numerical Model for Assessment of Water Flow and Contaminant Transport in the Unsaturated Zone. ICP/EXT-05-00748. Idaho National Laboratory, Idaho Falls, ID. March.

Rood, A.S, E.A. Caffrey, H.A. Grogan, C.D. Mangini, J.E. Till. 2020. Analysis of Leachate Management Practices for the Chemical Waste Management of the Northwest Facility in Arlington, OR. RAC Technical Memorandum No. 5-CWMNW Arlington-2020. May 29. Available at: https://www.oregon.gov/energy/safety-resiliency/Pages/Radioactive-Waste-Disposal.aspx.

RUST (RUST Environment & Infrastructure). 1998a. Hydrogeologic Investigation and Engineering Design Report for Landfill L-14, Arlington, Oregon. Prepared for Waste Management, Inc. February.

RUST. 1998b. Updated Site Conceptual Model Report for Arlington Facility, Arlington, Oregon. Prepared for Waste Management, Inc. March.

Sheppard, M.I. and D.H. Thibault. 1990. "Default Soil Solid/Liquid Partition Coefficients, K_ds, for Four Major Soil Types: A Compendium," *Health Physics*, 59: 4, pp. 471–482.

Simunek, J.M., M. Sejna, H. Saito, M. Sakai, and M.Th. van Genuchten. 2013. HYDRUS-1D Software Package for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media, Ver 4.17. Department of Environmental Sciences, University of California Riverside, Riverside, CA.

Sondrup, A.J., A.L. Schafer and A.S. Rood. 2018. *Performance Assessment for the Idaho National Laboratory Remote Handled Low-Level Waste Disposal Facility*. DOE/ID 11421, Rev 2, U.S. Department of Energy, Idaho Falls Operations Office, Idaho Falls, ID.

Tian, K., C.H. Benson, J.M. Tinjum, T.B. Edil. 2017. "Antioxidant Depletion and Service Life Prediction for HDPE Geomembranes Exposed to Low-Level Radioactive Waste Leachate." *Journal of Geotechnical and Geoenvironmental Engineering* DOI: 10.1061/(ASCE)GT.1943-5606.0001643.

Van Genuchten, M.Th. 1980. "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils." *Soil Society of America Journal* 44: 892–898.

Xu, M. and Y. Eckstein. 1995. "Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale" *Ground Water* 33(6): pp 905-908.

Yu, C., A.J. Zielen, J.J. Cheng, D.J. LePoire, E. Gnanapragasam, S. Kamboj, J. Arnish, A. Wallo III, W.A. Williams, and H. Peterson. 2001. User's Manual for RESRAD Version 6. ANL/EAD-4. Environmental Assessment Division, Argonne National Laboratory, July.

Appendixes

A) RAC Curriculum vitae
B) Bakken Oilfield waste raw analytical data
C) Supporting documentation package

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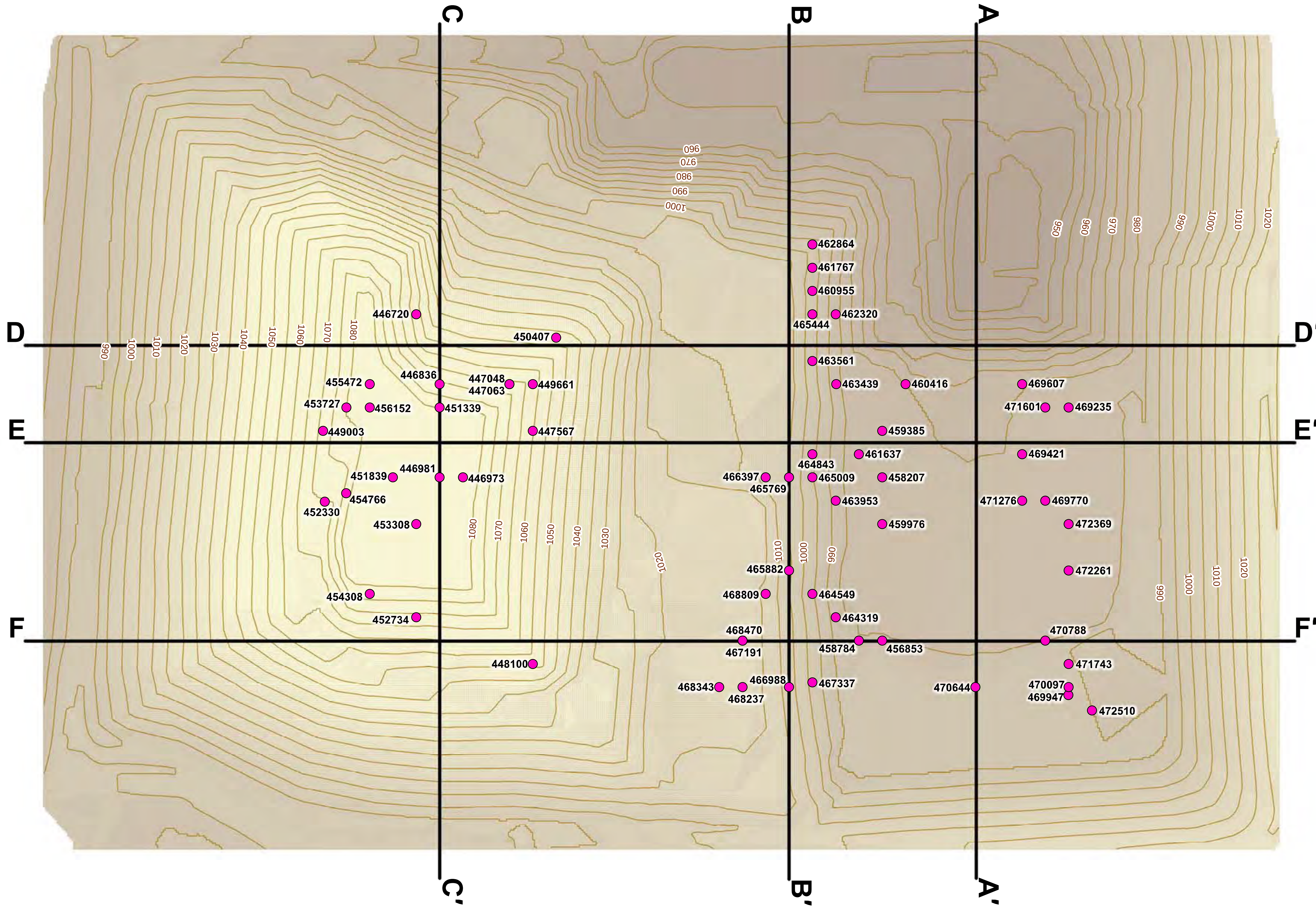
Attachment D

Waste Burial Locations and Depth



Legend

A ____ A' Cross-Section Location

Existing Waste Grade

Approximate Waste Location

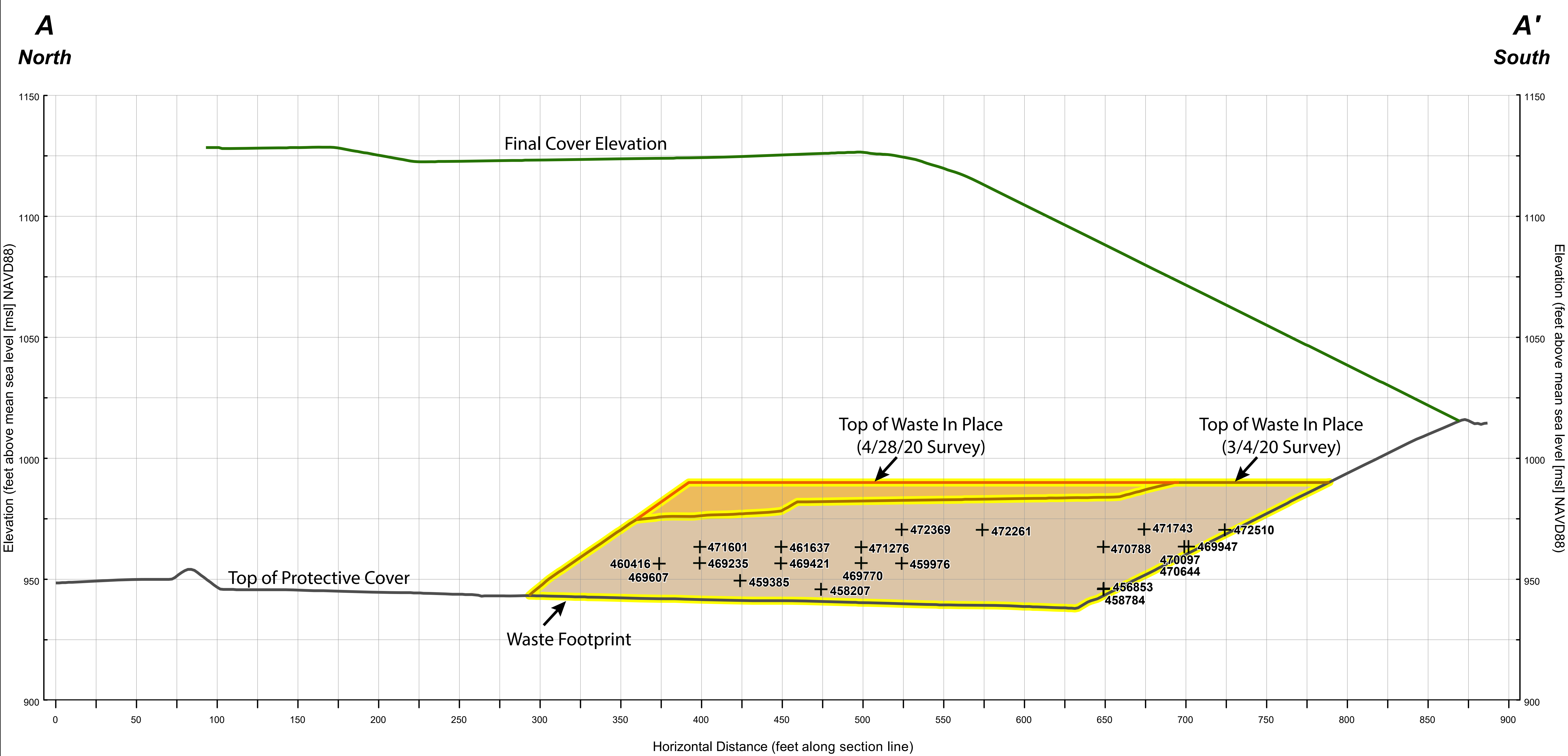
120 60 0 120 Feet

CWMNW Landfill 3D Model
Cross-Section Locations
Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
Arlington, OR

Geosyntec consultants

Figure 2

WR2856 | March 2020



Legend

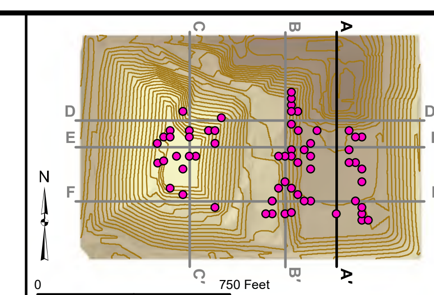
Model Layering

- Final Cover Grade
- Existing Waste Grade (4/28/20 Survey)
- Existing Waste Grade (3/4/20 Survey)
- Protective Cover Grade

- **460416** Approximate Waste Location
- Existing Waste (4/28/20)
- Existing Waste (3/4/20)

Note:
Vertical scale is 1 inch = 40 ft
Horizontal scale is 1 inch = 60 ft

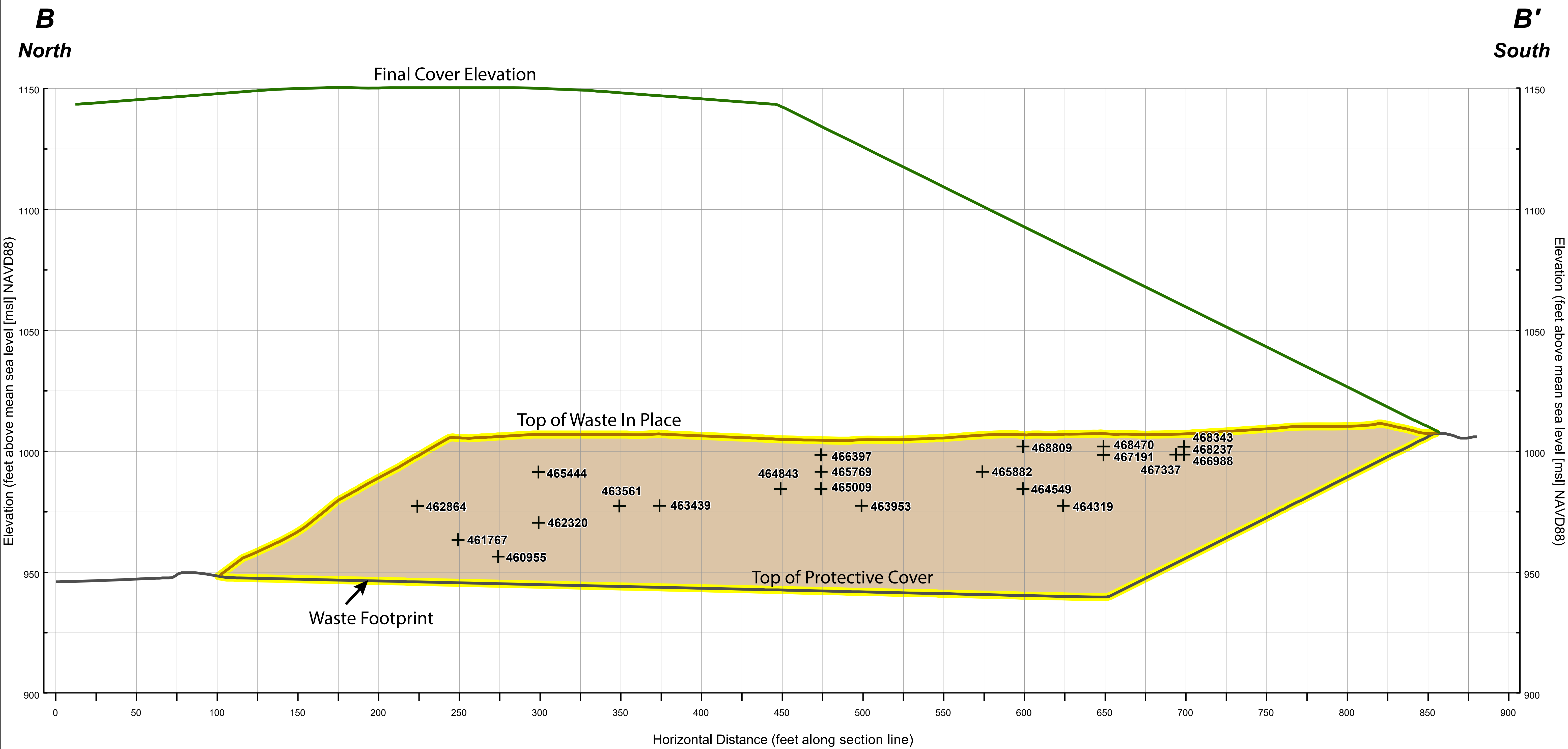
SCALE
1.5X Vertical Exageration
40 / 20 / 0
0 30 60 Feet



