**FINAL**

# SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN JOINT BASE LEWIS-MCCHORD, TACOMA, WASHINGTON ANNEX 14

## FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ASR | Archives Search Report |
| CD | Compact Disk |
| CFR | Code of Federal Regulations |
| CG | Commanding General |
| CoC | Chain-of-Custody |
| DGPS | Differential Global Positioning System |
| DoD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| DU | Depleted Uranium |
| ELAP | Environmental Laboratory Accreditation Program |
| ERM | Environmental Radiation Monitoring |
| ERMP | Environmental Radiation Monitoring Plan |
| HASL | Health and Safety Laboratory |
| ICP-MS | Inductively Coupled Plasma-Mass Spectroscopy |
| IMCOM | Installation Management Command |
| JBLM | Joint Base Lewis-McChord |
| kg | Kilogram |
| $m^2$ | Square Meters |
| mrem/y | Millirem per Year |
| mSv/y | MilliSievert per Year |
| NRC | U.S. Nuclear Regulatory Commission |
| OP | Observation Post |
| ORAP | Operational Range Assessment Program |
| PAERMP | Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans |
| QA | Quality Assurance |
| QC | Quality Control |
| RCA | Radiation Control Area |
| RESRAD | Residual Radiation |
| RSO | Radiation Safety Officer |
| SML | Source Material License |
| SOP | Standard Operating Procedure |
| TA | Training Area |
| TEDE | Total Effective Dose Equivalent |
| U-234 | Uranium-234 |
| U-235 | Uranium-235 |
| U-238 | Uranium-238 |
| UFP-QAPP | Uniform Federal Policy for Quality Assurance Project Plan |
| UXO | Unexploded Ordnance |

# 1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (ML16004A369) (U.S. Army 2015) and describes the additional details related to Joint Base Lewis-McChord (JBLM) in Tacoma, Washington, in addition to those presented in the PAERMP.

## 1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off installation migration of DU remaining from the use of the Davy Crockett weapons system at JBLM. The installation will retain the final version of this Site-Specific ERMP. In accordance with license condition #19, the U.S. Army is required to implement fully this Site-Specific ERMP within 6 months of NRC approval. This Site-Specific ERMP and its implementation is then subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

**Table 1-1. Recommended ERM Sample Location**

| Sample Location | Sample Media | Sample Frequency |
|---|---|---|
| Co-located surface water and sediment samples downstream (**AIA-SP02**) from the Range 52, OP9, and OP8 RCAs, as shown in Figure 1-2 based on the rationale presented in Section 2.1 | Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2 | Quarterly unless prevented by weather (e.g., regional flooding) |

## 1.2 INSTALLATION BACKGROUND

JBLM is a 92,368-acre installation located in western Washington, approximately 9 miles south of Tacoma (Figure 1-1). JBLM occupies portions of Pierce and Thurston Counties. The entire installation is operational and includes 230 ranges.

Camp Lewis, the original name of Fort Lewis, was established in 1917, named after Meriwether Lewis of the Lewis and Clark Expedition. Camp Lewis was renamed Fort Lewis in 1927 after becoming property of the Federal Government. Tacoma Field, an airfield, was opened in 1930 and was renamed McChord Field in 1940, in honor of Colonel William Caldwell McChord. McChord Field separated from Fort Lewis after the U.S. Air Force separated from the U.S. Army in 1947, and was renamed McChord Air Force Base. In 1992, McChord Field became an Air Mobility Command Base. In 2010, McChord Air Force Base joined Fort Lewis to become JBLM under the 2005 Base Realignment and Closure Act. JBLM is currently a training and mobilization center for all services.

