FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN
YAKIMA TRAINING CENTER, WASHINGTON
ANNEX 15

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

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DGPS	Differential Global Positioning System
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
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
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
TC	Training Center
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 Yakima Training Center (TC) in Washington State, 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 Yakima TC. 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 Locations

Sample Location	Sample Media	Sample Frequency
Three co-located surface water and sediment samples downstream from the Ranges 17 and 20 RCAs (**SWS-01**); Ranges 14, 17, and 20 RCAs (**SWS-02**); and from the Range 14 RCA (**SWS-05**), as shown in Figures 1-2 and 1-3 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

Yakima TC is a 327,231-acre installation located in south central Washington State, approximately 100 miles southeast of Joint Base Lewis-McChord (JBLM) and 4 miles east of Selah, Washington (Figure 1-1). Selah consists of commercial and small businesses along with residential communities.

Yakima TC has been in use since 1942 and includes 78 ranges that are operational and 2,481 acres that are other than operational, which includes the cantonment area and Selah Canyon. Three radiation control areas (RCAs) are located within Yakima TC: Range 14 (Figure 1-2), Range 17 (Figure 1-3), and Range 20 (Figure 1-3). All branches of the U.S. Army train at Yakima TC to sustain and improve unit readiness for both wartime and contingency operations. Yakima TC currently is a sub-installation of JBLM and houses several military and Federal Government tenants, including the Washington Army National Guard Mobilization and Training Equipment Site, Marine and Army Reserve Centers, and the Yakima Research Station. The installation's training facilities are also used by other Federal agencies and local law enforcement (Malcolm Pirnie 2008).