CWMNW Landfill 3D Model
Cross-Section A-A′
Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
Arlington, OR

Geosyntec consultants

WR2856	March 2020	Figure 3



Legend

Model Layering

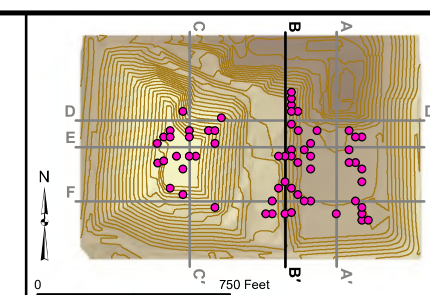
- Final Cover Grade
- Existing Waste Grade
- Protective Cover Grade

+ 460416 Approximate Waste Location

Existing Waste

Note:
Vertical scale is 1 inch = 40 ft
Horizontal scale is 1 inch = 60 ft

SCALE
1.5X Vertical Exageration
40 / 20 / 0
0 / 30 / 60 Feet



CWMNW Landfill 3D Model Cross-Section B-B′

Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
Arlington, OR

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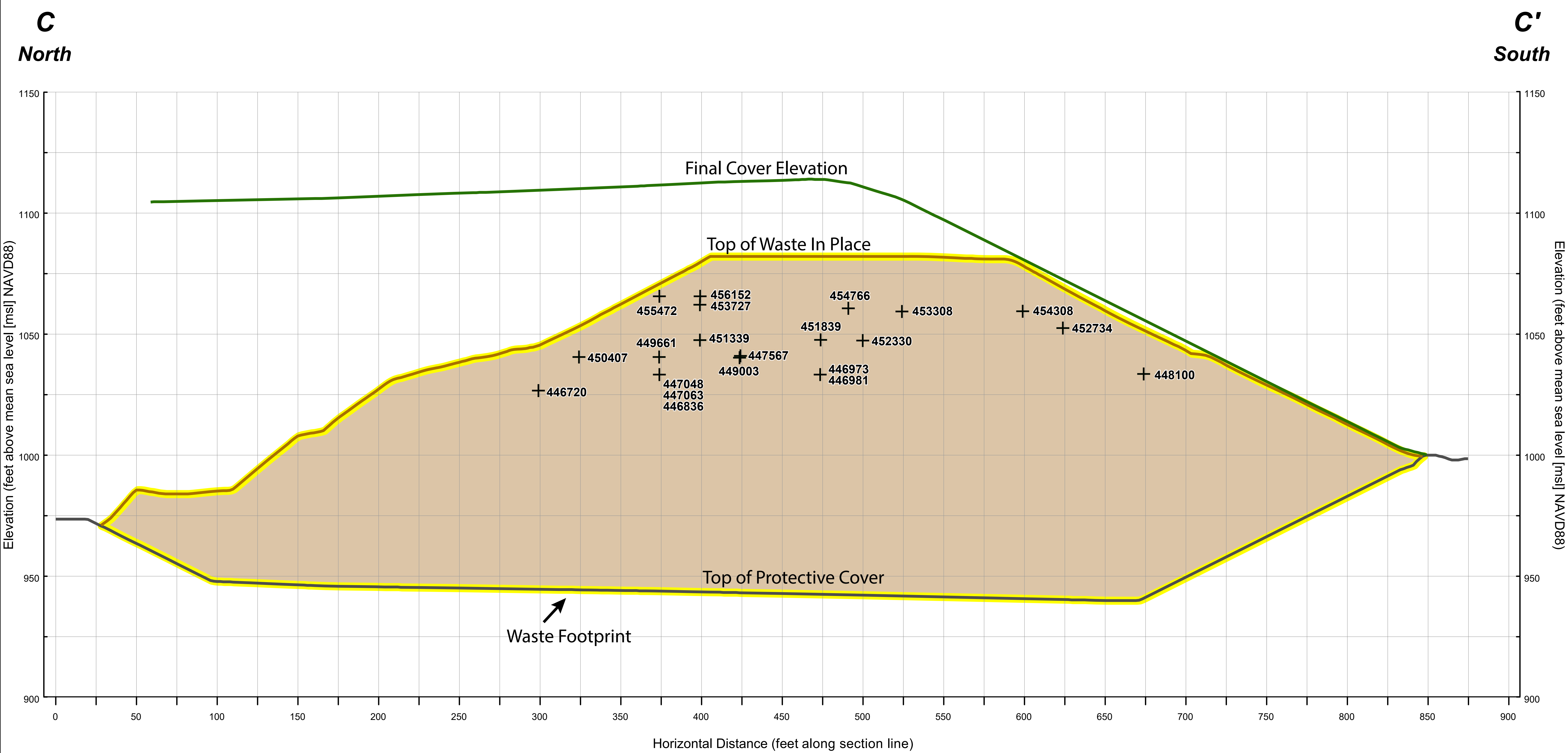
Figure 4



Legend

Model Layering

Final Cover Grade

Existing Waste Grade

Protective Cover Grade

460416 Approximate Waste Location

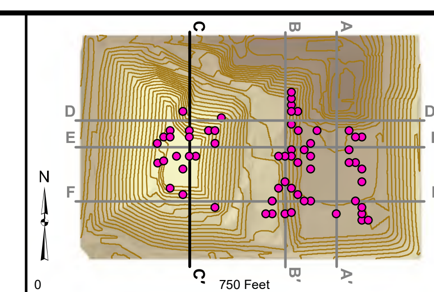
Existing Waste

Note:
Vertical scale is 1 inch = 40 ft
Horizontal scale is 1 inch = 60 ft

SCALE
1.5X Vertical Exageration

40 / 20 / 0

0 30 60 Feet



CWMNW Landfill 3D Model
Cross-Section C-C′
Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
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Figure
5

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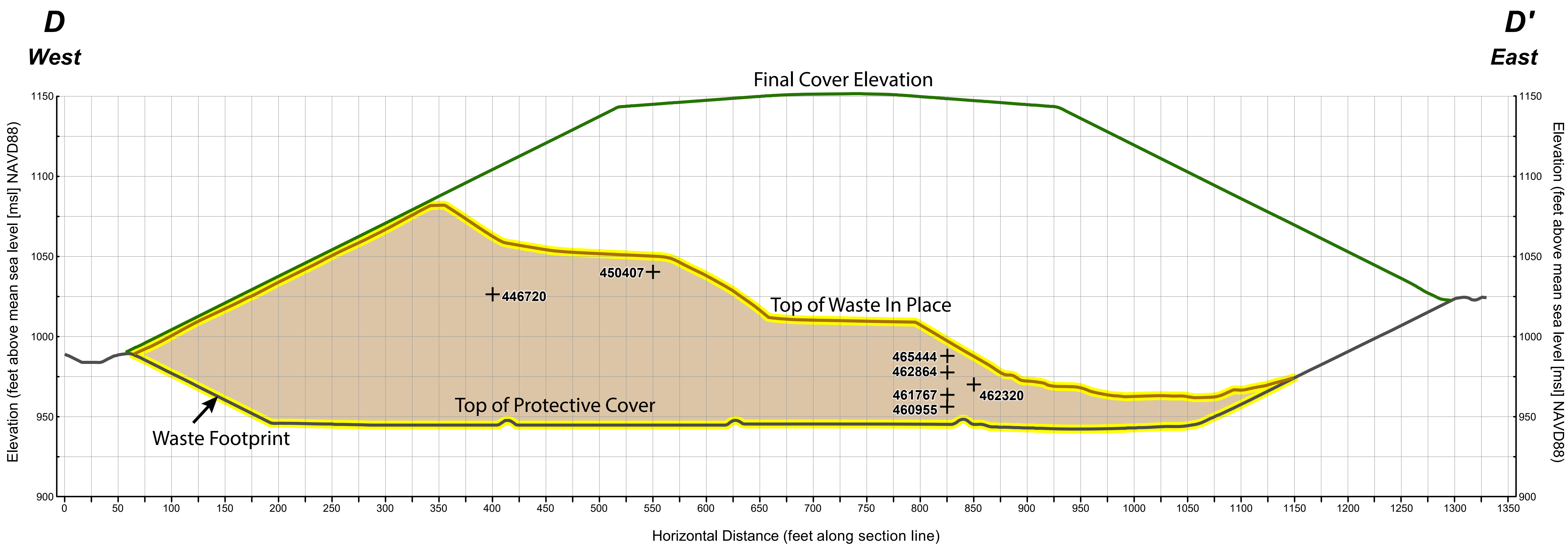


Legend

Model Layering

- Final Cover Grade
- Existing Waste Grade
- Protective Cover Grade

+ 460416 Approximate Waste Location

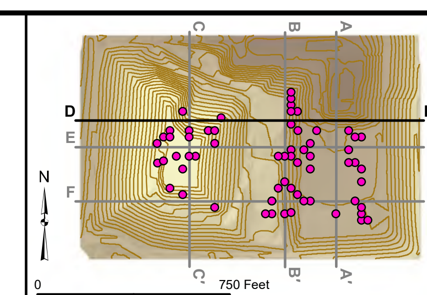
Existing Waste

Note:
Vertical scale is 1 inch = 66 ft
Horizontal scale is 1 inch = 100 ft

66
33
0

SCALE
1.5X Vertical Exageration

0 50 100 Feet



CWMNW Landfill 3D Model
Cross-Section D-D′
Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
Arlington, OR

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Figure
6

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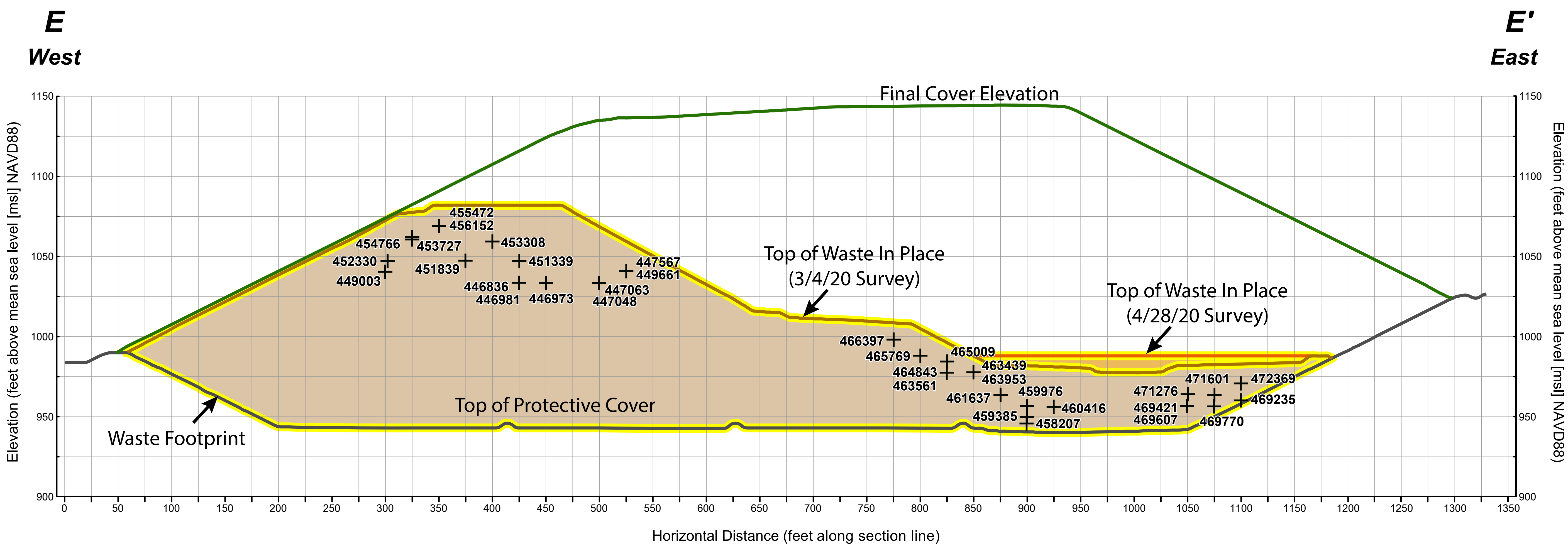


Legend

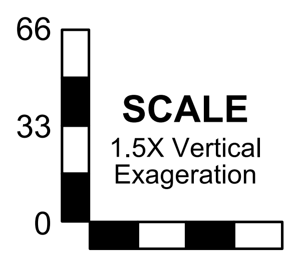
Model Layering

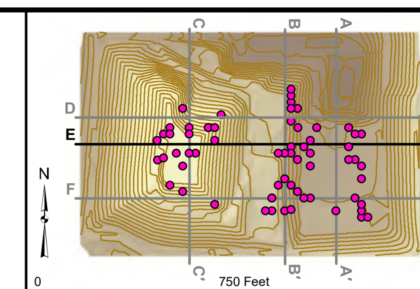
- Final Cover Grade
- Existing Waste Grade (4/28/20 Survey)
- Existing Waste Grade (3/4/20 Survey)
- Protective Cover Grade

- **460416** Approximate Waste Location
- Existing Waste (4/28/20)
- Existing Waste (3/4/20)

Note:
Vertical scale is 1 inch = 66 ft
Horizontal scale is 1 inch = 100 ft

SCALE
1.5X Vertical Exageration





CWMNW Landfill 3D Model
Cross-Section E-E′
Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
Arlington, OR

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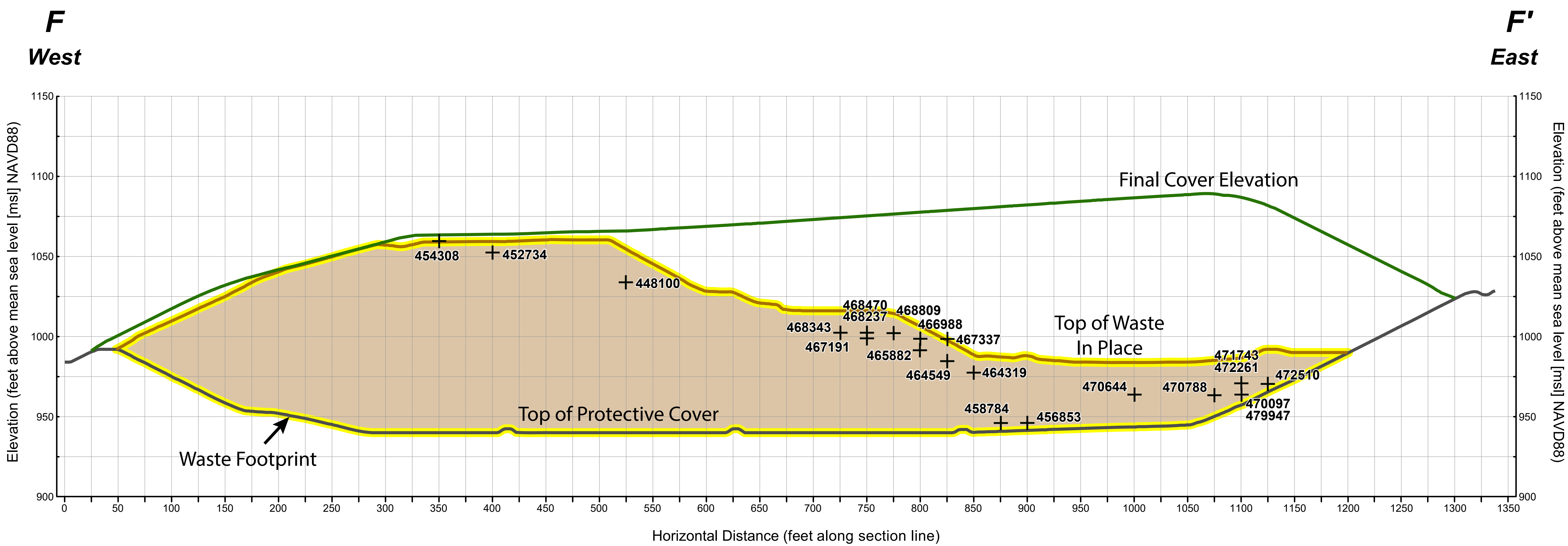
WR2856	March 2020	Figure 7