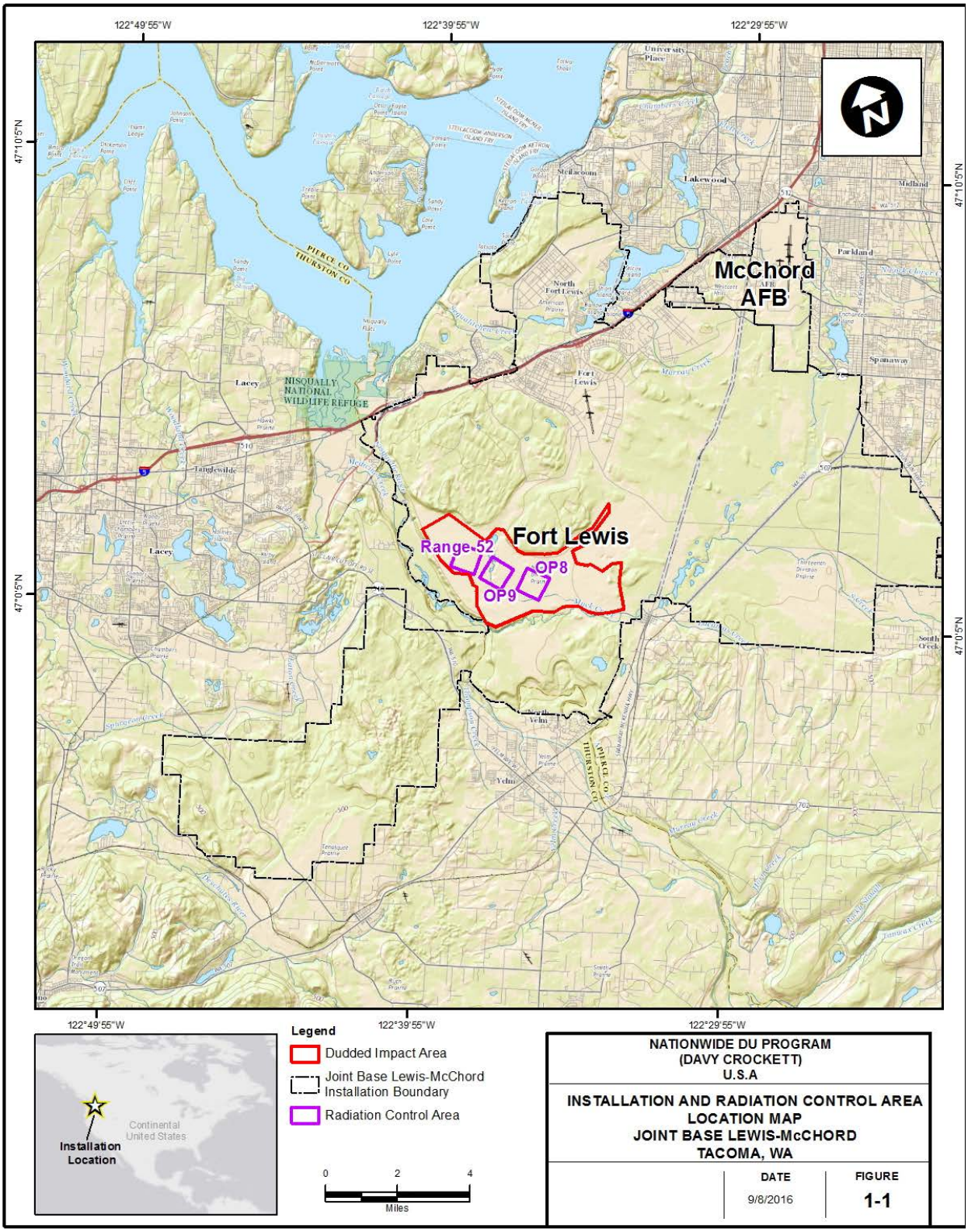


**Figure 1-1. Installation and Radiation Control Area Location Map**

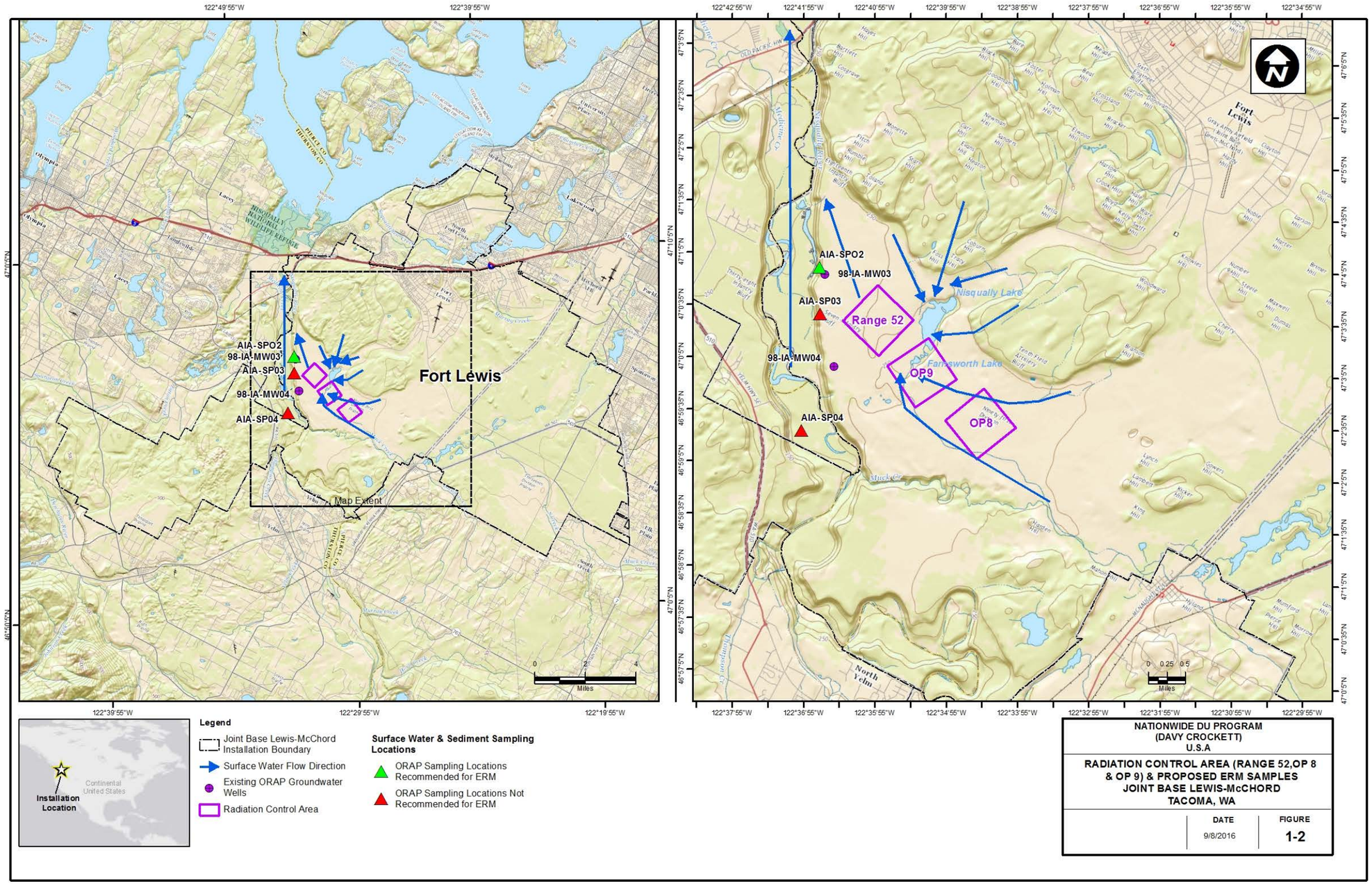


**Figure 1-2. Radiation Control Area (Range 52, OP 8, and OP 9) and Proposed ERM Samples**

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An Archives Search Report (ASR) (USACE 2008) confirmed the presence of three ranges where the Davy Crockett weapons system was used at Fort Lewis, known as Range 52, Observation Post (OP)-8, and OP-9 (Figure 1-2). Three radiation control areas (RCAs) have been established for these ranges. The nearest normally occupied areas to the Range 52 RCA, OP-8 RCA, and OP-9 RCA are located approximately 1.4, 2.6, and 1.8 miles, respectively, southwest of the RCAs.

## 1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU that was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), JBLM (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at JBLM; therefore, it is assumed that most, if not all, of the 340 kilograms (kg) of DU from the rounds fired into RCAs at JBLM and Yakima TA remains in the RCAs.

## 1.4 PHYSICAL ENVIRONMENT

JBLM is situated within the south Puget Sound region along Interstate-5, the major transportation corridor in western Washington. In general, the area where the RCAs is located in relatively level plain interrupted by well-rounded, isolated hills rising about 100 feet above the surrounding terrain.

