FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT POLK, LOUISIANA ANNEX 11

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

September 2016

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TABLE OF CONTENTS

Page

ACRONYMS AND ABBREVIATIONS iv

1.0 INTRODUCTION 1-1

1.1 PURPOSE 1-1
1.2 INSTALLATION BACKGROUND 1-1
1.3 HISTORICAL INFORMATION 1-3
1.4 PHYSICAL ENVIRONMENT 1-3
1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS 1-7

2.0 ERMP SAMPLE DESIGN 2-1

2.1 SURFACE WATER AND SEDIMENT 2-1
2.2 GROUNDWATER 2-2
2.3 SOIL 2-2

3.0 ERMP METHODOLOGY 3-1

3.1 SURFACE WATER SAMPLING 3-1
3.2 SEDIMENT SAMPLING 3-1

4.0 RESRAD CALCULATIONS 4-1

4.1 RESRAD INPUTS 4-2
4.2 RESULTS 4-3

5.0 REFERENCES 5-1

LIST OF TABLES

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

Table 2-1. U-238/U-234 Activity Ratios for Surface Water and Sediment Samples in 2013 2-2

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

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Polk RCA 4-2

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Polk RCA 4-3

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario 4-3

LIST OF FIGURES

Figure 1-1. Installation and Radiation Control Area Location Map 1-2

Figure 1-2. Radiation Control Area (Ranges 33 and 34A) and Proposed ERM Samples 1-5

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

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
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
IUA	Intensive Use Area
kg	Kilogram
LUA	Limited Use Area
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert 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
SLUA	Special Limited Use Area
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
WWII	World War II

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 Fort Polk, Louisiana, 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 Fort Polk, Louisiana. 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 (**SWS-04**) from the Range 33 and Range 34A 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

Fort Polk is located in western Louisiana, approximately 3 miles southeast of the town of Leesville and approximately 35 miles southwest of the city of Alexandria in Vernon Parish, Louisiana (Figure 1-1). The installation was established in 1941 as Camp Polk and provided training for soldiers during World War II (WWII). After WW II, the installation went through a series of deactivations and reactivations revolving around international crises. Camp Polk was renamed Fort Polk in November 1955 and was activated as a permanent installation in 1961. In 1993, Fort Polk became the home of the Joint Readiness Training Center, which remains the primary tenant today.

The operational range footprint at Fort Polk includes a total of 156 ranges encompassing 150,121 acres. Ownership of the main post, as indicated by the installation boundary, is divided into two portions. In general, the northern portion of the main post is owned by the U.S. Army while the southern portion, referred to as the Intensive Use Area (IUA), is owned by the U.S. Forest Service. In addition, operational ranges are included within the Limited Use Area (LUA) and the Special Limited Use Area [SLUA], which are owned by the U.S. Forest Service (EA 2013).