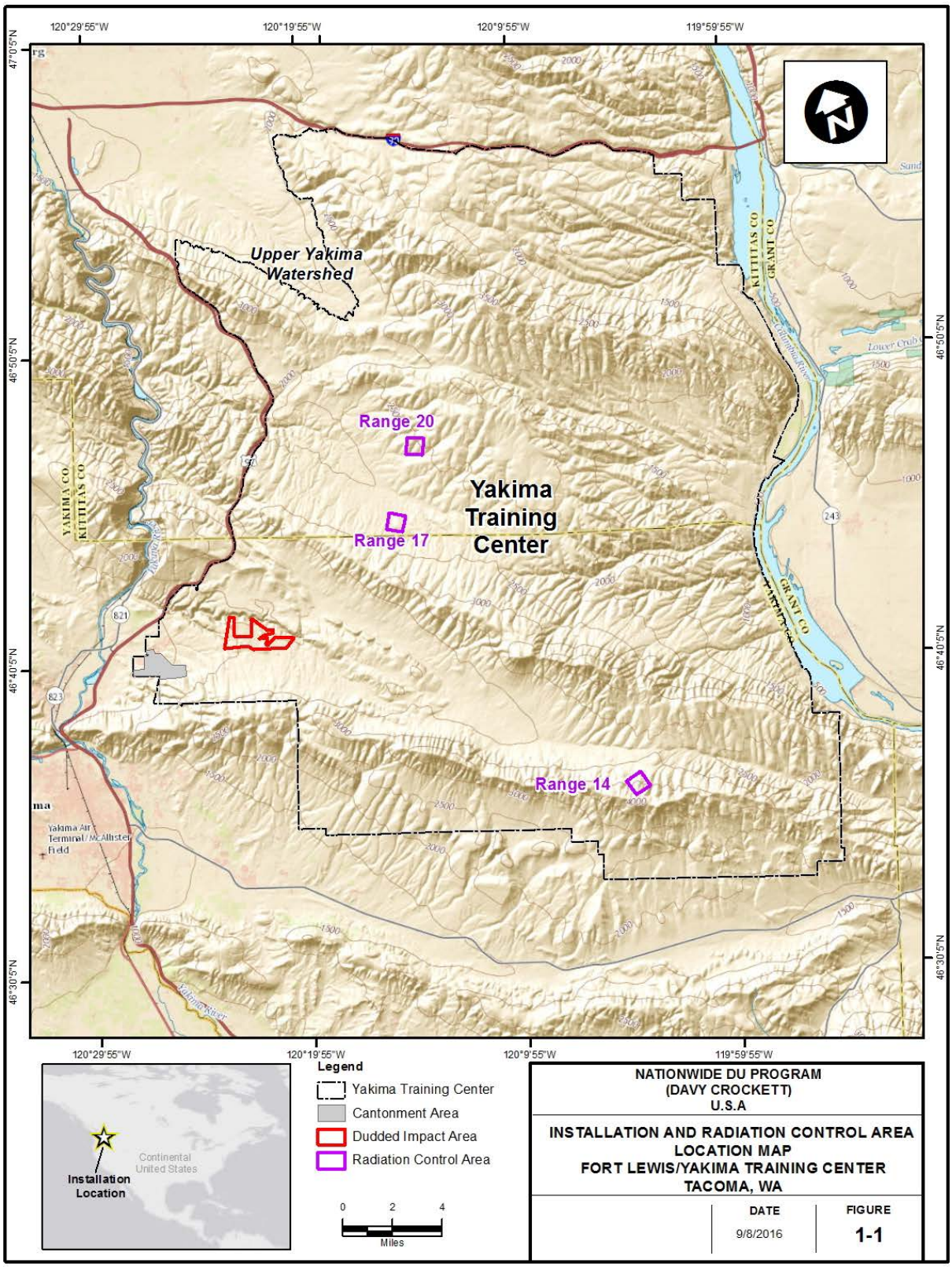

Figure 1-1. Installation and Radiation Control Area Location Map

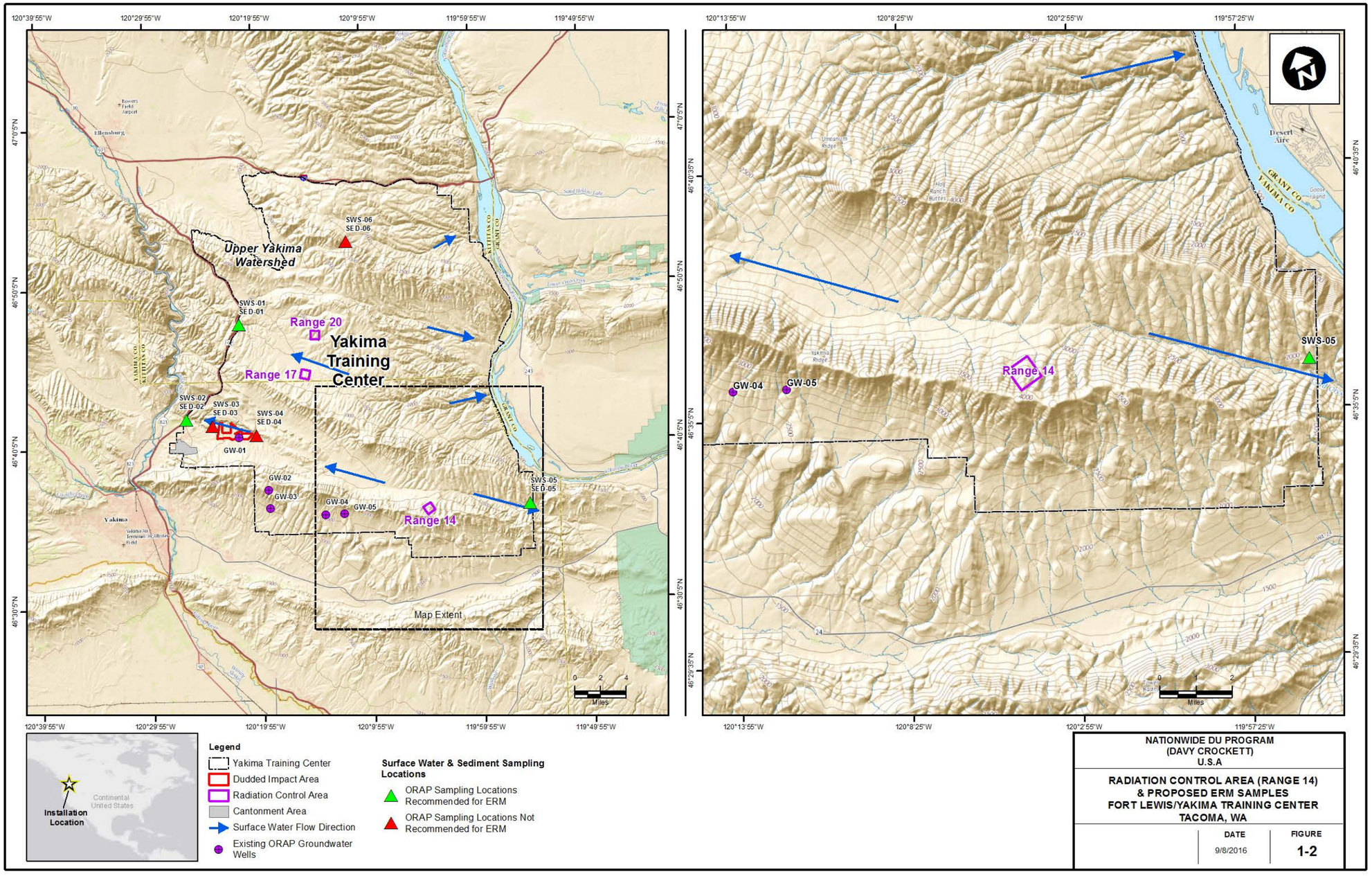

Figure 1-2. Radiation Control Area (Range 14) and Proposed ERM Samples

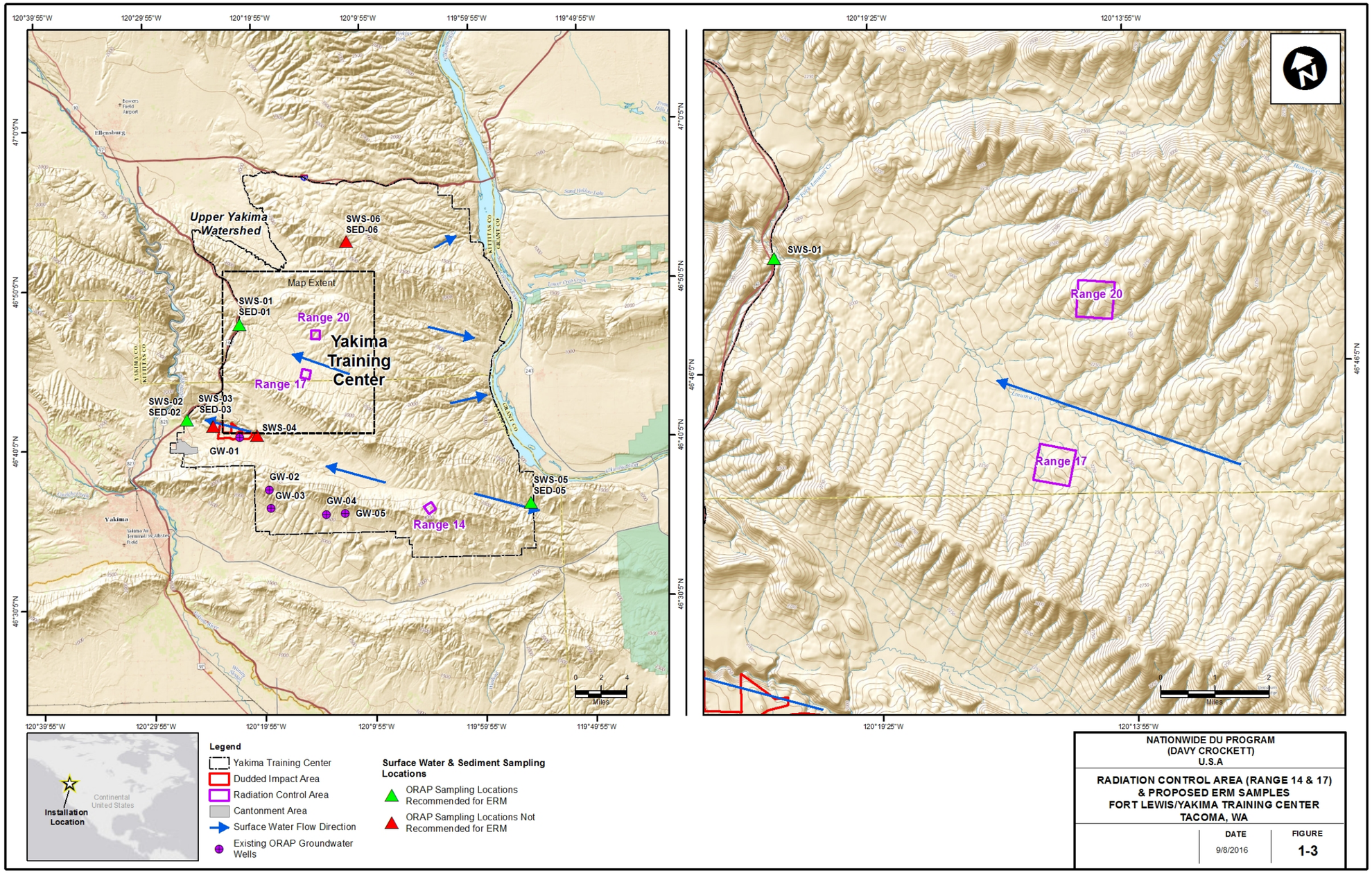

Figure 1-3. Radiation Control Area (Ranges 14 and 17) and Proposed ERM Samples

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which 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 Yakima TC; 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 TC remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Yakima TC is located in the Columbia Basin of Washington State. The region is semiarid and characterized by cool winters with light snowfall and hot, dry summers. Topography at Yakima TC varies from low plains to mountains that have been modified by glaciers and flooding, which created a network of drainages. Yakima TC drains into two major basins: the Columbia River Basin east of the installation and the Yakima River Basin to the west. The installation is further divided into 10 watersheds: Badger, Lmuma, Selah, Moxee, and Cold Creek watersheds (which drain toward the Yakima River); and Corral, Alkali, Hanson, Johnson, and Middle Creek watersheds (which drain toward the Columbia River). Stream flow within the installation boundary is attributed to winter precipitation, high flood flows during spring snowmelt, and summer thunderstorms.