According to the Environmental Assessment, Northwest Aviation Operations 160$^{th}$ Special Operations Aviation Regiment (U.S. Army 2012a), Andisols are the predominant soils along the Washington and Oregon Coast ranges, and along the Cascade Range. These soils are underlain by volcanic ash and cinders, and they commonly occur at high elevations in areas with past volcanic activity. They are productive soils but are somewhat prone to erosion because of low density. In the Puget Sound lowlands, Inceptisols are predominant. They are relatively young soils, and lack well-defined profile characteristics. Their productivity is largely dependent on local site conditions and may be high where moisture is adequate. Inceptisols formed on hillsides may be very erodible without their native vegetation. The Environmental Assessment, Sniper Field Fire Range (U.S. Army 2012b) indicates that the soil textures at the Yakima Training Center, located northeast of Yakima, Washington, in close proximity to JBLM, are silt loam and loam (predominantly a sand and silt mixture with a low clay content).

Groundwater naturally discharges along the cliffs adjacent to the Puget Sound, in creek beds, and west of the Artillery Impact Area above the Nisqually River along the 7$^{th}$ Infantry Bluff. Due to the abruptness of the bluff and the elevation drop down to the Nisqually River, groundwater likely follows preferential pathways where perched groundwater discharges as springs emerging from the outcrops along the river. Surface water within the central portion of JBLM moves north and west toward Puget Sound and the Nisqually River as overland flow. Therefore, the groundwater is unlikely to underflow the Nisqually River, and the expectation is that the river serves as a groundwater boundary.