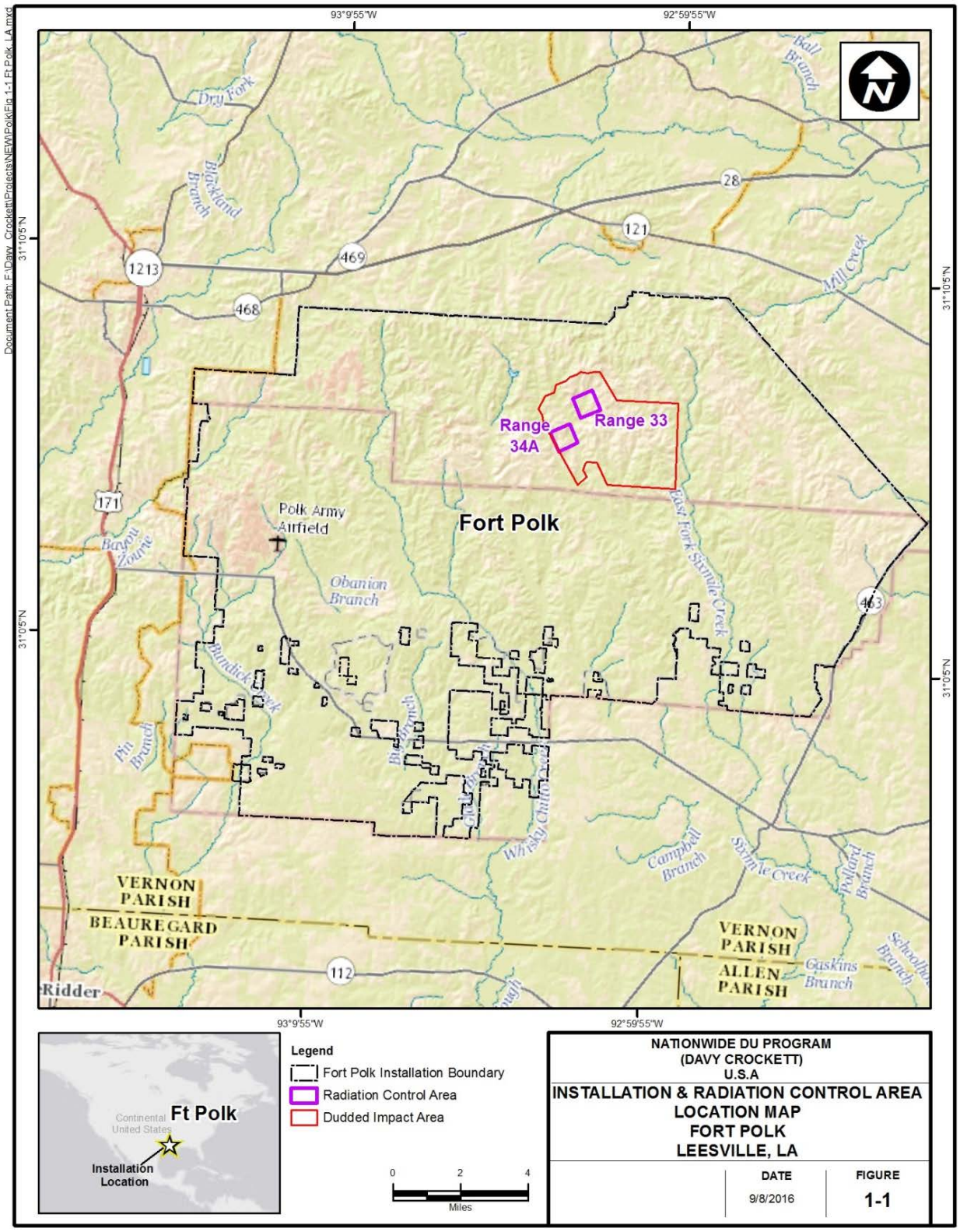

Figure 1-1. Installation and Radiation Control Area Location Map

An Archives Search Report (ASR) (USACE 2008) confirmed the presence of two ranges where the Davy Crockett weapons systems were used at Fort Polk. Ranges 33 and 34A or the radiation control areas (RCAs) consist of 247 and 242 acres, respectively (Figure 1-2).

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 potentially 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]), Joint Base Lewis-McChord (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 Ranges 33 and 34A; therefore, the U.S. Army assumes that most, if not all, of the 370 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Polk is located on the West Gulf Coastal Plain section of the Coastal Plain Physiographic Province. The terrain is characterized by flat to gently rolling plains in the southern portion of the installation and gently rolling to rolling plains across the remainder of the installation.

The operational range area on Fort Polk is drained by seven sub-watersheds: Anacoco Bayou, Calcasieu River, Bundick Creek, Whiskey Chitto Creek, Sixmile Creek, Tenmile Creek, and Kisatchie Bayou. The installation is located on a topographic high where nearly all streams originate on-range and flow off-installation in a radial pattern. Streams generally flow in a southerly direction and eventually empty into the Gulf of Mexico.