Legend

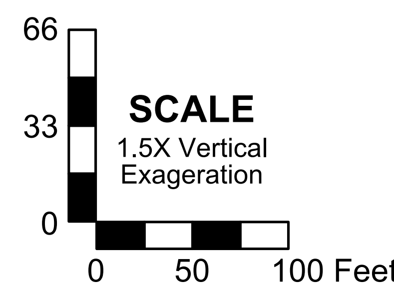
Model Layering

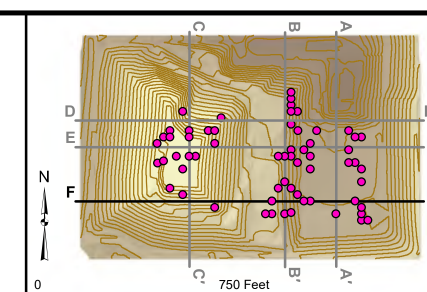
- Final Cover Grade
- Existing Waste Grade
- Protective Cover Grade

+ **460416** Approximate Waste Location

Existing Waste

Note:
Vertical scale is 1 inch = 66 ft
Horizontal scale is 1 inch = 100 ft





CWMNW Landfill 3D Model
Cross-Section F-F′

Chemical Waste Management of the Northwest
17629 Cedar Springs Lane
Arlington, OR

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Figure 8

Attachment E

Supporting Calculations: Physical Risk and GSR Analyses

Summary of On-Site Safety Metrics

Type	Remediation Alternative	# of Incidents from Remedy Implementation	# of Incidents from Personnel Transport (from SiteWise Output)	Total Number of Incidents
On-Site Fatality	Closure-in-Place	0.000	0.000	0.000
	Excavate and Redispose	0.073	0.018	0.090
On-Site Injury	Closure-in-Place	0.000	0.000	0.000
	Excavate and Redispose	7.007	1.446	8.453

On-Site Safety Calculation Worksheet

Remediation Alternative	Total Duration (Hours)	Total Labor (Hours)	Additional Laborer	Site Supervisor	Construction Project Manager	Construction Tech	Field Engineer	Project Engineer	Labor Requirements (Based on a Similar Project)
			Total Hours	Total Hours	Total Hours	Total Hours	Total Hours	Total Hours	
Closure-in-Place	0	0	0	0	0	0	0	0	
Excavate and Redispose	21,024	712,024	617,416	21,024	21,024	21,024	21,024	10,512	Operation duration is estimated based on simultaneous work of 4 operation units at the Site; each operation unit consists of a loader, an excavator, a grader, a water truck, a haul truck, and 8 laborers (including Equipment Operators). 1 Construction Technician, 1 Site Supervisor, 1 Field Engineer, 1 Project Manager, and 0.5 Project Engineer are present at the Site to manage operation of all operation units.

Labor Categories	Fatal Occupational Injuries (US Dept. of Labor, 2018c)			Non-fatal Occupational Injuries (US Dept. of Labor, 2018b)		
	US BLS Labor Categories	Fatalities Per Hour	Reference	US BLS Labor Categories	Injuries Per Hour	Reference
Additional Labor	Waste management and remediation services	1.06E-07	US Dept. of Labor (2018c)	Construction laborers	1.05E-05	US Dept. of Labor (2018a, Table R100)
Site Supervisor	First-line supervisors of construction trades and extraction workers	1.05E-07	US Dept. of Labor (2018c)	Construction occupations in private sector	5.77E-06	US Dept. of Labor (2018b, Table R72)
Construction Project Manager	First-line supervisors of construction trades and extraction workers	1.05E-07	US Dept. of Labor (2018c)	Construction occupations in private sector	5.77E-06	US Dept. of Labor (2018b, Table R72)
Construction Observation Tech/Engineer	First-line supervisors of construction trades and extraction workers	1.05E-07	US Dept. of Labor (2018c)	Construction occupations in private sector	5.77E-06	US Dept. of Labor (2018b, Table R72)
Field Engineer	Architectural, engineering, and related services	8.00E-09	US Dept. of Labor (2018c)	Construction occupations in private sector	5.77E-06	US Dept. of Labor (2018b, Table R72)
Project Engineer	Architectural, engineering, and related services	8.00E-09	US Dept. of Labor (2018c)	Construction occupations in private sector	5.77E-06	US Dept. of Labor (2018b, Table R72)

		Additional Laborer	Site Supervisor	Construction Project Manager	Construction Observation Tech/Engineer	Field Engineer	Project Engineer	Total
Number of Fatalities	Closure-in-Place	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Excavate and Redispose	6.56E-02	2.21E-03	2.21E-03	2.21E-03	1.68E-04	8.41E-05	7.25E-02
Number of Injuries	Closure-in-Place	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Excavate and Redispose	6.46E+00	1.21E-01	1.21E-01	1.21E-01	1.21E-01	6.07E-02	7.01E+00

Summary of Off-Site Safety Metrics

Risk Estimation	Remediation Alternative 1 Closure-in-Place	Remediation Alternative 2 Excavate and Redispose
Number of truck loads for moving the Bakken oilfield waste and materials	0	322
Total truck mileage, two ways (miles)	0	225,400
Fatalities in truck crashes (persons)	0.00E+00	3.61E-03
Occupant fatalities in truck crashes (persons)	0.00E+00	6.37E-04
Persons injured in large truck crashes (persons)	0.00E+00	1.12E-01
Fatal crashes (number of crashes)	0.00E+00	3.20E-03
Injury crashes (number of crashes)	0.00E+00	7.75E-02
Expected truck crashes with fatality to truck occupants	0.00E+00	5.67E-04
Expected truck crashes with injury (non-fatal) to truck occupants	0.00E+00	2.09E-02
Expected truck crashes with fatality to non-truck occupants	0.00E+00	2.63E-03
Expected truck crashes with injury to non-truck occupants	0.00E+00	5.67E-02

Notes:

These results exclude personnel transport (calculated elsewhere).

Off-Site Safety Calculation Worksheet

Assumptions		
Fatal crashes involving large trucks	1.42	Crash per 100 million miles traveled by trucks. Source = US DOT (2019).
Fatalities in large truck crashes	1.6	Person per 100 million miles traveled by trucks. Source = US DOT (2019).
Occupant fatalities in large truck crashes	0.28	Person per 100 million miles traveled by trucks. Source = US DOT (2019).
Injury crashes involving large trucks	34.4	Crash per 100 million miles traveled by trucks. Source = US DOT (2019).
Persons injured in large truck crashes	49.7	Person per 100 million miles traveled by trucks. Source = US DOT (2019).
Ratio of occupant to non-occupant fatalities in truck crashes[a]	0.177	-
Ratio of occupant to non-occupant injuries in truck crashes[a]	0.269	-

Note:

(a) US DOT reports that 17.7% of people killed and 26.9% of people injured in crashes involving trucks are truck occupants (US DOT, 2019). Here, we assume that the same percentages apply to the number of crashes that lead to fatality and injury of truck occupants and non-truck occupants.

Key Inputs		
Total weight of incremental equipment and materials to be hauled to the Site for closure (in addition to closure requirements established in CWMNW landfill permit)	0	US-tons
Inputs Specific to the Closure-in-Place Remediation Alternative		
Distance between the CWMNW landfill and the equipment and materials source depot	0	Miles

Mileage Estimates for Closure-in-Place Remediation Alternative		
Number of truckloads for moving equipment and materials to the CWMNW landfill	0	Truckloads
Total truck round-trip mileage for moving the equipment and materials	0	Miles

Risk Estimation	Closure-in-Place Remediation Alternative
Total truck mileage, two ways (miles)	0
Fatalities in truck crashes (persons)	0.00E+00
Occupant fatalities in truck crashes (persons)	0.00E+00
Persons injured in large truck crashes (persons)	0.00E+00
Fatal crashes (number of crashes)	0.00E+00
Injury crashes (number of crashes)	0.00E+00
Expected truck crashes with fatality to truck occupants	0.00E+00
Expected truck crashes with injury (non-fatal) to truck occupants	0.00E+00
Expected truck crashes with fatality to non-truck occupants	0.00E+00
Expected truck crashes with injury to non-truck occupants	0.00E+00

Off-Site Safety Calculation Worksheet

Assumptions		
Fatal crashes involving large trucks	1.42	Crash per 100 million miles traveled by trucks. Source = US DOT (2019).
Fatalities in large truck crashes	1.6	Person per 100 million miles traveled by trucks. Source = US DOT (2019).
Occupant fatalities in large truck crashes	0.28	Person per 100 million miles traveled by trucks. Source = US DOT (2019).
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Ratio of occupant to non-occupant fatalities in truck crashes[a]	0.177	-
Ratio of occupant to non-occupant injuries in truck crashes[a]	0.269	-

Note:

(a) US DOT reports that 17.7% of people killed and 26.9% of people injured in crashes involving trucks are truck occupants (US DOT, 2019). Here, we assume that the same percentages apply to the number of crashes that lead to fatality and injury of truck occupants and non-truck occupants.

Key Inputs		
Bakken oilfield comingled waste after excavation (fluffed)	3,244	Cubic yards
Density of waste before excavation	2,970	Pounds per Cubic Yards
Fluff factor	1.25	
Density of excavated waste (fluffed)	2,376	Pounds per Cubic Yards
Weight of each load to be hauled to off-site permitted landfill	12	US-tons
1 US Ton	2,000	Pounds
Inputs Specific to the Excavate and Redispose Remediation Alternative		
Distance between the CWMNW landfill and the permitted landfill in Grandview Idaho	350	Miles

Mileage Estimates for Excavate and Redispose Remediation Alternative		
Number of loads to be hauled from CWMNW Landfill in Arlington, Oregon, to the permitted landfill in Grandview, Idaho	322	Truckloads
Total truck round-trip mileage for moving the Bakken oilfield waste between CWMNW Landfill in Arlington, Oregon, to the permitted landfill in Grandview, Idaho	225,400	Miles

Risk Estimation	Excavate and Redispose Remediation Alternative
Total truck mileage, two ways (miles)	225,400
Fatalities in truck crashes (persons)	3.61E-03
Occupant fatalities in truck crashes (persons)	6.37E-04
Persons injured in large truck crashes (persons)	1.12E-01
Fatal crashes (number of crashes)	3.20E-03
Injury crashes (number of crashes)	7.75E-02
Expected truck crashes with fatality to truck occupants	5.67E-04
Expected truck crashes with injury (non-fatal) to truck occupants	2.09E-02
Expected truck crashes with fatality to non-truck occupants	2.63E-03
Expected truck crashes with injury to non-truck occupants	5.67E-02

Inputs and assumptions

Parameter	Amount	Unit	Reference
Key Inputs			
Total Excavation volume (in-place)	586,282	yd^3	Estimated
Comingled Bakken oilfield waste (in-place)	2,595	yd^3	Estimated
Overburden Excavation (in-place)	583,687	yd^3	Estimated
Percentage of overburden not encapsulated	33.3%	--	Personal communication with Jim Denson, WM, June 29, 2020
Percentage of overburden encapsulated in macro boxes	33.3%	--	Personal communication with Jim Denson, WM, June 29, 2020
Percentage of overburden contained in drums	33.3%	--	Personal communication with Jim Denson, WM, June 29, 2020
Volume of macro box	106.67	yd^3	Personal communication with Jim Denson, WM, June 29, 2020
Volume of 55 gal Drum	0.2723	yd^3	Personal communication with Jim Denson, WM, June 29, 2020
Loader output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Excavator output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Grader output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Water truck output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Haul truck output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Working day hours	8	Hours	assumption
Additional work performed by a loader and an excavator for unpacking and re-packing macro boxes	2	hour/Macro Box	Personal communication with Jim Denson, WM, June 29, 2020
Work performed by a loader, an excavator, and a haul truck to load drums to roll-offs, unload them, and re-place in another portion of the landfill	200	drum/day	Professional judgment
Reduction factor for adjusting the loader and excavator output rate when working for excavation and loading Bakken oilfield waste	0.5	--	Professional judgment
Number of loads to be hauled from CWMNW Landfill in Arlington, Oregon, to the permitted landfill in Grandview, Idaho	322	Truckloads	Estimated: see off-Site safety sheet for calculations
Distance between the CWMNW landfill and the permitted landfill in Grandview Idaho (one way)	350	Miles	
Average daily one-way commute distance for workers	12	Miles	Distance between the Site to Arlington, Oregon
How many operation units (one loader, one excavator, one grader, one water truck, and one haul truck) work at the Site	4	--	Professional judgment
Number of Laborers in each operation unit (including equipment operators)	8	People	Professional judgment
Number of Site Supervisors daily present at the Site	1	People	Professional judgment
Number of Construction Project Managers daily present at the Site	1	People	Professional judgment
Number of Construction Technicians daily present at the Site	1	People	Professional judgment
Number of Field Engineers daily present at the Site	1	People	Professional judgment
Number of Project Engineers daily present at the Site	0.5	People	Professional judgment

Parameter	Amount	Unit	Reference
Calculations			
Volume of bulk overburden	194,562	yd^3	
Volume of overburden encapsulated in macro boxes	194,562	yd^3	
Volume of overburden contained in drums	194,562	yd^3	
Number of macro boxes	1,824	--	
Number of drums	714,515	--	
Time to complete operation	2,628	Work-days	
Number of personnel present at the site each work day	37	People	
Total miles driven by personnel to commute (round trip)	2,302,564	Miles	

Notes:

CWMNW = Chemical Waste Management of the Northwest.