JBLM lies principally within the Chambers Creek and Nisqually River basins. The RCAs lie within the Nisqually River basin, and the Nisqually River receives some surface water from the relatively flat plain where the Range 52 RCA is located. Surface water also drains to Farnsworth and Nisqually Lakes from the OP-8 and OP-9 RCAs, and a portion of the Range 52 RCA. Farnsworth Lake and a portion of Nisqually Lake are located on the OP-9 RCA. Two tributaries flow north and northwest through the OP-9 RCA toward Farnsworth Lake, as shown in Figure 1-2. Water egress from Farnsworth and Nisqually Lakes is not evident from the topography map.

## 1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCAs at JBLM are as follows:

- ***Surface Water Use***—The only potable water source of concern is at the Nisqually Clear Creek Fish Hatchery, located between JBLM and the Nisqually River. This hatchery is operated by the Nisqually Indian Tribe as part of Coho Salmon restoration efforts (U.S. Army 2014a).
- ***Recreational Use***—Recreational and fishing activities on and around JBLM occur in the Puget Sound and Nisqually River. Surface water and sediment in these recreational areas are potential pathways for human receptors.
- ***Sensitive Environments***—The Nisqually River is a sensitive habitat for salmon, and enters the Billy Frank Jr. Nisqually National Wildlife Refuge, which is located at the northwestern corner of JBLM.
- ***Habitat***—The RCAs are located in a prairie terrain with Douglas fir and oak tree encroachment. Fresh-water lakes, Farnsworth Lake and Nisqually Lake, are located in the prairie. The Nisqually River forms part of the western border of JBLM.
- ***Ecological Receptors***—Ecological receptors include habitat for Federal- and state-listed threatened and endangered species (e.g., American bald eagle, bull trout, chinook salmon, killer whale, mardon skipper, mazama pocket gopher, northern spotted owl, Taylor's checkerspot, streaked horned lark, and water howellia).
- ***Groundwater Use***—JBLM has production wells used for drinking water located within the installation. Because the Nisqually River is considered to serve as a groundwater discharge boundary, potable wells across the river on the west side are not considered viable exposure routes for human receptors.

Human receptors identified at JBLM include downgradient and off-range residents, recreational users, and users of the potable water at the Nisqually Clear Creek Fish Hatchery. Ecological receptors identified at JBLM include wetlands and threatened and endangered species downstream.

# 2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCAs or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Range 52, OP-8, and OP-9 RCAs at JBLM are discussed in the following sections.

## 2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the quarterly collection of one collocated sample from a location downstream from the RCAs in JBLM (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a quarterly sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a quarterly basis unless sediment is inaccessible when a quarterly sampling event is planned (e.g., flooding).

The surface water and sediment sampling location at JBLM was selected based on the surface water hydrology of the Nisqually watershed, the locations of the three RCAs, and the potential for DU contribution, as follows:

- ***AIA-SP02***—This surface water sampling point is located in the pathway from the RCAs to the Nisqually Clear Creek Fish Hatchery and to the Nisqually River.

Additional locations were sampled during the Operational Range Assessment Program (ORAP) Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the Range 52, OP9, and OP8 RCAs based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***AIA-SP03 and AIA-SP04***—These surface water sampling points are not located in the pathway from the RCAs to the Nisqually Clear Creek Fish Hatchery. These sampling points are not relevant because sampling point AIA-SP02 is sufficient to monitor surface water runoff to both the Nisqually Clear Creek Fish Hatchery and to the Nisqually River.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCAs indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify the NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

Surface water and sediment sampling at JBLM will be performed quarterly or every 3 months. Effort shall be made to schedule sampling when surface water is likely to be present. In the event that the sampling location is dry when the field crew mobilizes to collect samples, only a sediment sample will be collected at that location. If surface water routinely flows from the RCA, then sampling of the surface water will occur every 3 months. If flow is intermittent, sampling will occur during that flow, but no less than 3 months apart. Sediment sampling will coincide with the surface water sampling effort.

ORAP Phase II environmental sampling was not conducted at JBLM based on the conclusions of the Phase I investigation (U.S. Army 2014a). The source-pathway-receptor interaction was determined to be unlikely, and environmental sampling of surface water and sediment was determined not to be necessary.

## 2.2 GROUNDWATER

Presently, two groundwater monitoring wells are located near the RCAs. Groundwater in the shallowest aquifer flows toward the Nisqually River away from the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater will likely be detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2015), groundwater sampling is not planned for JBLM.

ORAP Phase II environmental sampling was not conducted at JBLM based on the conclusions of the Phase I investigation (U.S. Army 2014a). The source-pathway-receptor interaction was determined to be unlikely and environmental sampling of groundwater was determined not to be necessary.

## 2.3 SOIL

If an area of soil greater than 25 square meters ($m^2$) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 $m^2$ unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014b]). The Installation Commander will then decide whether to allow the collection. Otherwise, JBLM does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2015).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

# 3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to JBLM will be coordinated with the JBLM Installation Safety Office and Range Control prior to mobilizing for fieldwork.