The Dudded Impact Area is drained to the south-southeast by West Fork Sixmile Creek and East Fork Sixmile Creek within the Sixmile Creek sub-watershed. However, only West Fork Sixmile Creek drains areas of the Dudded Impact Area associated with historical DU usage (i.e., Ranges 33 and 34A) (Figure 1-2).

Fort Polk is underlain by three aquifers (alluvial, Chicot, and Evangeline) that are further underlain by the Castor Creek confining unit. The Chicot and Evangeline aquifers serve as a primary source of drinking water in the vicinity of the installation and the Chicot aquifer is designated as a sole-source aquifer. The depth to water in the surficial unconfined aquifers ranges from 10 to 30 feet below ground surface (bgs). Locally, groundwater flow is generally to the southeast and reflects the dip direction of the geologic units, which varies from 50 to 70 feet per mile near the outcrop and may discharge to local surface water off-range. Depth to water increases significantly down-dip. Groundwater within the Chicot aquifer is generally encountered at 30 to 40 feet bgs in supply wells located on the Cantonment Area.

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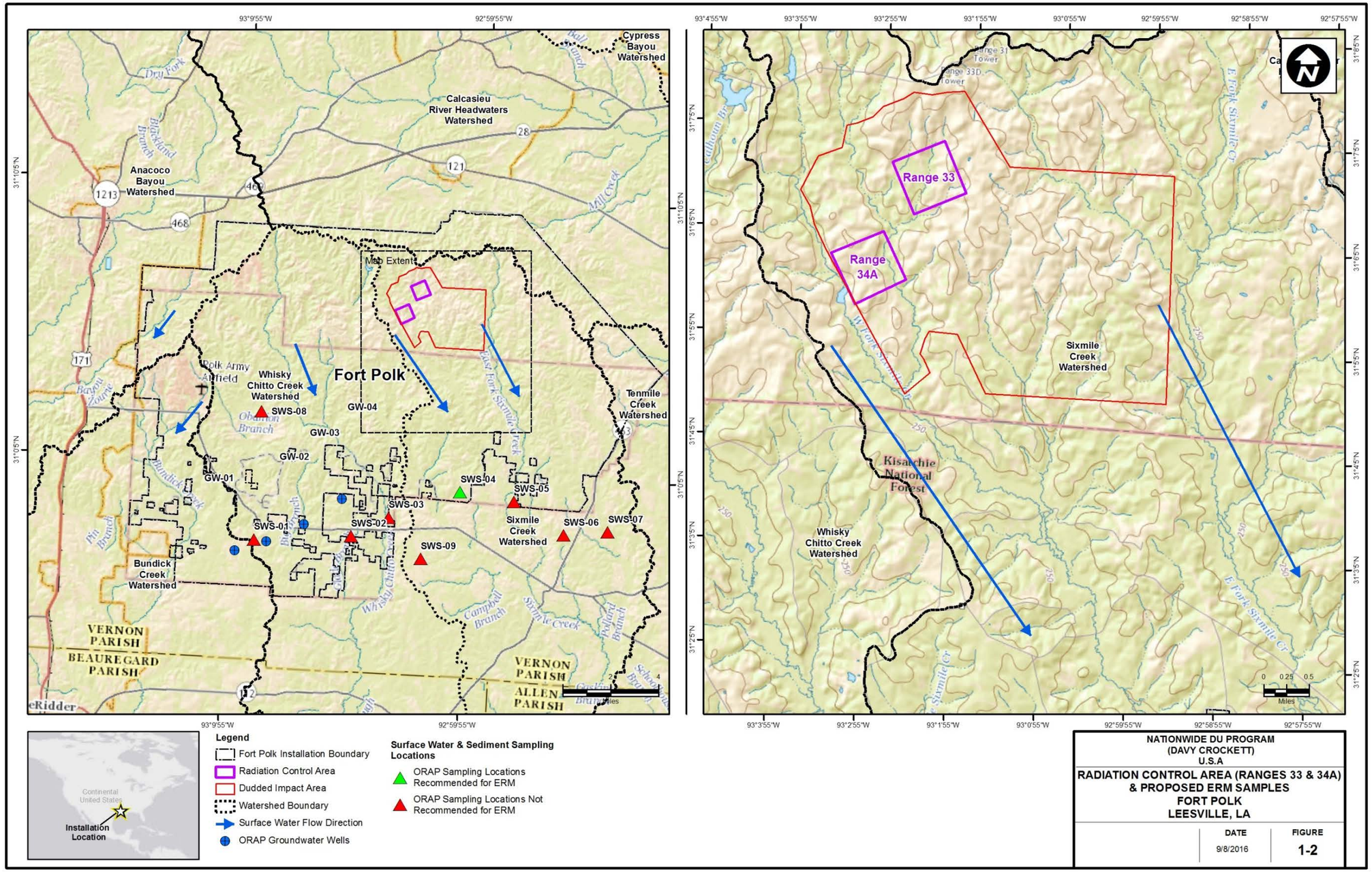