Yakima TC lies within the Yakima Fold Belt, which is a transitional zone between the Cascade Mountains and Columbia Plateau basalt that is identifiable in Figure 1-1. The Columbia River Basalt Group is an aquifer system consisting of basin-fill deposits occurring in six structural-sedimentary basins. Groundwater in the different hydrogeological units occurs under perched, unconfined, semiconfined, and confined conditions. The fold is characterized by a series of asymmetrical, elongated, tightly folded, southeast-trending synclines and anticlines. The extensive folding creates a complex groundwater system. Groundwater is present in four stratigraphic units of the Yakima Basalt Group (in ascending order): Grande Ronde Basalt, Wanapum Basalt, Saddle Mountain Basalt, and the unconsolidated overburden. The Wanapum Basalt and, to a lesser extent, the Grande Ronde Basalt are the primary aquifers utilized for public drinking water supply. Groundwater flows laterally along flow tops through vesicular and fractured zones, as well as through sedimentary beds between flows. Groundwater also flows vertically through the basalts along joints that formed as the rock solidified from molten lava. The depth to groundwater ranges from 20 feet below ground surface (bgs) in valleys to more than 200 feet bgs at higher elevations. Shallow groundwater flow is generally westward and eastward, following topography from higher elevations at the center of the installation, toward the Yakima River and Columbia River, respectively. The Upper Yakima watershed is north of the Lmuma Creek and Yakima River. Deeper groundwater flow is generally eastward toward the Columbia River. Deeper aquifers are recharged mainly from the area west of the installation and are generally confined or semiconfined, whereas shallower unconfined aquifers are recharged primarily by precipitation falling on ridge crests and rubble slopes, as well as by surface water infiltration in some creek beds. Shallow groundwater flow refers specifically to the overburden and deeper flow represents the Saddle Mountain, Wanapum, and Grande Ronde Basalt aquifers.

Two ridges are within the operational area of Yakima TC: the Umtanum and Yakima Ridge. The two ridges define an over-turned anticline, which creates a trough, channeling surficial groundwater flow west toward the Yakima River. In addition, the Yakima Ridge may create a hydrogeologic barrier, preventing groundwater from flowing southwest toward wells located within 4 miles downgradient. However, joints within the ridgeline may act as conduits and facilitate groundwater movement from the RCA area, southwest toward the Yakima River and to public supply wells. Lateral groundwater flow beneath the ranges at Yakima TC is mainly contained in the interflow material between major basalt flows, and the direction of groundwater flow is predominantly parallel to the structural dip of the basalt (USGS 2009). A large amount of vertical fracturing of the basalt into colonnades occurs, which can tie the more horizontal layers and inhibit flow. The structural gradient is affected by the surface topography and regional deformation, and this is reflected in the flow lines that can be derived from regional groundwater contours, which are nearly perpendicular to the ridge lines. Groundwater and surface water within Yakima TC are interconnected through springs present where ridges or incised stream valleys intercept aquifers.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

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

- ***Surface Water Use***—Surface water on and surrounding Yakima TC, including the Yakima River to the west and the Columbia River to the east and their tributaries, are used for recreational purposes such as sport fishing and swimming, as well as agricultural purposes such as irrigation. These streams also contain sensitive environments, habitats, and ecological receptors.
- ***Recreational Use***—Recreational activities occurring within 15 miles of and downstream from Yakima TC include fishing in the Columbia River and Yakima River. Kiddie Pond, within the cantonment area, is open to children for fishing.
- ***Sensitive Environments***—Sensitive environments at and around Yakima TC include riparian and wetland areas, wildlife protection areas, and habitats used by federally and state threatened and endangered species. Riparian and wetland areas are located along springs and creeks within Yakima TC with the most sensitive areas being Selah Creek, Lmuma Creek, Alkali Creek, Hanson Creek, and the western bank of the Columbia River.
- ***Habitat***—Riparian areas and wetlands occur along portions of perennial or intermittent streams, primarily along the Columbia River and Selah Creek. Riparian areas comprise only a small portion the land and are used disproportionately more by wildlife than other habitat. Upland shrub-steppe regions make up 95 percent of the Yakima TC habitat.
- ***Ecological Receptors***—There are both state and federally threatened and endangered species present on Yakima TC. Sensitive fish species on the Yakima TC include the Middle Columbia steelhead (*Oncorhynchus mykiss*), Upper Columbia steelhead (*Oncorhynchus mykiss*), and the Upper Columbia spring Chinook (*Oncorhynchus tshawytscha*). Additional federally and state threatened species include the American bald eagle (*Haliaeetus leucocephalus*), Ferruginous hawk (*Buteo regalis*), and the greater sage grouse (*Centrocercus urophasianus phaios*).
- ***Groundwater Use***—Groundwater within 4 miles downgradient from RCA ranges at Yakima TC is used for public and private drinking water supply. Off-installation public and private drinking water supply sources of concern include those in Selah, Yakima, and unincorporated areas of Yakima and Kittias Counties.

Potential human receptors include those within Yakima TC and near Yakima River relying on potential public and private wells within 15 miles from the RCA for drinking water. Ecological receptors include sensitive environments (e.g., wetlands and anadromous fish habitat).

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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 RCA 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 Yakima TC 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 collocated samples from each of three locations downstream from the RCAs on the Yakima TC (Figures 1-2 and 1-3) where surface water flows intermittently throughout the year. If surface water is not flowing when a quarterly sampling event is planned (e.g., frozen stream, 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., frozen stream, flooding).