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

## 3.1 SURFACE WATER SAMPLING

A surface water sample will be collected quarterly from AIA-SP02 and submitted for laboratory analysis. The grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities including documentation of the site conditions and the sample details will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

## 3.2 SEDIMENT SAMPLING

The collection of the sediment sample will coincide with the surface water sampling activities and consist of the compositing of at least 10 subsamples collected from various areas of the streambed. Sediment samples will be collected in the shallow surface water locations from multiple braided channels using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected

where the surface water flow is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from at least 10 subsample locations, starting downstream from the area to be sampled and moving upstream. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

# 4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (340 kg for JBLM and Yakima TA) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

**Table 4-1. Specific Activity and Mass Abundance Values**

| Nuclide | Specific Activity (Ci/g) | Mass Abundance (%)[b] |
|---|---|---|
| U-234 | $6.22 \times 10^{-3}$ | $3.56 \times 10^{-4}$ |
| U-235 | $2.16 \times 10^{-6}$ | 0.0938 |
| U-238 | $3.36 \times 10^{-7}$ | 99.9058 |
| Depleted uranium[a] | $6 \times 10^{-7}$ | 100 |

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

## 4.1 RESRAD INPUTS

### Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for JBLM RCAs

| Parameter | | Default Value | JBLM Range 52 | JBLM Range OP-8 | JBLM Range OP-9 | Justification or Source |
|---|---|---|---|---|---|---|
| Internal dose library | | DCFPAK 3.02 | FGR 11 & 12 | FGR 11 & 12 | FGR 11 & 12 | Conservative dose coefficients for site contaminants |
| **Contaminated Zone** | | | | | | |
| Soil concentrations (pCi/g) | U-234 | N/A | $3.35 \times 10^{-2}$ | $3.35 \times 10^{-2}$ | $3.35 \times 10^{-2}$ | Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance[a] × nuclide specific activity[a] / (CZ area × CZ depth × CZ density) |
| | U-235 | N/A | $3.06 \times 10^{-3}$ | $3.06 \times 10^{-3}$ | $3.06 \times 10^{-3}$ | |
| | U-238 | N/A | 0.51 | 0.51 | 0.51 | |
| Area of contaminated zone ($m^2$) | | 10,000 | 1,000,000 | 1,000,000 | 1,000,000 | One square kilometer |
| Depth of contaminated zone (m) | | 2 | 0.15 | 0.15 | 0.15 | NRC SML SUC-1593, Item 11, Attachment 5 |
| Fraction of contamination that is submerged | | 0 | 0 | 0 | 0 | ORAP Phase I Periodic Review document (U.S. Army 2014a) indicates depth to groundwater is 10 ft bgs |
| Length parallel to aquifer flow (m) | | 100 | 1,000 | 1,000 | 1,000 | Assuming groundwater flows to Nisqually River |
| Contaminated zone total porosity | | 0.4 | 0.45 | 0.45 | 0.45 | RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam determined from Yakima Training Center Sniper Field Fire Range EA Section 3.3 [U.S. Army 2012b]) |
| Contaminated zone hydraulic conductivity (m/y) | | 10 | 227 | 227 | 227 | RESRAD Manual Table E.2 (DOE 2001) for Silty Loam |
| Contaminated zone b parameter | | 5.3 | 5.3 | 5.3 | 5.3 | RESRAD Manual Table E.2 (DOE 2001) for Silty Loam |
| Average annual wind speed (m/s) | | 2.0 | 10.1 | 10.1 | 10.1 | www.usa.com for Lakewood, WA |
| Precipitation rate (annual rainfall) (m/y) | | 1.0 | 1.27 | 1.27 | 1.27 | www.usa.com for Lakewood, WA |
| Irrigation Rate (m/y) | | 0.2 | 0.2 | 0.2 | 0.2 | |
| Watershed area for nearby stream or pond ($m^2$) | | 1,000,000 | 1,000,000 | 1,000,000 | 1,000,000 | Total RCA |
| **Saturated Zone** | | | | | | |
| Density of saturated zone ($g/cm^3$) | | 1.5 | 1.5 | 1.5 | 1.5 | Assumed same as contaminated zone density |
| Saturated zone total porosity | | 0.4 | 0.45 | 0.45 | 0.45 | RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam determined from Yakima Training Center Sniper Field Fire Range EA Section 3.3 [U.S. Army 2012b]) |
| Saturated zone effective porosity | | 0.2 | 0.20 | 0.20 | 0.20 | RESRAD Manual Table E-8 (DOE 2001) for Silt |
| Saturated zone hydraulic conductivity (m/y) | | 100 | 227 | 227 | 227 | RESRAD Manual Table E.2 (DOE 2001) for Silty Loam |
| Saturated zone b parameter | | 5.3 | 5.3 | 5.3 | 5.3 | RESRAD Manual (DOE 2001) Table E.2 for Silty Loam |
| **Unsaturated Zone** | | | | | | |
| Unsaturated zone 1, total porosity | | 0.4 | 0.45 | 0.45 | 0.45 | RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam determined from Yakima Training Center Sniper Field Fire Range EA Section 3.3 [U.S. Army 2012b]) |
| Unsaturated zone 1, effective porosity | | 0.2 | 0.20 | 0.20 | 0.20 | RESRAD Manual Table E-8 (DOE 2001) for Silt |
| Unsaturated zone 1, soil-specific b parameter | | 5.3 | 5.3 | 5.3 | 5.3 | RESRAD Manual Table E.2 (DOE 2001) for Silty Loam |
| Unsaturated zone 1, hydraulic conductivity (m/y) | | 10 | 227 | 227 | 227 | RESRAD Manual Table E.2 (DOE 2001) for Silty Loam |