Figure 1-2. Radiation Control Area (Ranges 33 and 34A) and Proposed ERM Samples

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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 Range 33 and 34A RCAs at Fort Polk are as follows:

- ***Surface Water Use***—No known use of surface water exists for consumption of drinking water downstream from Fort Polk.
- ***Recreational Use***—Potential interaction with surface water and sediment is possible via recreational activities such as fishing and swimming within 15 miles downstream from the installation. During the Operational Range Assessment Program (ORAP) Phase II assessment, calculation of uranium activity ratios in surface water and sediment concluded that the detected isotopes originated from naturally occurring sources and are not attributable to DU containing munitions used at the installation (EA 2013).
- ***Sensitive Environments***—Sensitive environments downstream from Fort Polk include riparian and wetland areas, the Kisatchie National Forest, and scenic rivers.
- ***Habitat***—The presence of wetland areas, the Kisatchie National Forest, and scenic rivers provides the potential habitat for federally and state-listed species with a full aquatic developmental life-cycle (e.g., Kisatchie stream crayfish, southern creek mussel, and Louisiana pigtoe).
- ***Ecological Receptors***—The Dudded Impact Area (including the Range 33 and 34A RCAs) are drained by the West Fork Sixmile Creek, which includes off-range sensitive environments (Sixmile Creek, Kisatchie National Forest, and wetland areas) and ecological receptors, such as the Kisatchie stream crayfish, southern creek mussel, and Louisiana pigtoe.
- ***Groundwater Use***—Groundwater is used for public and private drinking water supply within 4 miles downgradient from the installation boundary. There are numerous wells downgradient from the installation's southern boundary that access water from the Chicot and Evangeline aquifers. However, the Dudded Impact Area including the RCAs does not have any downgradient well receptors within 4 miles (EA 2013).

In summary, potential human receptors include those within the Fort Polk area and Vernon Parish relying on potential public and private water wells outside the 4-mile distance downgradient from the RCAs. Ecological receptors include sensitive environments, such as Sixmile Creek, Kisatchie National Forest, and wetland areas.

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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 RCAs or in 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 RCAs (Ranges 33 and 34A) at Fort Polk 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 at Fort Polk (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 was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-04***—The selected perennial sampling point is located on the West Fork Sixmile Creek, downstream from Ranges 33 and 34A at the installation's southern boundary. This sample location allows for relatively easy access, and site conditions are similar to previous surface water sampling locations at Fort Polk. The stream channel at the SWS-04 location is approximately 20 feet wide.

