FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN
FORT SILL, OKLAHOMA
ANNEX 13

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

September 2016

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
ATTN: IMSO, Building 2261
2405 Gun Shed Road, Fort Sam Houston, Texas 78234-1223

Submitted To:

U.S. NUCLEAR REGULATORY COMMISSION
Office of Nuclear Material Safety and Safeguards
11545 Rockville Pike, Two White Flint North, Rockville, Maryland 20852-2738

THIS PAGE WAS INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
kg	Kilogram
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
SML	Source Material License
SOP	Standard Operating Procedure
SWMU	Solid Waste Management Unit
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
USGS	U.S. Geological Survey
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 Fort Sill, in Lawton, Oklahoma, in addition to those presented in the Programmatic Approach for 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 Sill. 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-06A**) from the FP 182/West Range RCA, 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 Sill is a 93,829-acre installation located in Comanche County, Oklahoma, 90 miles southwest of Oklahoma City (Figure 1-1). The installation is bound on the north by Wichita Mountains National Wildlife Refuge and the town of Medicine Park. Fort Sill is bordered to the south by the towns of Indiahoma and Cache and the city of Lawton. The installation boundaries extend approximately 26 miles from east to west and approximately 6 miles from north to south. Fort Sill lies within the Central Lowlands Province and is generally characterized as a region of rolling topography and moderate relief.

In 1869, Fort Sill was originally staked out by Major General Philip H. Sheridan, who led a campaign into Indian Territory to stop hostile tribes from raiding border settlements in Texas and Kansas. The last Indian lands in Oklahoma opened for settlement in 1901, and 29,000 homesteaders registered for the land lottery at Fort Sill. The frontier disappeared, and the mission of Fort Sill gradually changed from cavalry to field artillery. In 1902, the first artillery battery arrived at Fort Sill, and the last cavalry regiment departed in 1907. Historically, various training activities at Fort Sill included the Infantry School of Musketry, the School for Aerial Observers, the Air Service Flying School, and the Army Aviation School. In 1911, the School of Fire for the Field Artillery was founded at Fort Sill, where it continues to operate today as the renowned U.S. Army Fires School of Excellence.