The surface water and sediment sampling locations at Yakima TC are recommended based on the surface water hydrology of Selah Creek, Lmuma Creek, and the Upper Yakima Watershed for Range 14, Range 17, and Range 20 RCAs and the potential for DU contribution, and are located as follows:

- ***SWS-01***—Intermittent flow expected at sample location on Lmuma Creek in the Upper Yakima River watershed downstream from Ranges 17 and 20 RCAs where Lmuma Creek exits the installation.
- ***SWS-02***—Intermittent flow expected at sample location on Selah Creek in the Upper Yakima watershed downstream from Ranges 14, 17, and 20 RCAs where Selah Creek exits the installation.
- ***SWS-05***—Intermittent flow expected at sample location on Selah Creek downstream from RCA Range 14 where Selah Creek exits the installation to the Columbia River.

Additional locations were sampled during the Operational Range Assessment Program (ORAP) Phase II assessment (Figures 1-2 and 1-3). These locations were not selected for evaluation of the Yakima TC RCAs based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***SWS-03***—Intermittent flow expected at sample location on Selah Creek upstream from the Range 14 RCA. Even though SWS-03 is located downstream from the Range 14 RCA, the potential for DU migration off the installation will be captured (if present) by sampling farther upstream at SWS-02 located on the installation boundary.
- ***SWS-04***—Intermittent flow expected at sample location on Selah Creek upstream from the Range 14 RCA. Even though SWS-04 is located downstream from the Range 14 RCA, the potential for DU migration off the installation will be captured (if present) by sampling farther upstream at SWS-02 located on the installation boundary.

- ***SWS-06***—Intermittent flow expected at sample located west of the Columbia River and was used as a reference sample. This reference sampling location is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios.

Apart from portions of Lmuma Creek, all of the streams draining the RCAs on Yakima TC are intermittent, and many tributaries to the Columbia River discharge via subsurface flow when stream flows are low. Major storm and snowmelt events have the potential to erode soil and transfer it to surface water pathways. Even though the surface water flow at Yakima TC is intermittent, surface water and sediment sampling will be attempted quarterly. 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, then sampling will occur after that flow and no less than 3 months apart.

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 uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water 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).

The following locations were sampled during the ORAP Phase II assessment in 2012 and analyzed for uranium in sediment (EA 2013). The range of U-238/U-234 activity ratios from the May, June, and September sampling events are presented in Table 2-1.

Table 2-1. U-238/U-234 Activity Ratios for Sediment Samples

Sample Location	Number of Samples	Observed Ratios*
Sediment		
Lmuma Creek (SED-01)	3	0.77-1.09
Selah Creek (SED-02)	3	0.43-0.90
Selah Creek (SED-03)	3	0.81-0.92
Selah Creek (SED-04)	3	0.93-1.02
Cold Creek (SED-05)	3	0.71-1.18
Foster Creek (Reference) (SED-06)	3	0.69-0.98

* 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, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II assessment groundwater sampling in October 2010 were analyzed for explosives and perchlorate and not analyzed for uranium (EA 2013). The existing groundwater wells are shown in Figures 1-2 and 1-3.

Presently, no groundwater monitoring wells are located at or near 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 Yakima TC..

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 [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Yakima TC 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.

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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 this 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 Yakima TC will be coordinated with the Yakima TC 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 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). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.1 SURFACE WATER SAMPLING

Surface water samples will be collected quarterly from SWS-01, SWS-02, and SWS-05 and submitted as for laboratory analysis. The grab surface water samples 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 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.

3.2 SEDIMENT SAMPLING

The collection of sediment samples 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. Within some areas, water flow may be non-existent during dry weather. In this situation, only sediment samples will be taken. 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 TC) 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	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-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 Yakima Training Center RCAs

Parameter		Default Value	Range 14	Range 17	Range 20	Justification or Source
Internal dose library		DCFPA K 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	3.35×10^{-2}	3.35×10^{-2}	3.35×10^{-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	3.06×10^{-3}	3.06×10^{-3}	3.06×10^{-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	Depth to groundwater is generally 20 to 200 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	1,000	Groundwater flows east/west across RCAs
Contaminated zone total porosity		0.4	0.34	0.34	0.34	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Contaminated zone hydraulic conductivity (m/y)		10	5,550	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Contaminated zone b parameter		5.3	4.05	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Average annual wind speed (m/s)		2.0	7.4	7.4	7.4	www.usa.com for Yakima, WA
Precipitation rate (annual rainfall) (m/y)		1.0	0.45	0.45	0.45	www.usa.com for Yakima, WA
Saturated Zone						
Saturated zone total porosity		0.4	0.34	0.34	0.34	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Saturated zone effective porosity		0.2	0.28	0.28	0.28	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Saturated zone hydraulic conductivity (m/y)		100	5,550	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Saturated zone b parameter		5.3	4.05	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated Zone						
Unsaturated zone 1, total porosity		0.4	0.34	0.34	0.34	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Unsaturated zone 1, effective porosity		0.2	0.28	0.28	0.28	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Unsaturated zone 1, soil-specific b parameter		5.3	4.05	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	5,550	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand

[a] See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Yakima Training Areas RCAs

RCA Layout Parameter	Range 14				Range 17				Range 20			
Distance to nearest normally occupied area (m)	12,000				9,000				6,000			
Bearing of X axis (degrees)	180 (east)				135 (northeast)				180 (east)			
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	13,100	13,132	500	531.25	10,100	10,132	500	531.25	7,100	7,132
Leafy vegetables plot	500	531.25	13,134	13,166	500	531.25	10,134	10,166	500	531.25	7,134	7,166
Pasture, silage growing area	500	600	13,316	13,416	500	600	10,316	10,416	500	600	7,316	7,416
Grain fields	500	600	13,166	13,266	500	600	10,166	10,266	500	600	7,166	7,266
Dwelling site	500	531.25	13,000	13,032	500	531.25	10,000	10,032	500	531.25	7,000	7,032
Surface-water body	500	800	13,416	13,716	500	800	10,416	10,716	500	800	7,416	7,716
Atmospheric Transport Parameter												
Meteorological STAR file	WA_YAKIMA.str				WA_YAKIMA.str				WA_YAKIMA.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow (m)	12,000				9,000				6,000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	12,416				9,416				6,416			
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)	0				315				0			

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 Yakima TC does not exceed 1.0×10^{-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)	
Yakima Training Center Range 14	0.060	0.020
Yakima Training Center Range 17	0.060	0.022
Yakima Training Center Range 20	0.060	0.026

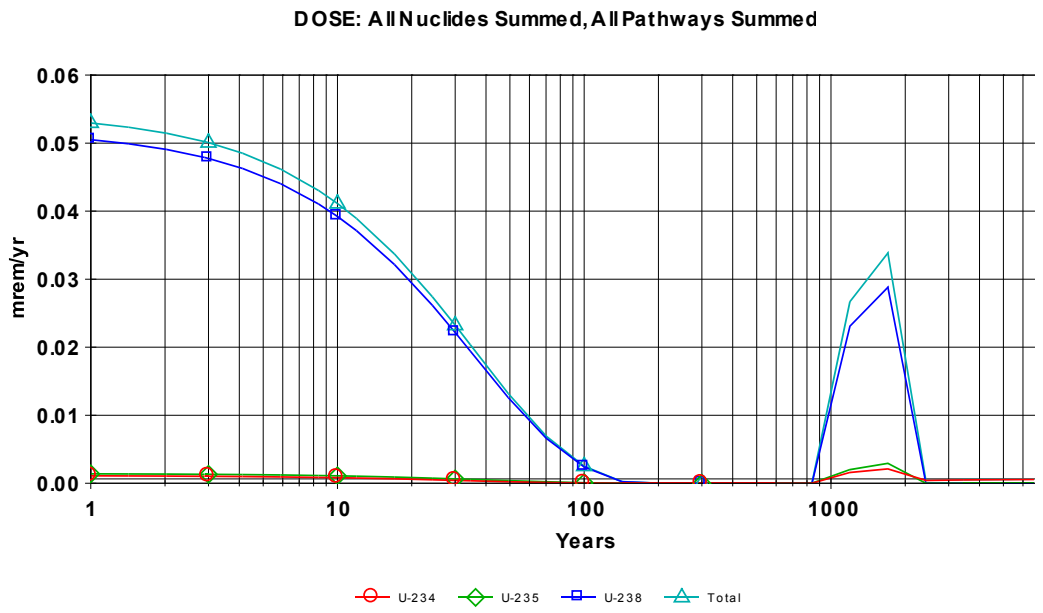
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

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

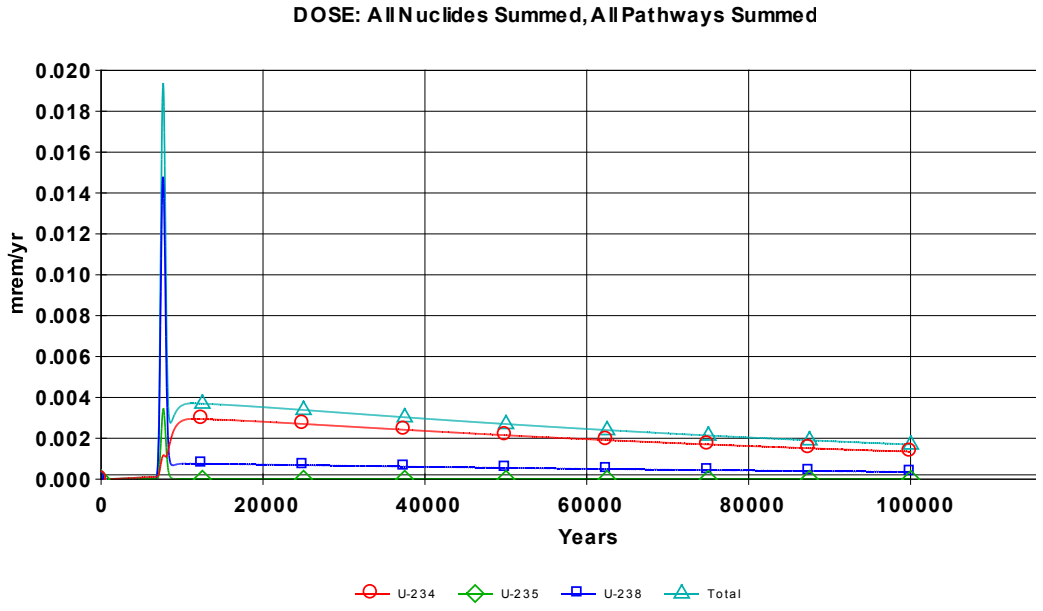
Figure 4-1. Residential Farmer Receptor Dose Graphs