SiteWise Input Parameters for Excavate and Redispose Remediation Alternative

Emission Source/Work Element		Unit	Quantity
Equipment			
Displace bulk overburden	Excavator	Hours	25,942
	Loader	Hours	25,942
	Grader	Hours	25,942
	Water Truck	Hours	25,942
	Haul Truck	Hours	25,942
Displace overburden encapsulated in macro boxes	Excavator	Hours	29,590
	Loader	Hours	29,590
	Grader	Hours	29,590
	Water Truck	Hours	29,590
	Haul Truck	Hours	29,590
Displace drums	Excavator	Hours	28,581
	Loader	Hours	28,581
	Haul Truck	Hours	28,581
Excavate Bakken oilfield waste and move to staging area	Excavator	Hours	346
	Loader	Hours	346
	Grader	Hours	346
	Water Truck	Hours	346
	Haul Truck	Hours	346
Waste Transportation			
Haul Bakken oilfield waste from the CWMNW Landfill in Arlington, Oregon, to the permitted landfill in Grandview, Idaho; total mileages for 332 roundtrips		Miles	225,400
Personnel Transportation			
Personnel commute between home and the site; total mileages calculated for roundtrips		Miles	2,302,564

Notes:

CWMNW = Chemical Waste Management of the Northwest;

Sustainable Remediation – Environmental Footprint Summary

Phase	Activities	GHG Emissions	Total Energy Used	On-Site NO_x Emissions	On-Site SO_x Emissions	On-Site PM_{10} Emissions	Total NO_x Emissions	Total SO_x Emissions	Total PM_{10} Emissions	Accident Risk Fatality from Personnel Transport	Accident Risk Injury from Personnel Transport
		Metric Ton	MMBTU	Metric Ton	Metric Ton	Metric Ton	Metric Ton	Metric Ton	Metric Ton	Person	Person
Remediation Alternative 1: Closure-in-Place	Materials	0.0	0.0	N/A	N/A	N/A	0.0	0.0	0.0	N/A	N/A
	Transportation - Personnel	0.0	0.0	N/A	N/A	N/A	0.0	0.0	0.0	0.000	0.000
	Transportation - Waste	0.0	0.0	N/A	N/A	N/A	0.0	0.0	0.0	0.000	0.000
	Equipment Use and Misc.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000
	Residual Handling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000
	Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000
Remediation Alternative 2: Excavate and Redispose	Consumables	0.0	0.0	N/A	N/A	N/A	0.0	0.0	0.0	N/A	N/A
	Transportation - Personnel	1,017.9	12,803.7	N/A	N/A	N/A	0.4	0.0	0.1	0.018	1.446
	Transportation - Equipment	345.4	4,508.0	N/A	N/A	N/A	0.1	0.0	0.0	0.002	0.142
	Equipment Use and Misc	9,525.9	152,661.8	62.5	14.6	5.9	69.4	18.2	6.9	0.021	5.228
	Residual Handling	48.2	876.6	0.0	0.0	0.0	0.3	0.1	0.8	0.000	0.000
	Total	10,937.5	170,850.1	62.5	14.6	5.9	70.2	18.4	7.8	0.041	6.815

Notes:

GHG = Greenhouse Gas; MMBTU = Million British Thermal Units; N/A = Not Applicable; NO_x = Nitrogen Oxides; PM_{10} = Particulate Matter Less Than 10 Microns in Diameter; SO_x = Sulfur Oxides.

Attachment F

Supporting Calculations: Cost Estimate Calculations

Table F.1 Remediation Alternative 1: Closure-in-Place

Item	Description	Qty	Units	Unit Rate	Item Cost	Total	Notes
Remedy Design						**$ 20,000**	
Remedy Implementation Capital Cost						**$ 500,000**	
1.0	**Remedy Implementation**						
1.1	Truck Portal Monitoring	1	LS	$ 500,000	$ 500,000		Quote from WM.
Annual Operation, Maintenance, and Monitoring Cost							
2.0	**Monitoring**						
2.1	Annual Monitoring & Reporting	30	LS/year		$ -		No incremental cost.
Future Cost						**$ -**	
3.0	**Radionuclide Monitoring**						
3.1	Groundwater Monitoring - Every five years during landfill operation starting 2021 and 30 year post-closure period	12	LS/5-year	$ 2,400	$ 28,800		Assumed 4 monitoring wells sampled every five years as long as the landfill is in operation (30 more years assumed based on available head space) and 30 year post-closure period; sampling, analysis, and reporting costs assumed $600 per sample (professional judgment).
3.2	Annual solid samples from flocked solids, spent filters, and carbon filter beds	30	LS/year	$ 3,600	$ 108,000		Assumed 6 solid samples collected annually during the 30 year operation period; sampling, analysis, and reporting costs assumed $600 per sample (professional judgment).
3.3	Landfill L-14 leachate	60	LS/year	$ 1,200	$ 72,000		Assumed 2 leachate samples collected annually during operation (30 more years assumed based on available head space) and 30 year post-closure period; sampling, analysis, and reporting costs assumed $600 per sample (professional judgment).
3.4	Combined Leachate Stream	60	LS/year	$ 1,200	$ 72,000		Assumed 2 samples collected annually, one from each of the two retention ponds, during operation (30 more years assumed based on available head space) and 30 year post-closure period; sampling, analysis, and reporting costs assumed $600 per sample (professional judgment).
Present Value Analysis		**Rate**	**Years**	**Cost**	**NPV**	**$ 85,105**	
4.0	**Monitoring**						
4.2	Radionuclide Monitoring - Annual	**7.0%**				**$ 85,105**	US EPA and US ACE (2000).
					Total	**$ 605,105**	Capital Cost + Net Present Value of O&M.

Notes:

LS = Lump Sum; NPV = Net Present Value; O&M = Operation and Maintenance; WM = Waste Management, Inc.

Table F.2 Remediation Alternative 2: Excavate and Redispose

Item	Description	Qty	Units	Unit Rate	Item Cost	Total	Notes
Remedy Design						$ 1,062,500	
1.0	**Remedy Design**					$ 850,000	
1.1	Truck Portal Monitoring	1	LS	$ 500,000	$ 500,000		Quote from WM.
1.2	Remedy Modeling, Engineering, and Design	1	LS	$ 350,000	$ 350,000		Professional judgment.
2.0	**Miscellaneous**					$ 212,500	
2.1	Contingency	1	%	25%	$ 212,500		Professional judgment.
Remedy Implementation Capital Cost						$ 209,695,166	
3.0	**Remedial Capital Cost**						
	Bakken Oilfield Waste and Overlaying Waste and Soil Excavation and Transport					$ 108,103,263	
3.1	Mobilization/Demobilization	1	LS	$ 500,000.00	$ 500,000		Professional judgment.
3.2	Excavate portion of overlying waste disposed as bulk waste, load to truck, dump in another portion of landfill	194,562	yd^3	$ 199.33	$ 38,782,758		One excavator, one loader, one grader, one water truck, and one haul truck perform this task at 60 yd^3/Day rate, collectively. Equipment unit costs are $195/hour excavator; $265/hour loader; $270/hour grader; $170/hour water truck; and $250/hour haul truck; 30% increase for upgrading Level C safety level to Level C plus supplied air. Equipment operator costs are included in the hourly unit costs.
3.3	Excavate portion of overlying waste packed in macro boxes; earthwork and hauling boxes to another portion of landfill	194,562	yd^3	$ 199.33	$ 38,782,758		Similar to Item 3.2; additional heavy equipment cost for unpacking and repacking macro boxes is accounted for in Item 3.4.
3.4	Unpacking and repacking macro boxes	1,824	Ea	$ 1,196.00	$ 2,181,530		Two hours additional work performed by a loader and an excavator for unpacking a macro box and repacking its content into a new one. Unit costs similar to Item 3.2.
3.5	Move portion of overlying waste contained in drums; load, move, and unload drums	714,515	Ea	$ 36.92	$ 26,379,880		One excavator, one loader, and one haul truck perform this task at 200 drum/Day rate, collectively. Equipment unit costs are similar to Item 3.2.
3.6	Excavate Bakken oilfield waste and move to staging area	2,595	yd^3	$ 299.00	$ 775,905		Excavation unit cost per volume increased 50% for locating filter socks and separating comingled Bakken oilfield waste from unimpeached waste.
3.7	Transportation of Bakken oilfield and comingled waste to off-site disposal site	112,700	Mi	$ 6.22	$ 700,431		Total miles hauled was estimated for 322 loads transported from Arlington, Oregon, to Grandview, Idaho (350 miles per load). The unit cost is from R.S. Means Co. (2019) Cost Data Book: Transportation of hazardous waste to disposal site; truck loads equal to 80 drums or 18 tons minimum $4.45/mile and maximum $7.98/mile.
4.0	**Disposal Cost in a Commercial TENORM-permitted Landfill**					$ 1,175,470	
4.1	Bakken oilfield and comingled waste	3,854	Ton	$ 305	$ 1,175,470		R.S. Means Co. (2019) Cost Data Book for Hazardous waste disposal charge minimum $155/ton and maximum $455/ton; waste quantity is equal in waste to Item 3.4 quantity multiplied by 1.25 fluff factor.
5.0	**Post-closure Activities**					$ 150,000	
5.1	Post-closure Reporting	1	LS	$ 150,000	$ 150,000		R.S. Means Co. (2019) Cost Data Book for Hazardous waste disposal charge minimum $155/ton and maximum $455/ton; waste quantity is equal in waste to Item 3.4 quantity multiplied by 1.25 fluff factor.
6.0	**Miscellaneous**					$ 100,266,433	
6.1	Health and Safety	0	%	0%	$ -		Decreased productivity due to protective equipment applied in unit costs above.
6.2	Air monitoring	1	LS	$100,000	$ 100,000		Professional judgment.
6.3	Permitting	1	%	5%	$ 5,471,437		Professional judgment.
6.4	Agency Oversight	1	%	10%	$ 10,942,873		Professional judgment.
6.5	Contingency	1	%	50%	$ 62,971,521		US EPA and US ACE (2000).
6.6	Project Management	1	%	5%	$ 9,445,728		US EPA and US ACE (2000), for work elements >$2M.
6.7	Construction Management	1	%	6%	$ 11,334,874		US EPA and US ACE (2000), for work elements >$2M.
Future Cost						$ -	
8.0	**Final Cover Maintenance**	30	Years	$ -	$ -	$ -	No incremental cost.
9.0	**Post Closure Monitoring Plans**	1	LS/year	$ -	$ -	$ -	No incremental cost.
Present Value Analysis		**Rate**	**Years**	**Cost**	**NPV**	$ -	
10.0	**Final Cover Maintenance**	7.0%	30	$ -	$ -	$ -	No incremental cost.
11.0	**Post Closure Monitoring Plans**	7.0%				$ -	No incremental cost.
					Total	$ 210,757,666	Capital Cost + Future Cost.
					Total	$ 210,757,666	Capital Cost + Net Present Value of O&M.

Notes:

Ea = Each; LS = Lump Sum; Mi = Miles; NPV = Net Present Value; O&M = Operations and Maintenance; TENORM = Technologically Enhanced Naturally Occurring Radioactive Material; WM = Waste Management, Inc.

Table F.3 Summary of Remediation Alternative Costs

Remediation Alternative		Capital Cost	Future O&M Cost (7% NPV)	Total (Capital + Future Cost)
1	Closure-in-Place	$520,000	$85,105	$605,105
2	Excavate and Redispose	$210,757,666	$0	$210,757,666

Notes:

NPV = Net Present Value; O&M = Operations and Maintenance.

Cost Estimate Supporting Documents

Inputs and Assumptions

Parameter	Amount	Unit	Reference
Key Inputs			
Total excavation volume (in-place)	586,282	yd^3	Estimated
Comingled Bakken oilfield waste (in-place)	2,595	yd^3	Estimated
Overburden excavation (in-place)	583,687	yd^3	Estimated
Fluff factor	1.25	--	Assumption
Percentage of overburden unencapsulated	33.3%	--	Personal communication with Jim Denson, WM, June 29, 2020
Percentage of overburden encapsulated in Macro boxes	33.3%	--	Personal communication with Jim Denson, WM, June 29, 2020
Percentage of overburden contained in drums	33.3%	--	Personal communication with Jim Denson, WM, June 29, 2020
Volume of Macro box	106.67	yd^3	Personal communication with Jim Denson, WM, June 29, 2020
Volume of 55 gallon drum	0.2723	yd^3	Personal communication with Jim Denson, WM, June 29, 2020
Loader output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Excavator output rate for excavating and re-placing waste (Safety Level C)	60	yd^3/day	Personal communication with Jim Denson, WM, June 29, 2020
Working day	8	hours	Assumption
Loader operation cost, including operator	265	$/hour	Contractor quote June 2020
Excavator operation cost, including operator	195	$/hour	Contractor quote June 2020
Water truck	170	$/hour	Contractor quote June 2020
60T haul truck, 8 hours per day, 40 hours per week during removal and replacement	250	$/hour	Contractor quote June 2020
Grader, 8 hours per day, 40 hours per week during removal and replacement	270	$/hour	Contractor quote June 2020
Cost factor for modifying safety level for supplying air	1.3	--	Personal communication with Jim Denson, WM, June 29, 2020
Additional work performed by a loader and an excavator for unpacking and re-packing Macro boxes	2	hour/Macro box	Personal communication with Jim Denson, WM, June 29, 2020
Work performed by a loader and an excavator to load drums to roll-offs, unload them, and re-place in another portion of the landfill	200	drum/day	Professional judgment
Number of laborers working at the Site along with operators	4	People	Professional judgment
Calculations			
Volume of bulk overburden	194,562	yd^3	
Volume of overburden encapsulated in Macro boxes	194,562	yd^3	
Volume of overburden contained in drums	194,562	yd^3	
Number of Macro boxes	1,824	--	
Number of drums	714,515	--	
Loader operation cost	45.93	$/$yd^3$	
Excavator operation cost	33.80	$/$yd^3$	
Water truck operation cost	29.47	$/$yd^3$	
Grader operation cost	46.80	$/$yd^3$	
Haul truck operation cost	43.33	$/$yd^3$	
Additional $ for loader and excavator for unpacking and re-packing Macro boxes	1,196	$/Macro box	
Drum relocation cost	36.92	$/drum	

Site-specific Labor and Equipment Unit Costs Provided by Waste Management

June 12, 2020

Additional 24-Hour Hazwopper Training & Escape Respirators

Train 15 Employees to 24 -hour Hazwopper

Labor	Quantity	Unit	Cost	Total
Operator -14 Each	336	HR	$85.00	$28,560.00
Superintendent	24	HR	$115.00	$2,760.00
Trainer	30	HR	$115.00	$3,450.00
			Subtotal	$34,770.00

Training Materials				
Trainer Materials	1	LS	$600.00	$600.00
Student Materials	14	EA	$48.00	$672.00
Training Facility	1	LS	$1,100.00	$1,100.00
			Subtotal	$2,372.00

Chemical Waste Management of the Northwest
Arlington Landfill L-13 Closure

EQUIPMENT	UNIT	RATE
200 Excavator	Hour	$110.00
312 Excavator	Hour	$85.00
40 Ton Haul Truck	Hour	$165.00
60 Ton Haul Truck	Hour	$200.00
4,000 Gal. Water Truck	Hour	$85.00
CAT 980 Loader	Hour	$180.00
CAT Skid Steer	Hour	$45.00
Vibratory Compactor	Hour	$100.00
Fuel/Lube Truck	Hour	$65.00
D6T with GPS	Hour	$175.00
All-Terrain Forklift	Hour	$60.00
Screen Plant	Hour	$210.00
16 Grader	Hour	$185.00
100 Ton Haul Truck	Hour	$250.00
50 Ton Haul Truck	Hour	$190.00

Attachment G

Radiological Monitoring Plan

RADIOLOGICAL MONITORING PLAN

CHEMICAL WASTE MANAGEMENT, INC.
ARLINGTON, OREGON

PF-CWM-RMP

Rev. 0

August 2020

Prepared for:
Chemical Waste Management
17629 Cedar Springs Lane
Arlington, OR 97812

Prepared by:
Perma-Fix Environmental Services
315 9th Street, Second Floor
New Brighton, PA 15066

Radiological Monitoring Plan for Chemical Waste Management, Inc. of the Northwest, Arlington, Oregon

RMP APPROVALS

By their specific signature, the undersigned certify that they prepared, reviewed, or provided comments on this Radiological Monitoring Plan (RMP) for Chemical Waste Management, Inc. of the Northwest, Arlington, Oregon.