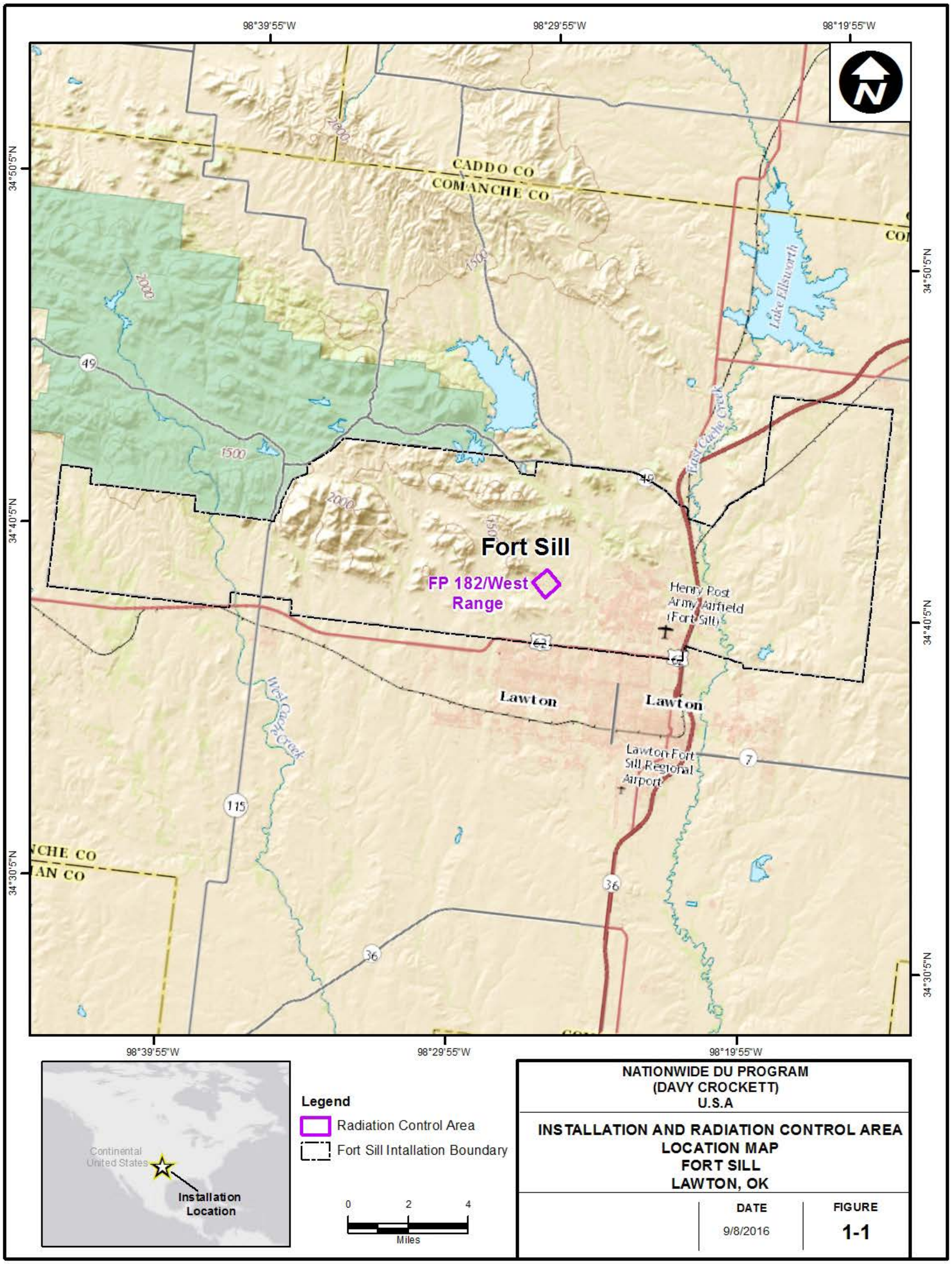


Figure 1-1. Installation and Radiation Control Area Location Map

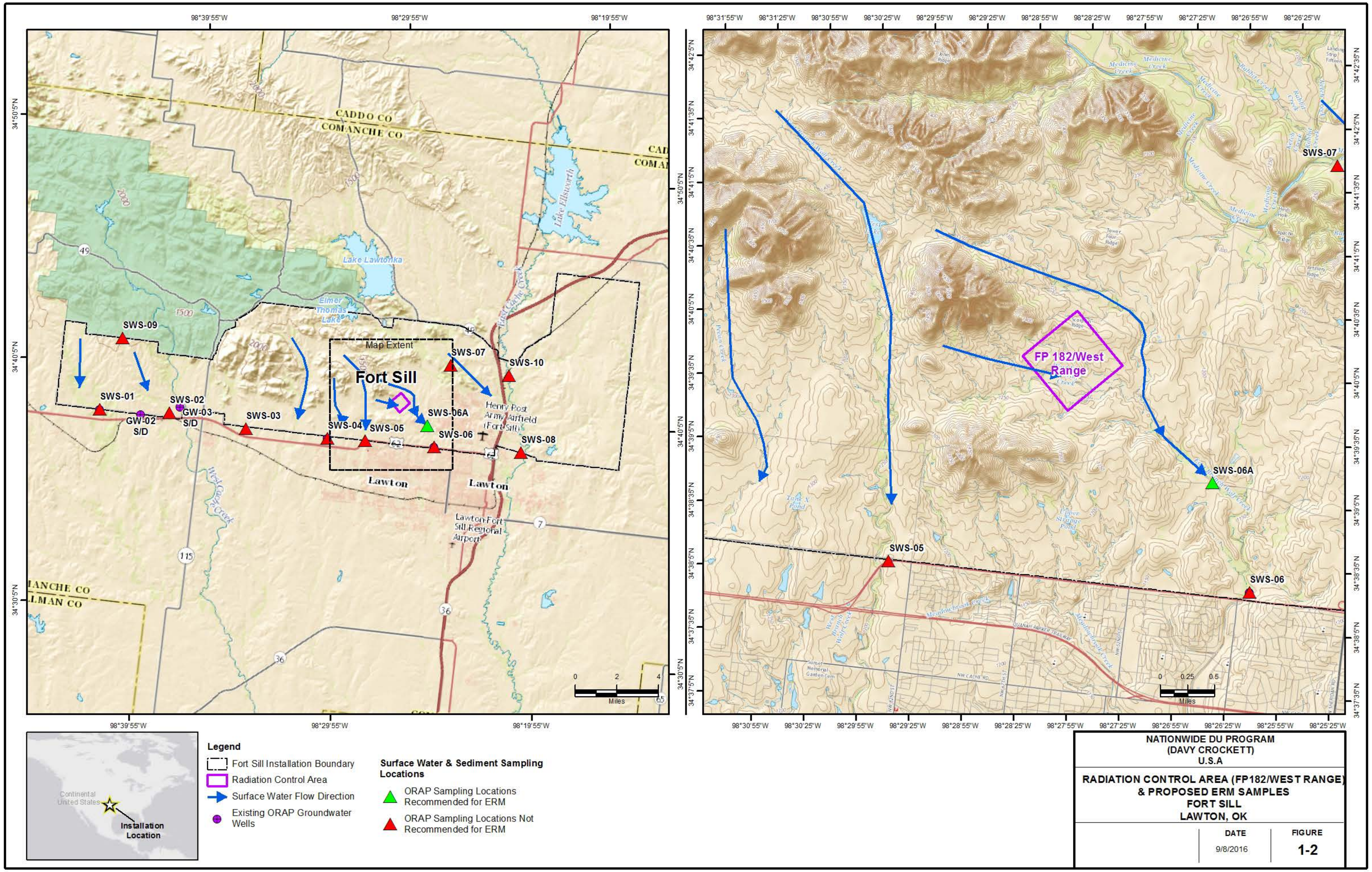


Figure 1-2. Radiation Control Area (FP 182/West Range) and Proposed ERM Samples

THIS PAGE WAS INTENTIONALLY LEFT BLANK

Currently, Fort Sill operates as the U.S. Army Field Artillery Center with the mission of training field artillery leaders, supporting unit training and readiness, and deploying operating forces. The installation mission is accomplished by the comprehensive use of 231 ranges located throughout the operational area footprint, including 4 major impact areas: the North and South Arbuckle Ranges, the West Range, and the Quanah Range, each surrounded by multiple firing points and training areas. Only the Cantonment Area, located adjacent to the city of Lawton in the south-central portion of the base, and the two smaller non-operational use areas, located centrally between the North and South Arbuckle Range Impact Areas, are excluded from training activities. The nearest normally occupied areas to the radiation control area (RCA) is a movie theater, which is located approximately 2.5 miles south of the RCA (Figure 1-2). The RCA is located in the West Range, more specifically at training range FP 182/West Range.