Yakima Training Center Range 14

RCA Onsite (RESRAD)

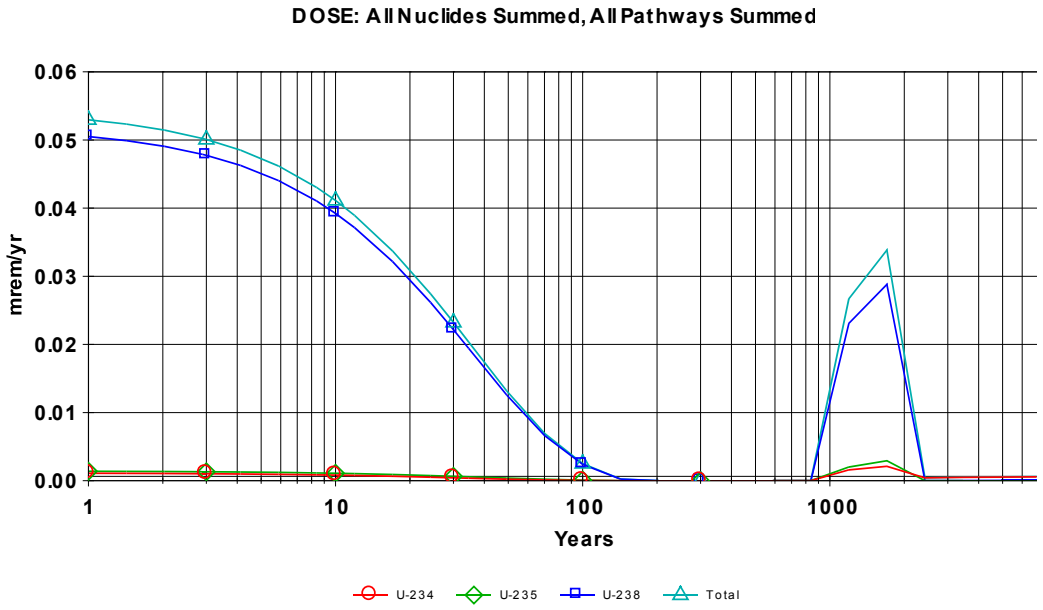


RCA Offsite (RESRAD-OFFSITE)

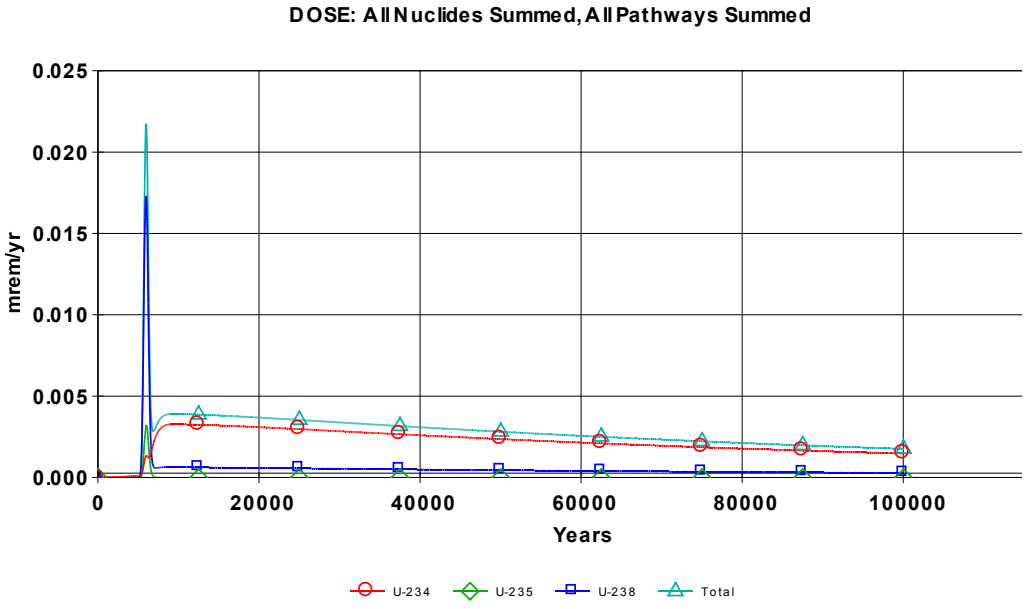


Yakima Training Center Range 17

RCA Onsite (RESRAD)