PREPARED BY:

__________________________________ ________________
Jason Hubler — Date
Radiological Engineer, Perma-Fix

REVIEWED BY:

__________________________________ ________________
Alejandro Lopez — Date
Certified Health Physicist, Perma-Fix

APPROVED BY:

__________________________________ ________________
Robert Mulholland — Date
District Manager, Chemical Waste Management

REVISION LOG

Item	Section	Revision
Initial Issue	N/A	0

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

$BaSO_4$	Barium Sulfate
$CaSO_4$	Calcium Sulfate
CHP	Certified Health Physicist
CWMNW	Chemical Waste Management of the Northwest
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
g	gram
HP	Health Physicist
HPGe	high purity germanium
hr	hour
K	potassium
MCA	Multi-Channel Analyzer
μR	microRoentgen
mR	milliRoentgen
mph	miles per hour
NIST	National Institute of Standards and Technology
NORM	Naturally Occurring Radioactive Material
OAR	Oregon Administrative Rule
PCB	polychlorinated biphenyl
pCi	picocurie
QAP	Quality Assurance Program
RCRA	Resource Conservation and Recovery Act
RMP	Radiological Monitoring Plan
RSO	Radiation Safety Officer
SOP	Standard Operating Procedure
TENORM	Technologically Enhanced Naturally Occurring Material
Th	thorium
TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
U	uranium
WM	Waste Management

PREFACE

Chemical Waste Management of the Northwest (CWMNW Arlington) provides area communities, businesses and industries with professional, safe, and efficient industrial and hazardous waste services. Located in Arlington, Oregon, CWMNW Arlington provides cost-effective services to customers across the United States. CWMNW Arlington also offers services worldwide through Waste Management's (WM) extensive rail transportation network.

The CWMNW Arlington facility is positioned on a 1,288 acre site, with 320 acres permitted for disposal operations. The site is buffered by over 11,000 acres of undeveloped property owned by WM. The disposal cells are designed to meet stringent U.S. Environmental Protection Agency (EPA) and state guidelines. The disposal cells are monitored by a sophisticated leachate collection system, groundwater monitoring network, and leak detection systems.

The CWMNW Arlington facility accepts Resource Conservation and Recovery Act (RCRA) industrial hazardous and non-hazardous waste. Many of the waste streams are treated by a variety of methods, including stabilization, macroencapsulation, microencapsulation, polychlorinated biphenyl (PCB) disposal, and thermal desorption-organic recovery.

This plan sets forth the operational approach for radiation monitoring of incoming waste and the evaluation of loads exceeding the 2X background threshold. Additionally, methods are provided for response to alarm conditions to determine if the load meets the rules set forth by the Oregon Department of Energy Chapter 345 Radioactive Waste Materials. The plan is designed to meet the requirements of Oregon Administrative Rule (OAR) 340-93 through OAR 340-97 and addresses specific compliance with OAR 345-050-0036, which are the Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) regulations.

1.0 SITE DESCRIPTION, PURPOSE, AND SCOPE OF ACTION PLAN

Site Name:	Chemical Waste Management, Inc. Arlington
Site Address:	17629 Cedar Springs Lane, Arlington, OR 97812
Site Contact:	Jim Denson
Owner Contact:	jdenson@wm.com
Facility type:	RCRA TSDF
Purpose:	The facility receives a variety of industrial wastes for treatment, storage, and land disposal.
Code:	OAR 345-050-0035
Part B Permit:	ORD 089452353

Chemical Waste Management of the Northwest (CWMNW) receives potentially radioactive materials that originate from natural formations in the earth's crust. These naturally occurring radioactive material (NORM) may be concentrated in waste residues that are generated. The NORM radionuclides are those of the uranium (U)-238, thorium (Th)-232, and U-235 decay chains. Various progeny within the NORM decay chains, including radium, may be prevalent depending on each waste materials' origin and generation. Potassium (K)-40 also may also be present and is ubiquitous in most soils at concentrations typically higher than uranium or radium isotopes. Radium and its daughter products can mobilize due to their higher solubility, and precipitate with dissolved mineral salts such as barium sulfate ($BaSO_4$) and calcium sulfate ($CaSO_4$). In their natural undisturbed state, these materials are of little concern. The liquid and solid wastes generated from select industrial, drilling, and mining processes typically contain various levels of NORM. Because these wastes have been processed or manufactured and NORM radionuclides have been concentrated in them, they meet the definition of technologically enhanced naturally occurring material (TENORM).

1.1 Scope of Plan

This Radiological Monitoring Plan (RMP, or Plan) has been developed to meet the rules set forth by the Oregon Department of Energy Chapter 345 Radioactive Waste Materials. The Plan will meet the requirements of Oregon Administrative Rule (OAR) 340-93 through OAR 340-97 as well as address specific compliance with OAR 345-050-0036, which are the TENORM regulations. The elements of this plan include:

- Overview of Site Operations.
    - Waste Profile Process
- Waste Receipt Process:
    - Radiological monitoring methods,
    - Radiological instrumentation,
    - Action Levels, and
    - Action Level responses.

2.0 OVERVIEW OF SITE OPERATIONS

CWMNW Arlington is a treatment and disposal facility for both hazardous and non-hazardous industrial wastes. CWMNW Arlington is currently permitted to accept the universe of Resource Conservation and Recovery Act (RCRA) and Toxic Substances Control Act (TSCA) waste.

2.1 Waste Profile Process

Prior to transporting waste to CWMNW Arlington, a waste profile will be completed by the generator and submitted to CWMNW for review and approval. Waste profiling for "qualifying waste" streams will require the material to be radiologically characterized by providing an analytical gamma spectroscopy result that is representative of the entire waste stream. The gamma spectroscopy result will be provided in units of picocuries per gram (pCi/g). At a minimum, the gamma spectroscopy report will include naturally occurring gamma emitters and other potential gamma emitting isotopes that the generator may believe is potentially present due to process knowledge.

Once the waste profile is approved, each incoming waste load is documented using the facility's point of sale and other specific tracking systems. Approved incoming waste will be monitored upon arrival at the CWMN radiation portal monitor, prior to waste disposal (Section 3.0).

2.1.1 Waste Sources/Types

CWMNW Arlington accepts a wide range of hazardous and non-hazardous industrial wastes for treatment and disposal. Waste material arrives from locations throughout North America and the world. During waste profiling activities, wastes identified by CWMNW and DOE as "qualifying wastes" require gamma spectroscopy analysis for isotopic review. "Qualifying wastes" are generated from the following industry sectors;

- Uranium mining,
- Phosphate wastes,
- Coal wastes,
- Petroleum refining wastes,
- Oil and gas exploration and production wastes,
- Drinking water treatment wastes,
- Mineral mining wastes,
- Metals processing wastes, and
- Geothermal wastes.

Many waste streams associated with these industries include NORM and/or TENORM. CWMNW does not accept radioactive wastes for disposal defined as special nuclear material, source material, byproduct material, or licensed material.

2.1.2 NORM/TENORM Waste

There are three naturally occurring decay series. The three series include the uranium series, thorium series, and actinium series. Isotopes of uranium, radium, and thorium occur in all three natural decay series. Each of the three series also produces a radon gas isotope as one of its progeny. **Appendix A** includes a diagram of the natural decay series. In the natural environment, the radionuclides in the three natural decay series are typically in a state that is approaching or has achieved secular equilibrium, in which the activities of all radionuclides within each series are nearly equal. Incoming waste material may contain NORM with decay series in secular equilibrium, or may contain NORM radionuclides in a state of disequilibrium. Based on the waste origin, analytical data may be required to accurately determine the nuclide composition.

3.0 WASTE RECEIPT PROCESS

Daily scheduling of waste shipments is recommended for incoming waste. The scheduled "qualifying wastes" (described in Section 2.1) are reviewed to ensure the initial waste profile process was properly followed and that the qualifying waste was profiled to include the required gamma spectroscopy analysis. Subsequent profile recertifications also require updated gamma spectroscopy analysis results. Once CWMNW approves the waste for disposal through the profile process, the waste load typically arrives at CWMNW Arlington via truck and rail. Rail shipments will be offloaded to an on-site transport vehicle and driven over private roads into the facility through a single entry point where screening of each load will be completed by radiation detectors. It is the intent of CWMNW Arlington that all wastes will be radiologically screened against pre-defined Action Levels as they enter the gate with a portal monitoring system (Primary on-site screening), prior to further acceptance activities at the facility.

If the Primary screening exceeds an Action Level, a secondary handheld isotope identification instrument will be used in conjunction with the primary portal monitor to perform additional screening on waste material. Waste sampling and analysis may be performed to further characterize or confirm the material composition. A combination of modeling and confirmatory gamma spectroscopy may be employed to develop correlations agreed upon for portal monitoring measurements and developing Oregon pathway exemptions for discrepant wastes.

This section describes the radiological instrumentation, Action Levels, and Action Level responses.

3.1 Radiological Instrumentation

There are many possible radiation instruments and monitoring systems that can be used to meet the applicable regulatory requirements. Instrumentation has been selected to meet those requirements and to be suitable for the anticipated volume of waste received at the facility. Onsite radiation monitoring will be performed using a combination of primary fixed detectors and if required secondary portable handheld detectors. The primary fixed portal monitoring equipment will be located near the main entrance in order to evaluate loads arriving by truck, or after it has been transferred to a truck from rail. The proposed location of the primary portal monitor is shown in **Figure 1** and a photograph of the proposed location is shown as **Figure 2**.

Figure 1. Proposed Truck Portal Monitor Location, Schematic

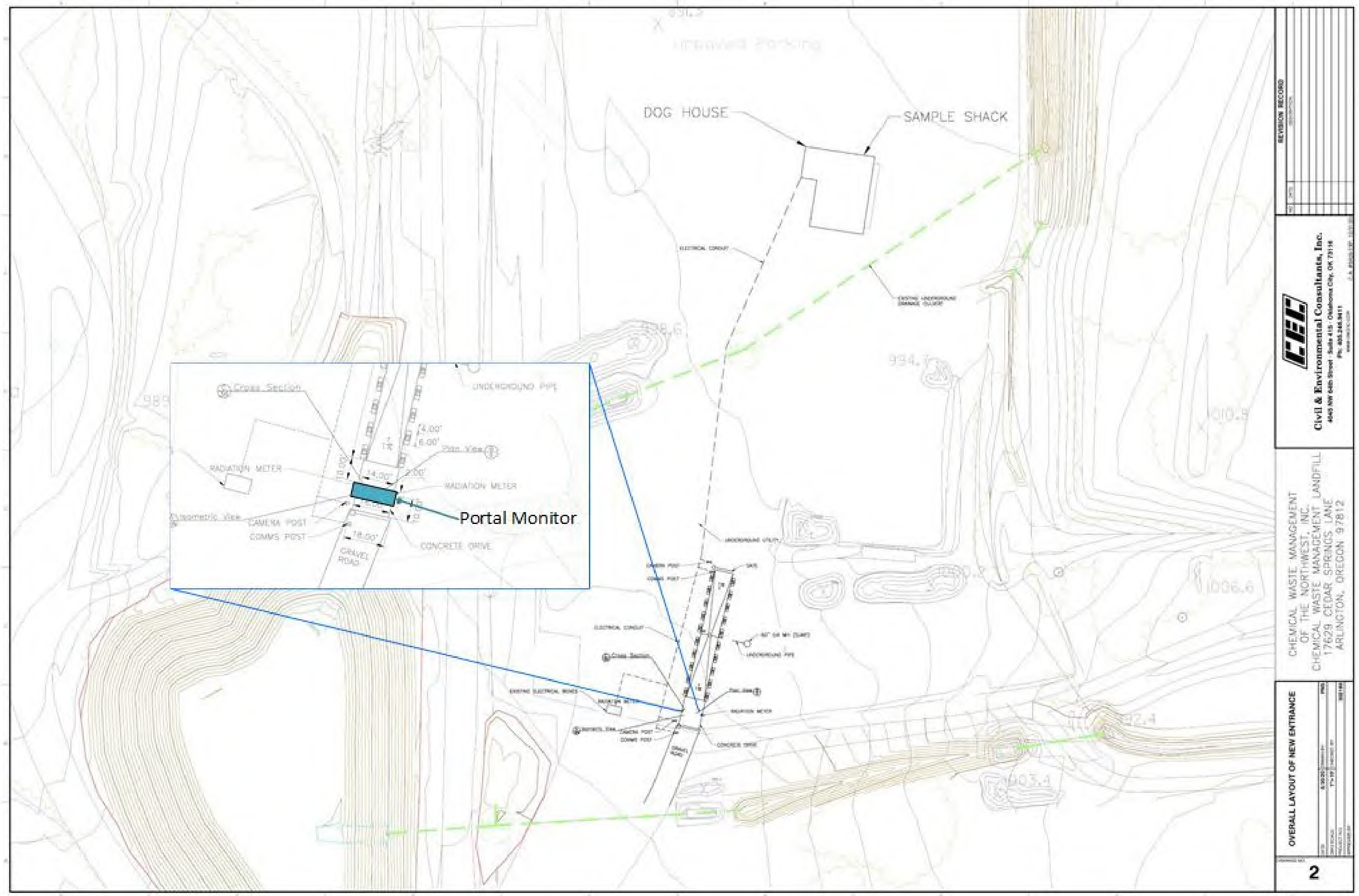


Figure 2. Proposed Truck Portal Monitor Location, Photograph

3.1.1 Primary Portal Monitor

A Ludlum Model 4525-7000 truck portal monitor system will be installed and operated as the primary instrument to monitor the radiation levels of incoming trucks. Incoming trucks will pass through the monitors during entry into the facility. The portal monitor system includes two large volume plastic scintillation detectors with a combined detector volume of 115 liters. The detectors are operated and monitored with a computer workstation. The computer will process and record the detector measurements and provide feedback when one of the Action Levels (described in Section 3.4) are encountered. The unit continuously takes background measurements and updates the system alarm accordingly. **Figure 3** is a photograph of a typical Model 4525-7000 truck portal monitor system.

The Ludlum Model 4525-7000 truck portal monitor system includes:

- Two large volume gamma scintillation detectors with weatherproof protection;
- Real-time data logging, reporting, and alarm notification;
- Audible and/or visual alarm function;
- Alarms for radiation, overspeed, sensor failure, instrument failure, and low battery;

- 8-hour battery backup; and
- Real-time background adjustment.