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]), 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 the RCA; therefore, it is assumed that most, if not all, of the 120 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Sill is located in the Osage Plains section of the Central Lowland Province of Oklahoma and can be divided into three distinct landforms: low plains, high plains, and low hills.

Surface water drainage across Fort Sill is divided into three watersheds with boundaries generally from north-to-south and containing both intermittent and perennial creeks. Approximately 90 percent of the land area is within the West Cache and East Cache Creek watersheds, while the remaining 10 percent is within the Beaver Creek watershed to the east. The RCA is located within the East Cache Creek watershed.

Many of the surface water systems within the East Cache Creek watershed originate north of the installation and exit the installation's southern boundary through one perennial creek (East Cache Creek) and a number of intermittent creeks. Intermittent West Cache Creek was noted to have sustained flow during the U.S. Army Operational Range Assessment Program (ORAP) Phase I assessment (EA 2014). These creeks are sourced by Elmer Thomas Lake, Lake Lawtonka, and Lake Ellsworth to the north, which capture runoff from the Wichita Mountains. Based upon a review of precipitation patterns and stream flow data from U.S. Geological Survey (USGS) gauging stations on Little Beaver Creek (25 miles southeast of Fort Sill) and Jimmy Creek (20 miles northwest of Fort Sill), the highest stream flows (wet season) typically occur from May to June.