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

- ***SWS-03 and SWS-05***—While these locations are also generally downgradient from the RCAs, neither location is part of the sub-watershed that captures surface water flow from the RCAs and discharges into the West Fork Sixmile Creek. SWS-03 is located on Birds Creek, which is part of the Whiskey Chitto Creek watershed, and SWS-05 is located on the East Fork Sixmile Creek sub-watershed.
- ***SWS-09***—This location is farther south of SWS-04 and was used as a reference sample location during the ORAP Phase II assessment as it is not influenced by runoff from the RCAs. Furthermore, as discussed above, background/reference sampling is not required under this Site-Specific ERMP.

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 on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238/uranium-234 (U-238/U-234) activity ratio exceeds 3.0, the U.S. Army will notify 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 samples will be attempted to be collected quarterly. In the event that the sampling location is dry when the field crew mobilizes to collect the samples, only a sediment sample will be collected at that location. If surface water routinely flows from the RCA, sampling of the surface water will occur every 3 months. If flow is intermittent, then sampling will occur during that flow, but no less than 3 months apart.

The recommended downstream sampling location, SWS-04, for the environmental radiation monitoring (ERM) and the reference location, SWS-09, were sampled during the ORAP Phase II assessment in 2013 and analyzed for uranium for both surface water and sediment (EA 2013). The U-238/U-234 activity ratios from the wet and dry season sampling events in 2012/2013 is presented in Table 2-1.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water and Sediment Samples in 2013

Sample Location	Number of Samples	Observed Ratios*
Surface Water		
Downstream (SWS-04)	8	Non-detect-1.42
Reference (SWS-09)	4	Non-detect-0.87
Sediment		
Downstream (SWS-04)	3	0.64-0.92
Reference (SWS-09)	3	0.76-1.77

* 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 quantitative assessment in 2013 were not analyzed for radiological parameters (EA 2013). 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 Fort Polk.

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, Fort Polk 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 RCA 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 the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedure (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 Fort Polk will be coordinated with the Fort Polk 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

A surface water sample will be collected at SWS-04 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 stream beds 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 on 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 (370 kg) 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 Fort Polk RCA

Parameter		Default Value	Fort Polk Ranges 33 and 34A	Justification or Source
Internal Dose Library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	3.64×10^{-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	3.33×10^{-3}	
	U-238	N/A	0.55	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 10 to 30 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.43	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand (Soil is loamy fine sand from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	6.5	www.usa.com for Fort Polk, LA
Precipitation rate (annual rainfall) (m/y)		1.0	1.5	www.usa.com for Fort Polk, LA
Saturated Zone				
Saturated zone total porosity		0.4	0.43	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Saturated zone effective porosity		0.2	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Saturated zone hydraulic conductivity (m/y)		100	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.43	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Unsaturated zone 1, effective porosity		0.2	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand

[a] See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Polk RCA

RCA Layout Parameter	Fort Polk Ranges 33 and 34A			
Distance to nearest normally occupied area (m)	6,400			
Bearing of X axis (degrees)	0 (west)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	7500	7532
Leafy vegetables plot	500	531.25	7534	7566
Pasture, silage growing area	500	600	7716	7816
Grain fields	500	600	7566	7666
Dwelling site	500	531.25	7400	7432
Surface-water body	500	800	7816	8116
Atmospheric Transport Parameter				
Meteorological STAR file	LA_ALEXANDRIA.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	6,400			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	6,816			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	180			

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 Fort Polk 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 SML SUC-1593.

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

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Polk Ranges 33 or 34A	6.4×10^{-2}	4.2×10^{-2}