[a] See Table 4-1.

## Table 4-3. Nondefault RESRAD-OFFSITE Input Parameters for JBLM RCAs

| RCA Layout Parameter | JBLM Range 52 | | | | JBLM Range OP-8 | | | | JBLM Range OP-9 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance to nearest normally occupied area (m) | 2,250 | | | | 4,200 | | | | 2,900 | | | |
| Bearing of X axis (degrees) | 315 (southwest) | | | | 315 (southwest) | | | | 315 (southwest) | | | |
| X dimension of primary contamination (m) | 1,000 | | | | 1,000 | | | | 1,000 | | | |
| Y dimension of primary contamination (m) | 1,000 | | | | 1,000 | | | | 1,000 | | | |
| Location | X Coordinate (m) | | Y Coordinate (m) | | X Coordinate (m) | | Y Coordinate (m) | | X Coordinate (m) | | Y Coordinate (m) | |
| | Smaller | Larger | Smaller | Larger | Smaller | Larger | Smaller | Larger | Smaller | Larger | Smaller | Larger |
| Fruit, grain, non-leafy vegetables plot | 500 | 531.25 | 2350 | 2382 | 500 | 531.25 | 4300 | 4332 | 500 | 531.25 | 3000 | 3032 |
| Leafy vegetables plot | 500 | 531.25 | 2384 | 2416 | 500 | 531.25 | 4334 | 4366 | 500 | 531.25 | 3034 | 3066 |
| Pasture, silage growing area | 500 | 600 | 2566 | 2666 | 500 | 600 | 4516 | 4616 | 500 | 600 | 3216 | 3316 |
| Grain fields | 500 | 600 | 2416 | 2516 | 500 | 600 | 4366 | 4466 | 500 | 600 | 3066 | 3166 |
| Dwelling site | 500 | 531.25 | 2250 | 2282 | 500 | 531.25 | 4200 | 4232 | 500 | 531.25 | 2900 | 2932 |
| Surface-water body | 500 | 800 | 2666 | 2966 | 500 | 800 | 4616 | 4916 | 500 | 800 | 3316 | 3616 |
| **Atmospheric Transport Parameter** | | | | | | | | | | | | |
| Meteorological STAR file | WA_SEATTLE_TACOMA.str | | | | WA_SEATTLE_TACOMA.str | | | | WA_SEATTLE_TACOMA.str | | | |
| **Groundwater Transport Parameter** | | | | | | | | | | | | |
| Length parallel to aquifer flow (m) | 325 | | | | 325 | | | | 325 | | | |
| Distance to well (parallel to aquifer flow) | 1250 | | | | 3200 | | | | 1900 | | | |
| Distance to surface water body (SWB) (parallel to aquifer flow) (m) | 666 | | | | 3616 | | | | 2316 | | | |
| Distance to well (perpendicular to aquifer flow) (m) | 0 | | | | 0 | | | | 0 | | | |
| Distance to right edge of SWB (perpendicular to aquifer flow) (m) | -150 | | | | -150 | | | | -150 | | | |
| Distance to left edge of SWB (perpendicular to aquifer flow) (m) | 150 | | | | 150 | | | | 150 | | | |
| Anticlockwise angle from x axis to direction of aquifer flow (degrees) | 135 | | | | 135 | | | | 135 | | | |

## 4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at JBLM does not exceed $1.0 \times 10^{-2}$ milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