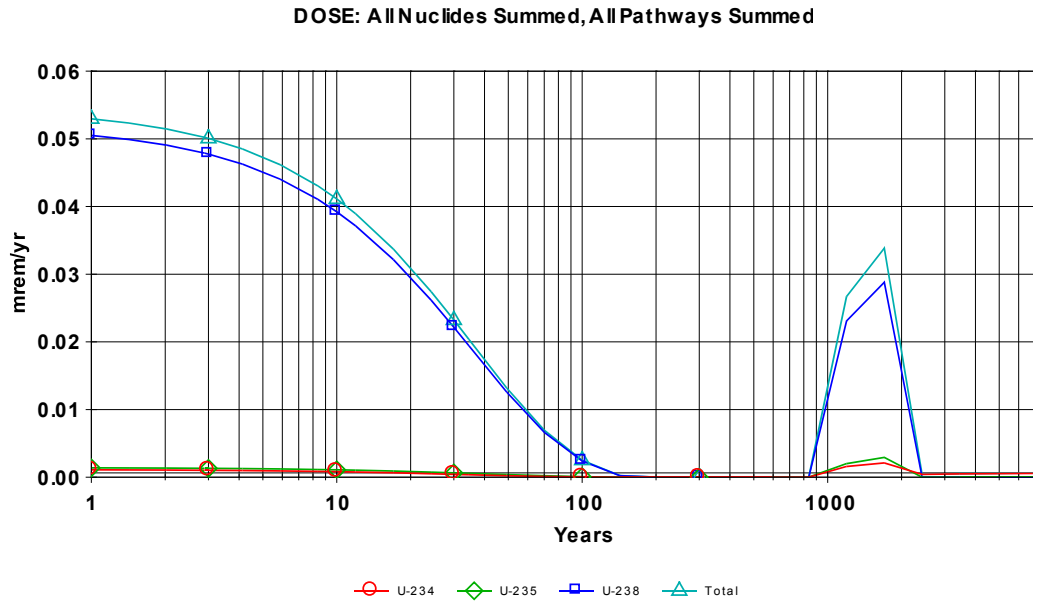


RCA Offsite (RESRAD-OFFSITE)

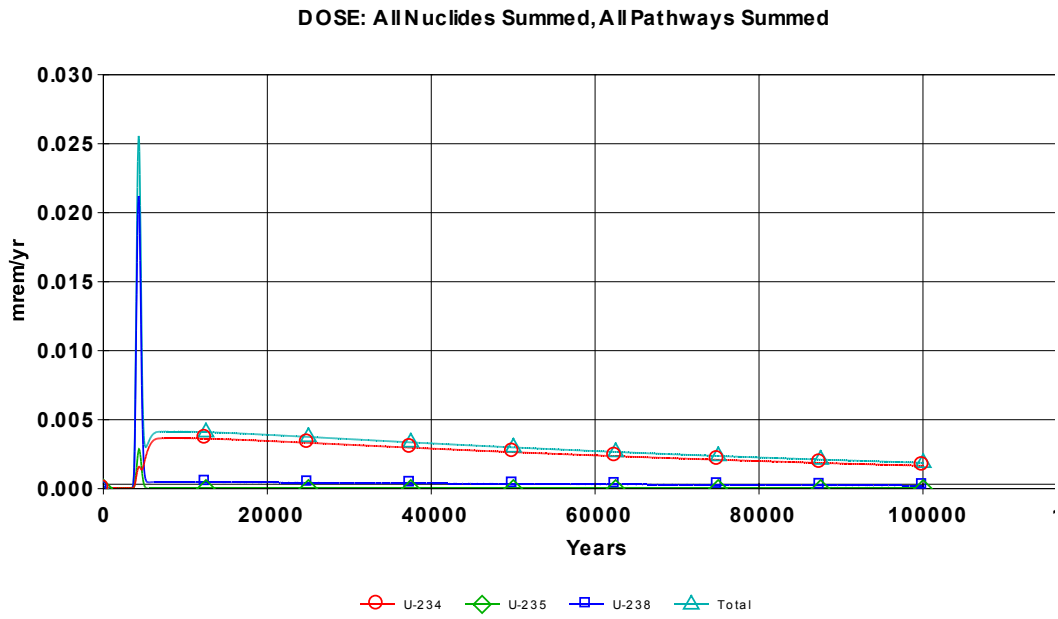


Yakima Training Center Range 20

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



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:

$$A_i = \lambda_i N_i$$

λ_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,

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

λ_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	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-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:

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

ε 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) = 3.7×10^{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 $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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