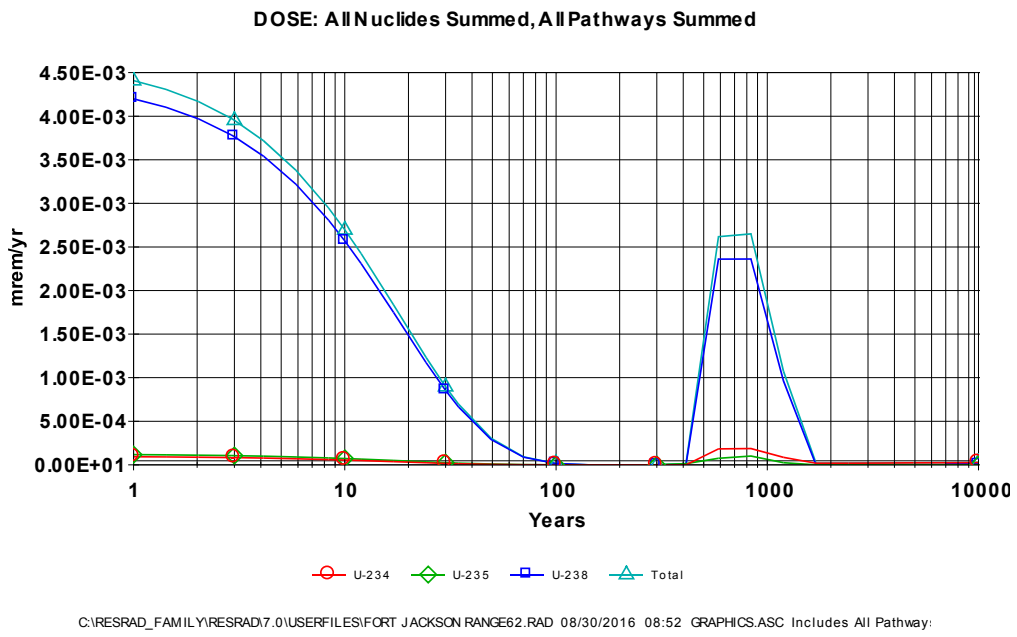
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

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

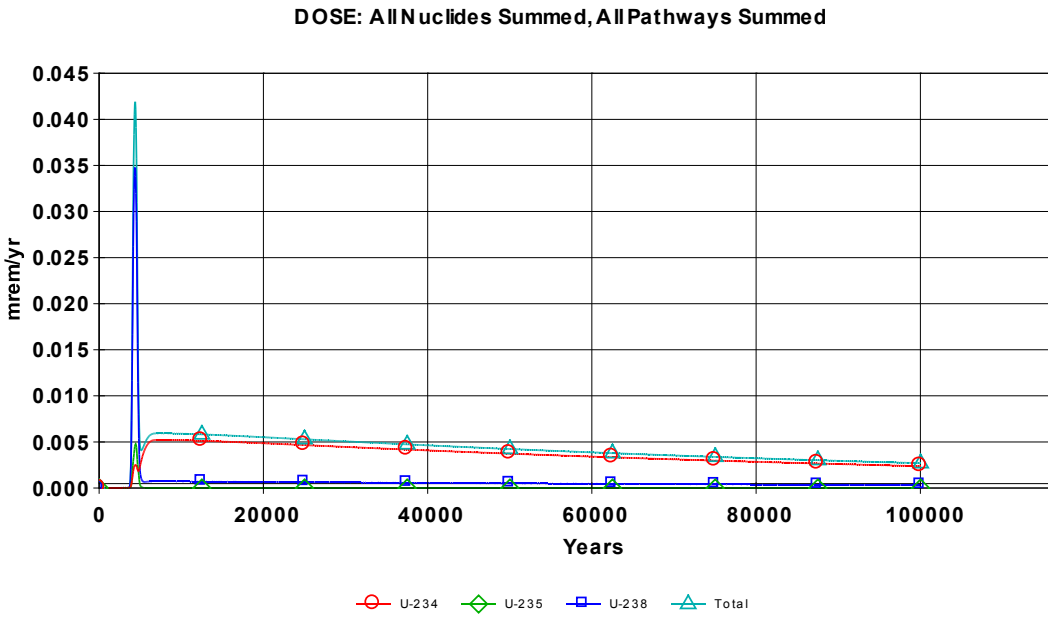
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Polk Ranges 33 or 34A

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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