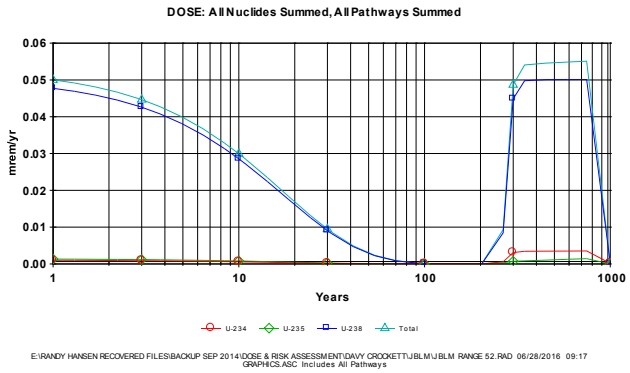
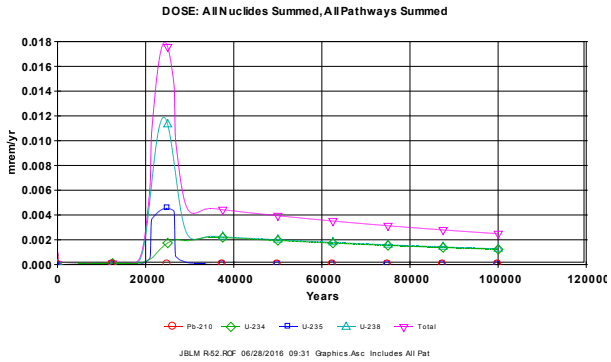
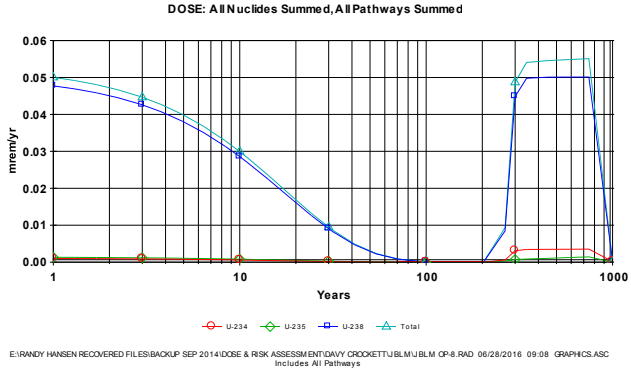
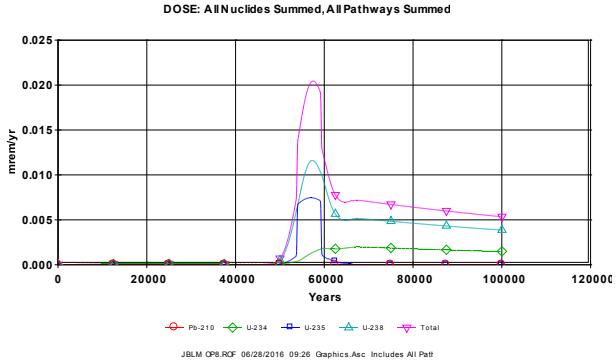
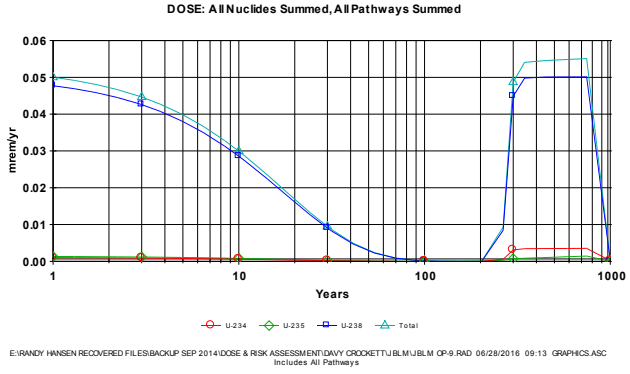
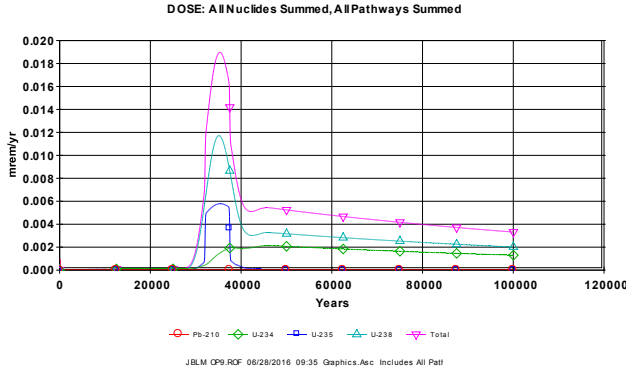
**Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario**

| RCA | RCA Onsite[a] (RESRAD) | RCA Offsite[b] (RESRAD-OFFSITE) |
|---|---|---|
| | Maximum Annual Dose (mrem/y) | |
| JBLM Range 52 | 0.060 | 0.019 |
| JBLM OP-8 | 0.060 | 0.021 |
| JBLM OP-9 | 0.060 | 0.020 |

[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

## Figure 4-1. Residential Farmer Receptor Dose Graphs

| RCA Onsite (RESRAD) | RCA Offsite (RESRAD-OFFSITE) |
|---|---|
| **JBLM Range 52** | |
|   |   |
| **JBLM OP-8** | |
|   |   |
| **JBLM OP-9** | |
|   |   |

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**Attachment 1**

**Analysis of NRC's Default Value for Depleted Uranium Specific Activity**

## Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

$S$ is the specific activity of the mixture of naturally occurring uranium isotopes, $S_i$ is the specific activity for uranium isotope $i$, $a_i$ is the relative molar mass abundance for uranium isotope $i$ in the depleted uranium, and $i$ denotes the uranium isotopes uranium-234 ($^{234}$U), $^{235}$U and $^{238}$U.