Figure 3. Ludlum 4525-7000 Truck Portal Monitor

3.1.2 Portable Radiological Survey Instrumentation

CWMNW Arlington will have a handheld portable radiation instrument onsite capable of radioisotope identification. The instrument will also serve as a secondary and backup portable dose or exposure rate instrument, and at a minimum will include:

- Multi-Channel Analyzer (MCA) spectrometer,
- Capability to detect exposure rates from < 10 microRoentgens per hour (μR/hr) to 100 + milliRoentgens per hour (mR/hr), and
- Radionuclide identification based on energy spectral analysis using an internal software library that includes the NORM isotopes discussed above.

The portable MCA will provide the following functions:

- Scanning of trucks or trains and/or samples of the waste contents of wastes exceeding an action limit to obtain an accurate, energy-independent indication of dose rate in μR/hr;
- Performing area radiation measurements; and
- Radionuclide characterization.

In the event that the primary truck portal monitor is not functional, waste material will be hand surveyed using the handheld survey instrument, capable of detecting radiation levels at the prescribed Action Levels defined below. Vehicles will not be received for disposal if the truck portal monitor is not functioning and the handheld detector is not available.

3.1.3 Use and Maintenance

- Both the portable and fixed radiological instrumentation will be calibrated to a National Institute of Standards and Technology (NIST) traceable source by the manufacturer or a licensed commercial calibration facility.
- Instruments will have a documented daily response check prior to its first use each day. This will include a documented response to a dedicated exempt-quantity radioactive check source. The battery condition and voltage will also be verified during this response check.
- An example of the truck portal monitor daily check form is provided as **Appendix B**.
- The handheld radiation detector setup and daily response check standard operating procedure (SOP) is provided as **Appendix C**.
- CWMNW may perform gamma spectroscopy analysis onsite using a High Purity Germanium (HPGe) detector system or utilizing an offsite analytical laboratory. The onsite HPGe system will be maintained according to the Quality Assurance Program (QAP), provided under separate cover.
- Radioactive check sources will remain in a locked or secure place accessible to only trained CWMNW staff.
- Background levels will be established and documented prior to measurements.
- Employees operating and maintaining radiological instrumentation will be trained in their proper use and maintenance.

3.2 Gamma Spectroscopy Unit

CWMNW may elect to self-perform onsite gamma spectroscopy analyses on waste material samples. The onsite gamma spectroscopy system will consist of an HPGe detector equipped with MCA controlled by laboratory software capable of identifying and quantifying gamma emitting nuclides. Procedures and count times will be developed to facilitate decisions with pathway exemption status. The setup, calibration, and operation of the HPGe detector system will be addressed under separate cover with detailed SOPs and the QAP. Samples will be analyzed at an offsite analytical laboratory if an onsite system is not in operation.

3.3 Truck Survey Procedure

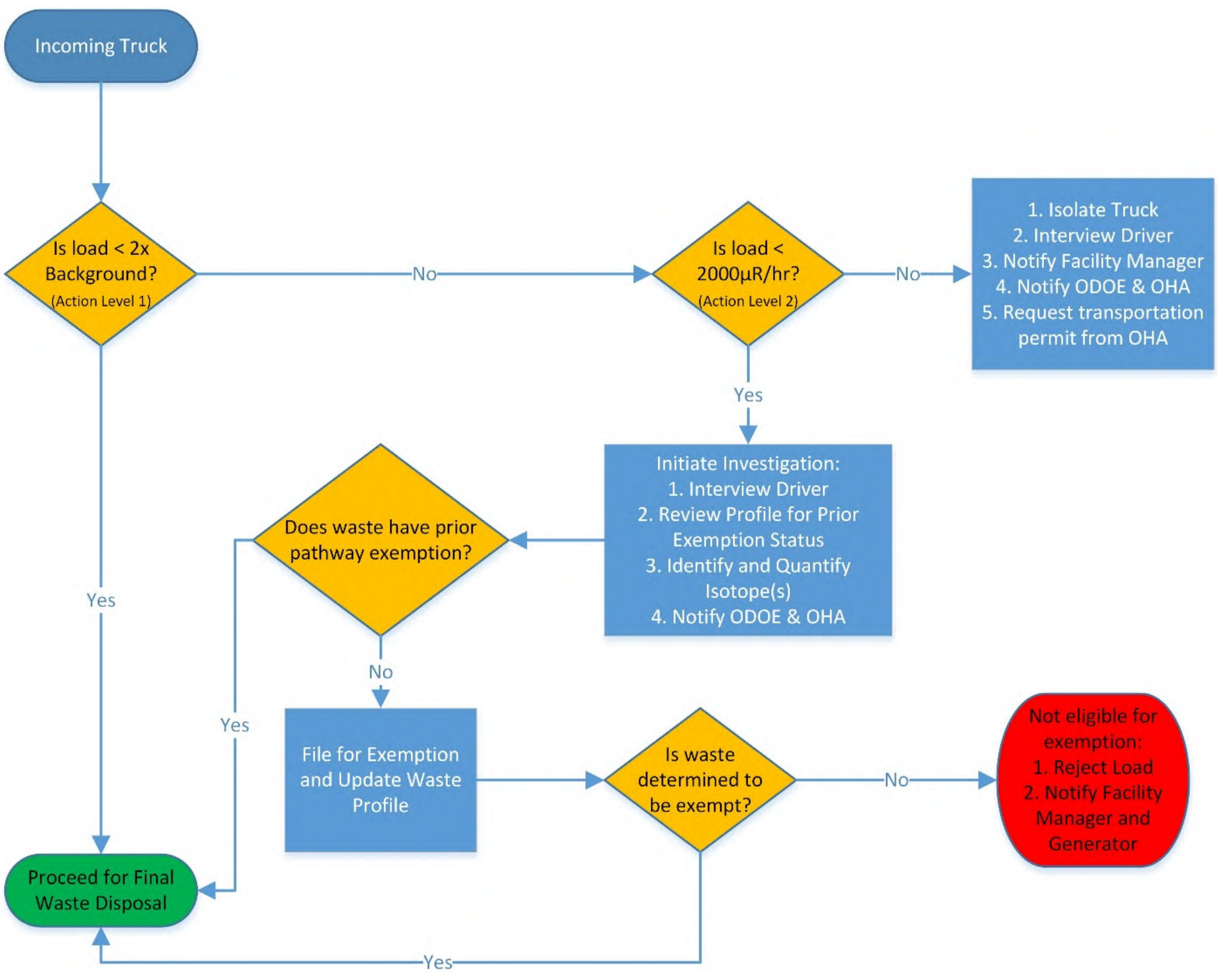
Incoming waste material will be required to pass through the primary truck portal monitoring system prior entering the facility. The truck monitor will have two Action Levels programmed into the software such that if a measurement is equal to or above an Action Level, the system will generate an alarm.

The truck will approach the portal monitor at a maximum speed of 5 miles per hour (mph). With the truck centered between the portal monitor sides, the truck will pass through the portal with a maximum speed of 5 mph. The system will process the measured radiation levels of the load against the predetermined Action Levels and signal whether an alarm has been triggered or if the load is acceptable for entry into the facility. The system will automatically log the measurement results along with a record of the alarm, if triggered. If no alarm is triggered, the material is acceptable for entry without additional radiological screening.

3.4 Action Levels and Responses

This RMP has two defined Action Levels, described in the following subsections. A flow chart illustrating the incoming waste process and requirements for Action Level exceedances is shown as **Figure 3**.

Figure 3. Action Level Response Flowchart



3.4.1 Action Level 1

The exposure rate threshold for Action Level 1 is two times (2x) the ambient background for monitoring of material in a waste load. Indication of the exceedance will be made by the truck portal monitor with an audible or visual response within the receiving department. Trucks that pass through the detector without a measurement greater than 2x ambient background will be allowed to proceed to the proper area for final non radiological characterization.

3.4.2 Action Level 1 Response

If an exposure rate above 2x background is identified in a waste load, the following actions are required to determine whether the waste is acceptable for disposal or if the waste is discrepant (**Section 3.5**):

- The truck will turn around to exit the screening lane and return for a second pass through the portal monitor (maximum speed of 5 mph). If the response is less than 2x background, the truck will be allowed to enter the facility. If the second pass results in a measurement greater than 2x background, move the truck to the staging area for additional processing.
- Evaluate whether the driver has recently had a stress test or other nuclear medicine test or procedure in which radioactive material was ingested, injected, or otherwise taken into the body by the driver.
  - If it is determined the driver is the source of the alarm, the truck will return for a third pass though the portal monitor with an alternate driver to confirm the portal monitor response is less than 2x background.
  - If it is determined the driver is not the source of the alarm, continue the alarm investigation described below.
- Conduct a review of the waste manifest and approved profile to determine if the profile has an approved exemption.
- If it has an exemption, perform a radiological survey as described in **Appendix D** using the portable isotope identifier instrument to identify the radionuclides present, convert dose to isotope concentration (for those identified) based on isotope-specific conversion factor (μR/hr to pCi/g), and compare to the isotope exemption level.
  - If concentration is below exemption level (or within acceptable range), the load can be disposed.
  - If the concentration is above the exemption level or above acceptable range, or if the radionuclides identified by the portable isotopic identifier to not match the waste form (or are not considered NORM isotopes), the waste is considered discrepant and additional actions are required as described in **Section 3.5**. If necessary, a physical sample may be collected for analysis via gamma spectroscopy.
- If it does not have an exemption, the waste is classified as discrepant waste (**Section 3.5**). Conduct a radiological survey as described in **Appendix D** using the portable isotope identifier instrument to identify the radionuclides present. If necessary, a physical sample may be collected for analysis via gamma spectroscopy.
- Notify the State of Oregon Department of Energy (DOE and Oregon Health Authority (OHA).

If the sample results are inconsistent with the waste manifest or profile either in radioactivity concentration or radionuclides identified, the waste is considered discrepant and proceed to **Section 3.6**.

3.4.3 Action Level 2

The exposure rate threshold for Action Level 2 is 2,000 μR/hr (2 milli-Roentgen per hour) above the ambient background for monitoring of material in a waste load. This Action Level is consistent with DOT regulation requiring exposure rates no greater than 2 mrem/hr (2,000 μR/hr) in the cab of a vehicle.

3.4.4 Action Level 2 Response

If an exposure rate above 2,000 μR/hr is identified in a waste load, the following actions are required:

- Immediately notify the facility emergency coordinator.
- Move the truck to a pre-designated secure holding area for vehicle isolation.
- Evaluate whether the driver has recently had a stress test or other nuclear medicine test or procedure and advise the driver to move away from the truck.
- Notify the Oregon DOE and OHA.
- No additional action will be performed without the specific instruction and permits to do so by the State DOE and/or OHA.

3.5 Waste Discrepancy

WM defines a radiological waste as being discrepant if:

- There is an inconsistency between the isotopes listed in the material's waste profile and the isotopes of the material of a load received at the facility. The inconsistency is defined as either:
  - Measured concentrations of NORM isotopes of the received load at levels triggering the portal alarm and higher than those pre-approved in the waste profile, or
  - Isotopes identified are not considered NORM radionuclides (i.e. medical or licensed material)

If a discrepancy between the waste received at the facility and its waste profile is identified, CWMNW will perform the following actions:

- Notify the generator and request process knowledge to assist in the resolution of the discrepancy(s).
- Discuss the discrepancy and identify the appropriate course of action to resolve the container/shipment in question, such as;
  - Re-profiling the discrepant waste for re-approval by ODOE,
  - Submitting a pathway exemption for the waste through ODOE,
  - Storage and shipment to another disposal facility, or
  - Rejection

Discrepant material will be evaluated to determine whether the material can ultimately be acceptable for disposal at the facility based on information including but not limited to discussions with or information from the generator, ODOE and OHA; facility conditions for storage, treatment, and disposal; CWMNW management's judgement; and laboratory analyses.

3.6 Waste Rejection

It is the intent of CWMNW to minimize the unnecessary movement of a waste material between CWMNW and the generator to reduce the potential exposure to human health and the environment. However, if it is determined that the waste cannot be disposed of at CWMNW and the material is rejected, the following process will be followed:

- Stage the waste in a pre-designated area, pending acceptance by an authorized transporter
- Notify the generator and provide analytical results to the generator for determination whether waste material is compliant with applicable U.S. Department of Transportation (DOT) regulations
- Notify OHA of the rejected load
- Obtain the required permits for public road transportation

4.0 RECORDS AND REPORTS

Facility Records:

- Third Party Physicist audit reports; maintained in the operating record
- Training materials, attendance sheets, verification of competency; maintained in the operating record
- Spill/leak occurrences, or any emergency response action, on an Incident Report Form maintained in the operating record as part of the facility emergency response plan
- Other records as requested by Oregon DOE and/or OHA

These records are retained either in hard copy or electronically in the facility operating record for a period of 5 years.

Data Management:

- ***Radiation Screening and Equipment Calibration Records***:
  - Records of alarms; maintained in the portal unit computer.
  - Records of Daily background and calibration, maintained in the portal unit computer and hardcopy logs
  - Instrument calibrations and certifications; maintained in the operating record
- ***Load Tickets;***
  - **WM FastLane^{tm} Scale Tickets**; Records pertaining to each incoming load brought to the facility are managed in the WM FastLane^{tm} proprietary point of sale scale house load ticket system these include;
    - Weight (or volume) of waste received;
    - Approved Profile Number
    - Generator ID (name, address, county, state);
    - Name of transporter;
    - Disposal facility name and address;
- ***Records pertaining to the following are kept separately in WM and other proprietary computer systems***
    - Profile and Approval Records
    - Record of each rejected load and the reason for rejecting the load; maintained in the operating record
    - Record of all incidents, to include the date, time, location, a brief narrative, and a description of the incident and its final disposition maintained in the operating record
    - Load Manifests are housed in the EPA Electronic Manifest System and maintained in the operating record

4.1 Plan Revision

This Plan will be reviewed at least annually by the Technical Manager and/or District Manager, and the Health Physicist (HP) Consultant to ensure its accuracy and applicability. The Plan will be revised following any significant applicable change in operations, or if there is a change in regulations that affects operations and the Plan content. If radiation levels or radionuclide characterization result in unexpected or unplanned findings, the Plan may be revised to increase or decrease the established radiological controls and practices and submitted to the State of Oregon for approval before implementation. The revised Plan will be submitted to the Oregon, Department of Energy and Oregon Health Authority. The revised Plan will be submitted to the State of Oregon, Bureau of Land Recycling and Waste Management.