Rather than looking up each $S_i$ in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope $S_i$ is the activity $A_i$ per mass $m_i$ for the isotope $i$. Also, by definition:

$$A_i = \lambda_i N_i$$

$\lambda_i$ is the decay constant and $N_i$ is the number of atoms of uranium isotope $i$ in the sample with mass $m_i$. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

$\lambda_i$ is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If $N_i$ is set to Avogadro's number ($N$ = 6.02 × 10$^{23}$),[2] then, by definition, $m_i$ is the mass of a mole of isotope $i$, given by $M_i$, which is the atomic weight of isotope $i$ with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including $^{236}$U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

| Isotope | Natural Relative Molar Mass Abundance | Half-life (s) | Molar Mass (g) | Specific Activity[4] | |
|---|---|---|---|---|---|
| | | | | (Bq g$^{-1}$) | (Ci g$^{-1}$) |
| $^{234}$U | 0.000054 | $7.75 \times 10^{12}$ | 234.04 | $2.30 \times 10^{8}$ | $6.22 \times 10^{-3}$ |
| $^{235}$U | 0.007204 | $2.22 \times 10^{16}$ | 235.04 | $7.99 \times 10^{4}$ | $2.16 \times 10^{-6}$ |
| $^{238}$U | 0.992742 | $1.41 \times 10^{17}$ | 238.05 | $1.24 \times 10^{4}$ | $3.36 \times 10^{-7}$ |

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for $^{234}$U and $a_{0,\text{U-235}}$ similarly for $^{235}$U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of $^{234}$U in depleted uranium and $D_{\text{U-235}}$ similarly for $^{235}$U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of $^{234}$U relative to the depletion of $^{235}$U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

$\varepsilon$ is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of $^{238}$U and is much less than one. $n$ is the number of enrichment stages.

For large $n$:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = $3.7 \times 10^{10}$ becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\text{Ci g}^{-1} \end{aligned}$$

Dividing by $10^{-7}$ Ci g$^{-1}$ and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for $^{234}$U and $^{235}$U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g$^{-1}$. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

# 5.0 REFERENCES


DOE (U.S. Department of Energy). 2001. User's Manual for RESRAD Version 6. July.

IDQTF (Intergovernmental Data Quality Task Force). 2012. Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) Manual, Optimized UFP-QAPP Worksheets. March.

NRC (U.S. Nuclear Regulatory Commission). 2016. Source Material License Number SUC-1593, Docket No. 040-09083 Amendment 1 (ADAMS Accession No. ML16039A234). March 21.

U.S. Army. 2012a. Environmental Assessment, Northwest Aviation Operations 160th Special Operations Aviation Regiment, Joint Base Lewis-McChord, Washington. April.

U.S. Army. 2012b. Environmental Assessment, Sniper Field Fire Range, Joint Base Lewis-McChord Yakima Training Center. Project Number (PN) 65386. NEPA Tracking Number 07-PWE-051b. February.

U.S. Army. 2014a. Operational Range Assessment Program Phase I Qualitative Assessment Report Addendum Joint Base Lewis-McChord, Tacoma, Washington. Contract No. W9128F-10-D-0056. March.

U.S. Army. 2014b. Risk Management. Department of the Army Pamphlet (DA PAM) 385-30. Headquarters, Department of the Army, Washington, DC. December 2.

U.S. Army. 2015. Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans (NRC ADAMS accession number ML16004A369).

USACE (U.S. Army Corps of Engineers). 2008. Final Installation Specific Archive Search Report on the Use of Cartridge, 20MM Spotting M101 Davy Crockett Light Weapon M28 at Fort Lewis and Yakima Training Center, Washington. U.S. Army Corps of Engineers, St. Louis District. Revised, July.

Yu, C. et al. 2016a. RESRAD (onsite) (Version 7.2) [Computer Program]. Available at http://web.ead.anl.gov/resrad/RESRAD_Family/ (Accessed August 24, 2016). July 20.

Yu, C. et al. 2016b. RESRAD-OFFSITE (Version 3.2) [Computer Program]. Available at http://web.ead.anl.gov/resrad/RESRAD_Family/ (Accessed July 14, 2016). June.

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