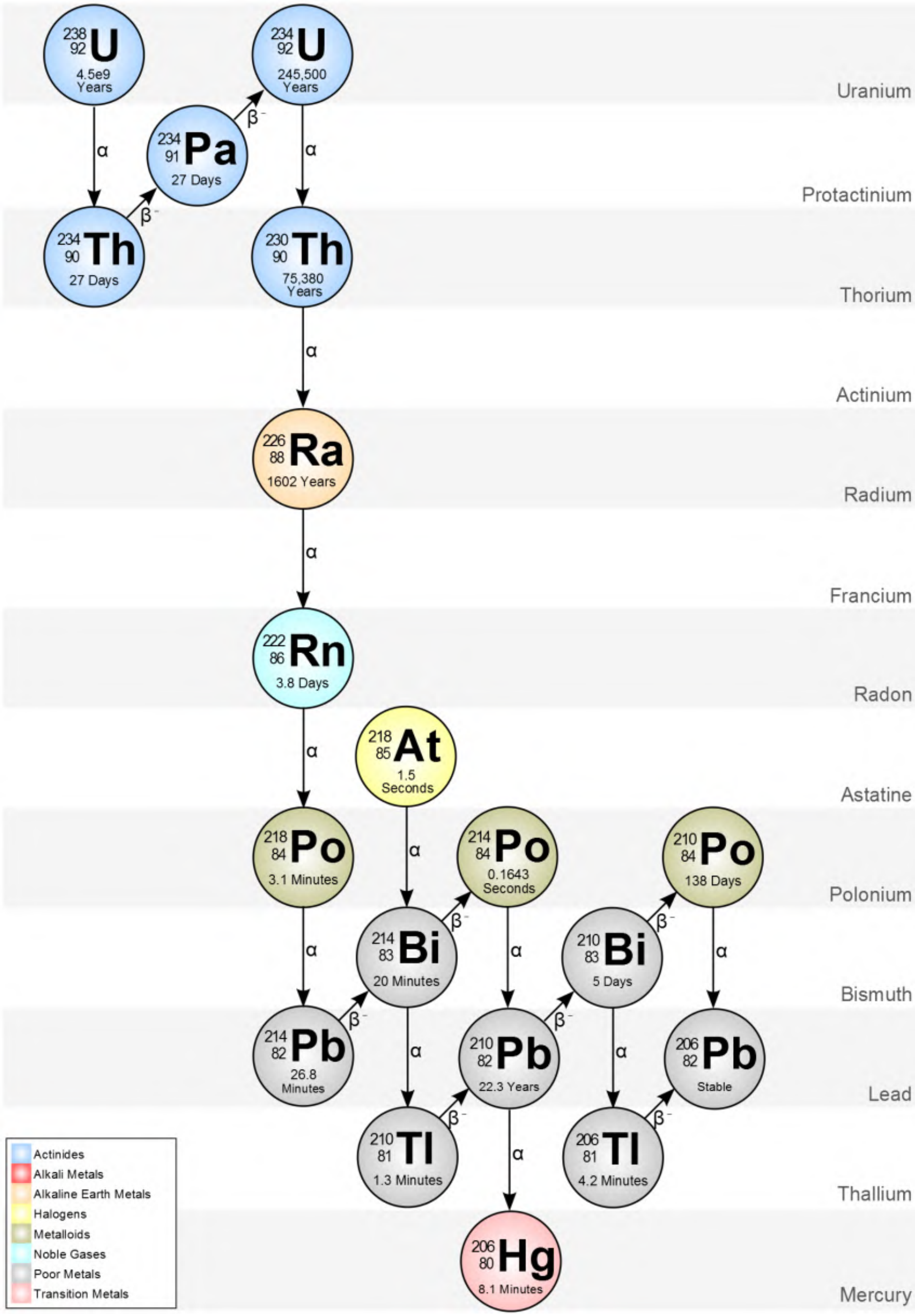
5.0 CREDENTIALS OF PERSON PREPARING/REVIEWING THIS PLAN

- Jason Hubler, Radiological Engineer
- Alejandro Lopez, Certified Health Physicist (CHP), American Board of Health Physics

Curriculum Vitae and Credentials Packet: Available upon request.

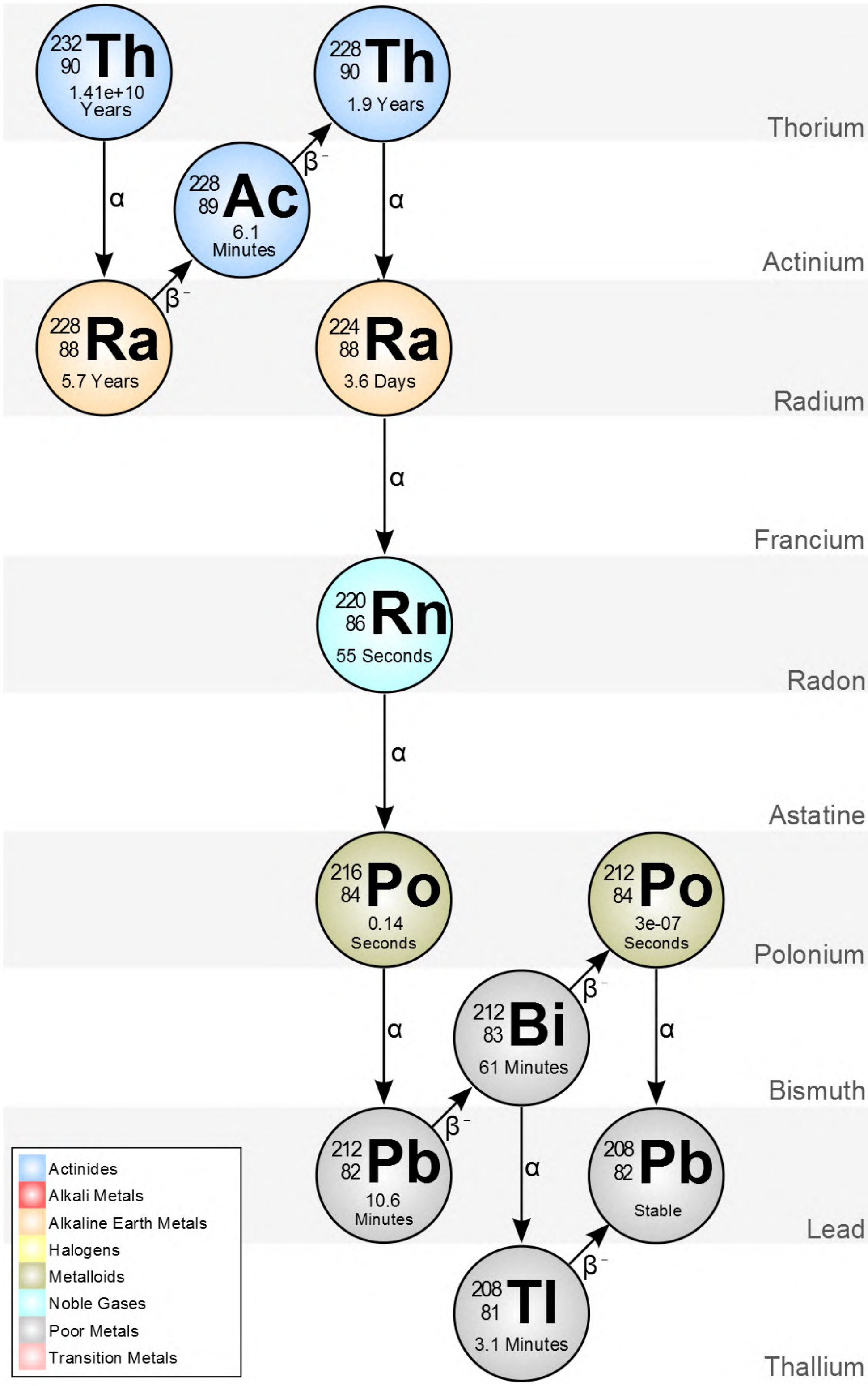
Appendix A
Natural Decay Series

Natural Uranium Decay Series



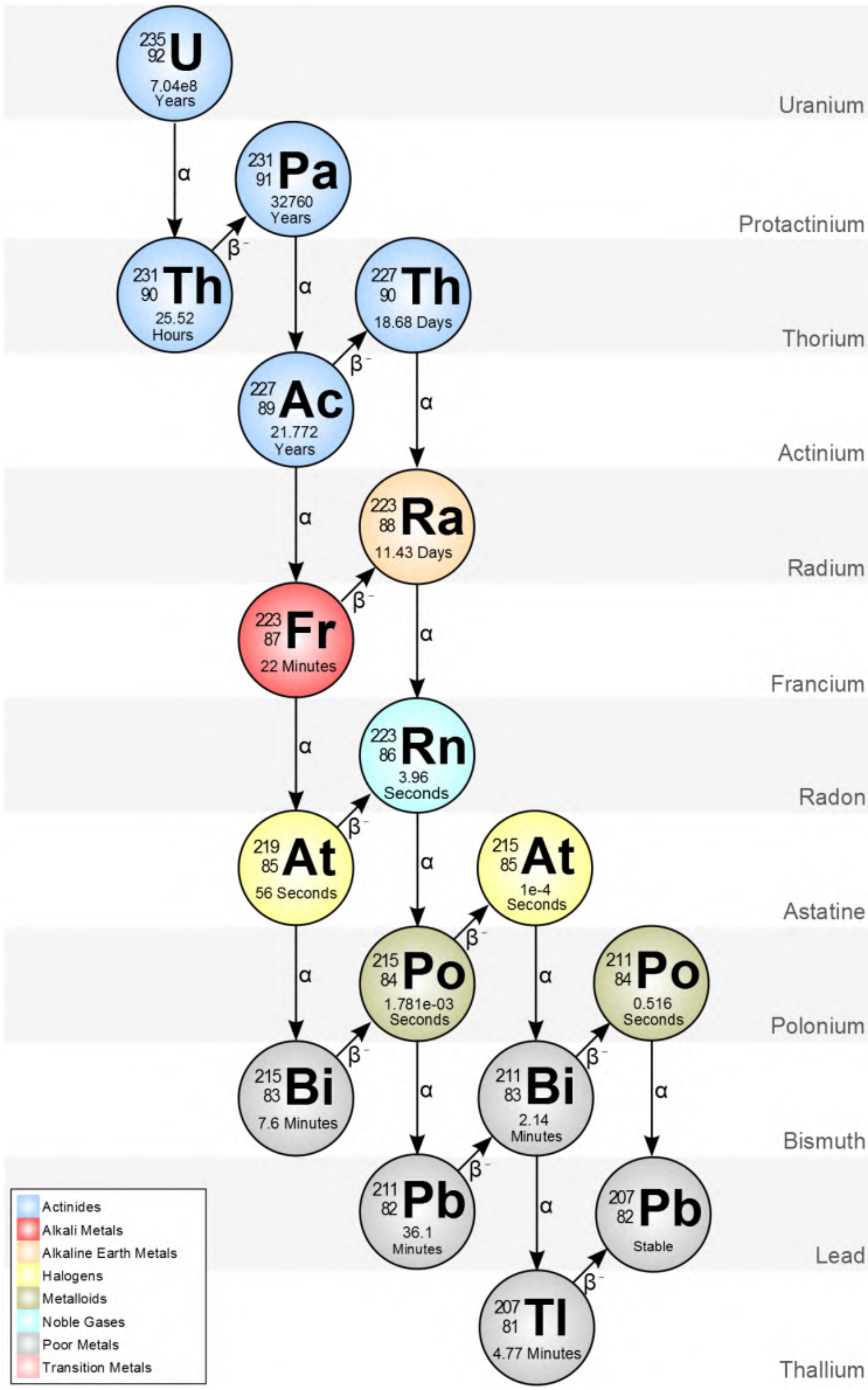
Source: http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html

Natural Thorium Decay Series



Source: http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html

Natural Actinium Series (U-235)



Source: http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html

Appendix B
Truck Portal Monitor Daily Check Form

Appendix B
(Typical)

CHEMICAL WASTE MANAGEMENT – Arlington, OR Facility LUDLUM MODEL 4525-7000 – DAILY SYSTEM CHECK FORM				
CHECK MADE BY	**DATE / TIME**	**NO SYSTEM ERRORS**	**AUDIBLE / VISIBLE ALARM**	**RADIATION TEST OK**
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
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Appendix C
RSP-101, Setup and Daily Response Checks, Handheld Instruments

APPROVED:

______________________________ 07/28/20
Technical Manager, CWM Arlington Date

______________________________ 07/28/20
Certified Health Physicist, Perma-Fix Date

1.0 PURPOSE

This procedure establishes consistent methodology for performing handheld radiation instrument setups and daily response checks at the Chemical Waste Management, Inc. (CWM) Arlington, OR Facility (CWM Arlington).

2.0 APPLICABILITY

This procedure is applicable to all personnel trained and qualified to survey incoming waste material or perform routine gamma exposure or gamma dose rate surveys at CWM Arlington.

3.0 REFERENCES

1. Oregon Administrative Rules Department of Energy Chapter 345 “Energy Facility Siting Council” Chapter 50 “Radioactive Waste Materials”
2. Oregon Administrative Rules Department of Environmental Quality Chapter 340, Division 93 “Solid Waste: General Provisions”
3. Radiological Monitoring Plan, CWM Arlington, Oregon, Rev. 0, July 2020
4. RSP-102, “Incoming Waste, Handheld Survey”
5. 49 Code of Federal Regulations (CFR) 173.441, “Radiation Level Limitation”

4.0 GENERAL

4.1 Discussion

Radiological surveys are performed to detect and assess radiological conditions which may be encountered at CWM Arlington.

4.2 Definitions

Contact Dose Rate: A radiation dose rate as measured at contact or within 1/2 inch of the surface being measured.

CPM: Counts per minute.

Dose Rate: The quantity of absorbed dose delivered per unit of time.

DOT: U.S. Department of Transportation.

DPM: Disintegrations per minute.

General Area Dose Rate (GA Dose Rate): The highest radiation dose rate accessible to any portion of the whole body measured at a distance of 30 centimeters (cm) (12 inches) from a significant radiation source or combination of sources.

Survey: An evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of ionizing radiation under a specific set of conditions.

5.0 RESPONSIBILITIES

5.1 Technical Manager

The Technical Manager is responsible for:

- Implementation of this procedure,
- Performing audits of the radiological survey program at inter at intervals not exceed twelve (12) months,
- Ensuring appropriate radiation surveys are performed to measure and document radiation levels,
- Ensuring all completed surveys are adequately reviewed, and
- Providing technical direction to the Survey Technician.

5.2 Survey Technician

Survey Technicians are responsible for:

- Conducting and documenting radiation surveys;
- Performing all necessary pre/post use operability checks; and
- Creating neat, legible, and concise records.

6.0 PREREQUISITES

Prior to performing a radiation survey, personnel should review previous survey data and familiarize themselves with possible radiological hazards.

7.0 PRECAUTIONS AND LIMITATIONS

- Personal Protective Equipment (PPE) should be appropriate for the level of contamination expected and shall be in compliance with Site Safety and Health Plan (SSHP), Radiological Monitoring Plan, or other work-specific controlling documents. At a minimum, gloves should be worn while collecting waste samples.

8.0 APPARATUS

- Gamma exposure rate or gamma dose rate survey instruments.
- PPE.

9.0 RECORDS

Survey documentation is to be completed per this procedure.

10.0 PROCEDURE

Ensure that the instrument has been calibrated within the last year. Select the survey instrument based on the anticipated hazards and dose rates as determined by a review of previous survey data and ongoing work activities. Obtain survey forms and any other material required to document survey results.

Instrument set-up and subsequent operational checks should be performed in the same location, with consistent temperature and radiation background levels.

Use a gamma check source with an activity sufficient to produce contact exposure rates at least 10 times higher than background. Cesium (Cs)-137 is typically used since it emits 662 kiloelectron volt (keV) gamma rays which are representative of the mid-range of gamma energies. Alternate sources may be used with Technical Manager approval.

Source positioning devices (i.e., jigs) should be used to ensure a reproducible geometry between instrument checks. Source geometry must be consistent between initial instrument set-up and subsequent operational checks.

10.1 Instrument Source Check

1. Obtain the selected instrument.
2. Obtain the corresponding Daily Field Source Check Log – Exposure Rate Instruments form (Attachment 1). This form will be referred to as the "Source Check Log." Initiate a new Source Check Log, if necessary.
3. Perform a physical inspection of the instrument. Place particular emphasis on the following items:
    - Instrument case is not visibly damaged beyond minor scrapes and scratches;
    - Analog display is not cracked or otherwise damaged;
    - Switches and buttons are functional;
    - Audio, if present, is functional; and
    - Calibration labels are legible and the instrument is within the calibration period.
4. Note results of physical inspection on the Source Check Log.
5. Verify the battery level is within the acceptable range on the analog display. Replace batteries and re-verify, as necessary.
6. Note battery check results on the Source Check Log.
7. Verify the high voltage (HV) level is within the acceptable range on the analog display, if present. Place the instrument out-of-service if the HV is outside the acceptable range.
8. Note the HV check results on the Source Check Log.
9. If acceptable background ranges have not been established, perform the following:
    - Obtain a blank Exposure Rate Instrument Set-Up Sheet (Attachment 2). This form will be referred to as the "Set-Up Sheet."
    - Record the basic source and instrument information at the top of the form.
    - Using the instrument and the source jig (without source), obtain and record 10 background readings. The instrument should be removed from the source jig

and repositioned after each reading is obtained. Make sure the location where readings are obtained has stable background levels and is the location used for subsequent source checks.

- Calculate and record the average background value and ± 20% values on both the set-up and source check logsheets.

10. Obtain and record an average background reading on the source check log.
11. Compare the average background reading to the acceptable range. If background response is outside this range, report the condition to the Technical Manager for evaluation; otherwise continue with the source check process.
12. Obtain the source to be used for instrument source checks.
13. If acceptable source check ranges have not been established, perform the following:
    - Obtain the Set-Up Sheet used to determine acceptable background ranges for the instrument.
    - Using the instrument and the source jig (with source), obtain and record 10 contact source readings. The instrument and source should be removed from the source jig and repositioned after each reading is obtained. Make sure the location where readings are obtained is the same location where previous background readings were obtained.
    - Calculate and record the average source value and ± 20% values on both the set-up and source check logsheets.
14. Load the source and instrument onto the source jig.
15. Obtain and record the “CONTACT” reading.
16. Verify the contact reading is within the acceptable range (± 20%).
17. If the contact source reading falls outside the acceptable range, tag the instrument out of service and notify the Technical Manager; otherwise continue.
18. Complete the source check log including technician initials. The instrument is now ready for use.
19. Ensure sources and forms are stored properly after use in the designated storage location.

11.0 DOCUMENTATION

11.1 General

1. Record all information on instrument setup forms in a neat and legible manner.
2. Forms are retained in instrument logbooks of field files during instrument use (i.e., calibration) cycle. Records are then reviewed by the Technical Manager or designee for completeness and forwarded to Project Records for retention.

12.0 ATTACHMENT

Attachment 1 Daily Field Source Check Log – Exposure Rate Instruments (Typical)

Attachment 2 Exposure Rate Instrument Set-Up Sheet (Typical)

Attachment 1 (Typical)

DAILY FIELD SOURCE CHECK LOG
- EXPOSURE RATE INSTRUMENTS

MONTH / YEAR: ____________________

INSTRUMENT DATA			Date/Time	Physical	Battery	High Voltage	Audio	Background	Contact Source	PASS or FAIL	Tech. Initials
	INSTRUMENT										
MODEL											
SERIAL#											
CAL DUE											
HV											
SOURCE DATA											
ISOTOPE											
SERIAL #											
ACTIVITY uCi											
INSTRUMENT RANGES											
	Background	Contact Source									
+ 20 %											
- 20 %											
Units (Circle One											
uR urem mR mrem R rem											

Remarks:	Reviewed by:

Attachment 2 (Typical)

EXPOSURE RATE INSTRUMENT SET-UP SHEET

Set-Up Location: ____________________

INSTRUMENT DATA		READING (n)	Background Rate	Contact Source Rate	CALCULATED AVERAGE AND RANGES		
	INSTRUMENT	1			Background		Contact Source
MODEL		2				Average + 20%	
SERIAL #		3				Average	
CAL DUE DATE		4				Average - 20%	
HV		5					
SOURCE DATA		6			Units (Circle One)		
ISOTOPE		7			uR urem mR mrem R rem		
SERIAL #		8			REMARKS		
		9					
ACTIVITY (uCi)		10					

Performed By:	Date/Time:	Reviewed By:	Date/Time:

Appendix D
RSP-102, Incoming Waste Handheld Survey

TITLE:	Incoming Waste Handheld Survey	NO.:	RSP-102
		PAGE:	1 of 7
		DATE:	July 2020

APPROVED:

Technical Manager, CWM Arlington — 07/28/20 Date

Certified Health Physicist, Perma-Fix — 07/28/20 Date

1.0 PURPOSE

This procedure establishes consistent methodology for performing radiation surveys using handheld radiation instruments for incoming waste material at the Chemical Waste Management, Inc. (CWM) Arlington, OR Facility (CWM Arlington).

2.0 APPLICABILITY

This procedure is applicable to all personnel trained and qualified to perform radiation surveys of waste material at CWM Arlington.

3.0 REFERENCES

1. Oregon Administrative Rules Department of Energy Chapter 345 "Energy Facility Siting Council" Chapter 50 "Radioactive Waste Materials"
2. Oregon Administrative Rules Department of Environmental Quality Chapter 340, Division 93 "Solid Waste: General Provisions"
3. *Radiological Monitoring Plan*, CWM Arlington, Oregon, Rev. 0, July 2020
4. RSP-101, *Setup and Daily Response Checks, Handheld Instruments*

4.0 GENERAL

4.1 Discussion

Radiological surveys are performed to detect and assess radiological conditions which may be encountered at CWM Arlington.

4.2 Definitions

Contact Dose Rate: A radiation dose rate as measured at contact or within 1/2 inch of the surface being measured.

Dose Rate: The quantity of absorbed dose delivered per unit of time.

Survey: An evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of ionizing radiation under a specific set of conditions.

5.0 RESPONSIBILITIES

5.1 Technical Manager

The Technical Manager is responsible for:

- Implementation of this procedure,
- Performing audits of the radiological survey program at inter at intervals not exceed twelve (12) months,
- Ensuring appropriate radiation surveys are performed to measure and document radiation levels,
- Ensuring all completed surveys are adequately reviewed, and
- Providing technical direction to the Survey Technicians.

5.2 Survey Technician

Survey Technicians are responsible for:

- Conducting and documenting radiation surveys;
- Performing all necessary pre/post use instrument operability checks; and
- Creating neat, legible, and concise records.

6.0 PREREQUISITES

Prior to performing a radiation survey, personnel should review previous survey data and familiarize themselves with possible radiological hazards.

7.0 PRECAUTIONS AND LIMITATIONS

Personal Protective Equipment (PPE) should be appropriate for the level of contamination expected and shall be in compliance with Site Safety and Health Plan (SSHP), Radiological Monitoring Plan, or other work-specific controlling documents. At a minimum, gloves should be worn while collecting waste samples.

8.0 APPARATUS

- Gamma dose rate or gamma exposure rate survey instruments,
- Radioisotope identifying instrument, and
- PPE.

9.0 RECORDS

Survey documentation is to be completed as described in this procedure. Summary results of the survey will be documented using an established CWM Arlington form, an example of which is provided as Attachment 1.

10.0 PROCEDURE

Select an appropriate dose rate (μrem/hr) or exposure rate (μR/hr) instrument such as the Ludlum Model 19, Ludlum Model 3000 with Ludlum 44-2 (or equivalent).

Ensure that the instrument has been calibrated within the last year.

10.1 Daily Instrument Check

1. Prior to use each day, power on the instrument and ensure that the instrument is in good working condition and in good repair.
   a. Check the battery level of the instrument.
2. Perform an Instrument Source Check according to RSP-101, *Setup and Daily Response Checks, Handheld Instruments* and document the results accordingly in the Daily Field Source Check Log – Exposure Rate Instruments.
   a. If the source response check (SRC) fails (measurement is greater than the upper limit or less than the lower limit of the SRC range), redo step 2 of this procedure and ensure that the source is placed correctly on the detector.
   b. If the SRC continues to fail, do not use the instrument and send it to an approved repair/calibration facility.

10.2 Radiological Waste Survey

1. Ensure that the area around the truck/container is free of tripping hazards.
2. Ensure that the truck/container is not parked near a known source of radiation.
3. Ensure that the instrument is currently calibrated and has been performance checked prior to the survey.
4. Power on the instrument and adjust the meter so that it is on the lowest setting that does not produce an off scale value (if applicable). This adjustment is not necessary if a digital meter face is being used.
5. Record a background measurement.
   a. Collect a background measurement near the location where the truck will be scanned and at least 2 meters (6 feet) from the truck/container or a known radiation source.
   b. Hold the radiation-sensitive portion of the meter at waist height then let the pin or digital face of the meter stabilize. Some minimal variation in the reading will occur.
   c. Record the reading.
6. Scan the perimeter of the waste load with the detector no more than 2 inches from the accessible surface.
7. The scan should be conducted around the approximate vertical center of the load (if the container is completely filled).
8. Scan slowly enough to detect variation in radiation levels that could exceed 10 μR/hr above background.
9. Ensure that the audible indicator and fast time response functions on the meter are used to make detection easier.
10. Take enough readings to indicate whether the radioactive material is uniformly dispersed in the load.
11. At a minimum, record the average and the highest reading from each load.

12. Compare the readings to the site Action Levels and respond accordingly.

10.3 Documentation

1. Record all information on survey forms in a neat and legible manner.
2. Document all surveys on a form with an approved project heading. Technician logbooks may be used for documenting surveys (e.g., daily routines, material transfers, minor posting changes, etc.) as authorized by the Technical Manager, and providing instrument serial numbers are documented with survey data.
3. When recording information on survey forms, check all appropriate boxes and circle all appropriate answers.
4. Use a survey form with pre-drawn diagrams when available. If not, draw a diagram or picture of the object surveyed. Should a diagram not be appropriate, use a lined survey form.
5. Assign the next sequential survey number to the survey from the survey number logbook.
6. Complete the following information for all surveys:
   - Date and time of survey;
   - Location of survey;
   - Instrument type and serial numbers and associated supporting information (i.e., detector efficiencies, calibration dates, background values, etc.);
   - Hazardous Work Permit (HWP) number, if applicable;
   - Reason for survey; and
   - Name and signature of surveyor.
7. The use of Greek alphabet and other nuclear industry standard nomenclature (e.g., “k” = 1,000) is acceptable when documenting surveys.

10.3.1 Survey Log Number Book

1. A survey log number book is to be used to assign a unique sequential number to each survey form package. This number provides the ability to track individual surveys as well as ensuring the submittal of a complete documentation package for archiving.
2. Unless otherwise directed by the Technical Manager, survey numbers will be assigned with the following format:

   CWMyy-xxxx

   Where “CWM” corresponds to “Chemical Waste Management, Arlington,” yy is the last two digits in the year, and xxxx refers to the sequential survey number.
3. As surveys are generated, the Survey Technician will take the next sequential number on the form and fill in the remaining boxes with a brief description of the reason for the survey as well as the date and Technician’s initials.

10.3.2 Technician Review and Evaluation

- After completing the surveys, evaluate the results against previous surveys or anticipated results.
- Take any immediate actions required based on survey results.
- Ensure all relevant supporting documentation (e.g., count room print-outs, etc.) are attached to the survey package and that the package is properly paginated.
- Submit documentation to the Technical Manager or designee for supervisory review.

10.3.3 Supervisory Review

- Ensure that the survey form is complete and legible.
- Ensure that all required information has been completed.
- Ensure that any changes, single line cross-outs, or deletions are initialed and dated at time performed.
- Verify that results are consistent with those anticipated.
- If results are not consistent, ensure that appropriate actions have been taken to explain the results or re-examine the area.
- Sign-off in the appropriate review section of the survey form and submit the package to Document Control for retention/transmittal to Project Files.

Survey forms shall be completed in their entirety. This includes attaching printouts, diagrams, or other supporting documentation; appending sequential page and survey tracking numbers; a review for completeness and accuracy; and appending the appropriate signatures of personnel performing the survey and/or analyzing samples.

Once complete, the survey package shall be submitted to the Technical Manager, or designee, for final review and approval signature.

Survey documentation shall be maintained according to established document control and retention requirements.

11.0 ATTACHMENTS

Attached forms are examples and may be modified in conjunction with the Technical Manager, as needed, without revision to this procedure.

Attachment 1 CWM Arlington Survey Form (Typical)

Attachment 1, CWM Arlington Survey Form (Typical)

General Information

Survey No. ____

Site Name: ____

Technician(s): ____

Date: ____

Item(s) Surveyed: ____

Survey Type/Data Codes

☐ Routine Surveys (RS) ☐ Incoming

☐ Characterization Surveys (CH) ☐ Final Status (MS)

☐ Shipping Surveys (SS) ☐ Unrestricted Release Surveys (UR)

Instrument Information

	Instrument Model	Detector Model	Instrument Serial Number	Calibration Due Dates
Gamma Survey:				
Exposure Rate:				
Total Alpha:				
Total Beta:				

Page 1 of 2

☐ Smear

△ Static Measurement

Technician: ____ Date: ____ RSO Review: ____ Date: ____

Survey Data Sheet

Survey No		**Item Surveyed**	
Date		**Comments**	
Survey Tech			
Cnt Room Tech			
Date Counted			
Survey Type			
Level of Posting			

Notes

PCF = Probe Correction Factor

T_b = Background count time

T_s = Sample count time

R_b = Background count rate

Bcpm = Background cpm

MDCR = Minimum Detectable Count Rate (net cpm)

MDC = Minimum Detectable Concentration (dpm per $100cm^2$)

Total Activity

dpm = (cpm - Bcpm)/(eff * PCF)

Removable Activity

dpm = (cpm - Bcpm)/eff

*dpm results are per $100cm^2$

Parameters	***Gamma***			***Total Activity***		***Removable Activity***	
Units	CPM	uR/hr	uRem/hr	Alpha	Beta-Gamma	Alpha	Beta-Gamma
Instrument Model							
Instrument SN							
Cal. Due Date							
Efficiency							
Background Counts							
PCF							
Tb							
Ts							
MDCR							
MDC							

No.	*Descriptions*	*cpm*	*uR/hr*	*uRem/hr*	*gross counts*	**dpm*	*gross counts*	**dpm*	*gross counts*	**dpm*	*gross counts*	**dpm*
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

Technician:	Date:	RSO Review:	Date:	Page 2 of 2