The nearest known domestic or public supply well is approximately 4.5 miles downgradient from the RCA. Domestic or public supply wells are screened within one of three aquifers. Since the three aquifers recharge from youngest to oldest, and since all of the potential receptor wells are also screened within one of these aquifers, it is unnecessary to describe additional aquifers within this report. The groundwater flow is to the southeast (EA 2014). The Quaternary alluvium, Permian Post Oak Conglomerate, and Cambro-Ordovician Arbuckle-Timbered Hills aquifers are described below:

- ***Quaternary Alluvium—***The Quaternary alluvium is the least prevalent member of the Fort Sill groundwater system and is present along most of the major surface water pathways with an increased prevalence along the southern third of Fort Sill. The alluvium consists of sand, clay, and gravel, and is recharged by stream flow and/or precipitation on the floodplain.
- ***Permian Post Oak Conglomerate—***The Permian Post Oak Conglomerate aquifer occurs along the flanks of the igneous rocks of the Wichita Mountains and overlies the Arbuckle-Timbered Hills aquifer. This aquifer comprises a combination of cobbles, gravel, sand, silt, clay, shale, and limestone conglomerate. Recharge occurs through direct infiltration via precipitation and indirect recharge through overlying alluvium, which includes runoff from the low-permeability Cambrian volcanic complexes comprising the Wichita Mountains. The thickness of the Post Oak Conglomerate is approximately 300 feet below ground surface (bgs) at the installation boundary and thickens to the south. Outcrops of the Quaternary alluvium occur as thin and localized units within the stream valleys.
- ***Cambro-Ordovician Arbuckle-Timbered Hills Aquifer—***The Cambro-Ordovician Arbuckle-Timbered Hills comprises mainly dolomite with interbedded shale, outcrops only in two small sections of Fort Sill: near the south-central boundary and a small area along the northern boundary of the installation. The total thickness of the aquifer can range from several feet to upwards of 6,000 feet well southeast of Fort Sill. Aquifer recharge within the installation occurs primarily though the Post Oak Conglomerate on the southern flank of the Wichita Mountains. Aquifer depth, according to available well information, is between 700 and 1,020 feet. Due to the depth to water averaging approximately 140 feet bgs, it is likely that an upward gradient exists within this aquifer.

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 RCA at Fort Sill are as follows:

- ***Surface Water Use***—Surface water migrating downstream from Fort Sill within the East Cache Creek watershed and associated tributaries contains ecological receptors, including sensitive wetlands. Surface water comprises a portion of the drinking water for Fort Sill and the town of Lawton, Oklahoma to the south; however, the surface water is captured upstream of the installation.
- ***Recreational Use—***A potential for recreational fishing downstream from Fort Sill exists.
- ***Sensitive Environments***—Sensitive environments (i.e., wetlands) are found within the non-operational areas of Fort Sill. Additional wetlands are identified downstream from Fort Sill along each of the tributaries exiting the installation to the south.
- ***Habitat***—Primary habitat types at Fort Sill include forested areas and scrubland or grassland areas. The installation is located within a transition zone of eastern tall grass prairie and southwestern short grass prairies, which comprise the dominant habitat. Habitat for Federal-and/or state-listed threatened and endangered species (black capped vireo (*[Vireo atricapilla]*) is found on in the northern portions of the West and Quanah Ranges of Fort Sill; however, the habitat is not found in the RCA.

- ***Ecological Receptors***—The National Wetlands Inventory identified sensitive environments (i.e., wetlands) within 1 mile downstream from the installation boundary within the East Cache Creek watershed.
- ***Groundwater Use***—No wells currently exist on Fort Sill. Most historical wells installed on the installation were monitoring wells surrounding solid waste management units (SWMUs). The unconfirmed location of a local supply well was noted during the ORAP Phase II assessment; however, the location of this well is unknown and is presumed to be abandoned. Production wells and private landowner supply wells are used for potable water downgradient from Fort Sill. The nearest of these wells to the RCA is approximately 4.5 miles downgradient from the RCA; therefore, consumers of waters from these wells are considered potential receptors. Production wells and private landowner supply wells are screened within either the Cambro-Ordovician Arbuckle-Timbered Hills or Permian Post Oak Conglomerate aquifers and may receive recharge via percolation of precipitation from surface areas, including the RCA.

Potential human receptors include those to the southeast of the RCA beyond the installation boundary that rely on private wells or potential public wells for potable water. Ecological receptors include sensitive environments to the south of the RCA receiving surface water (e.g., wetlands).

THIS PAGE WAS INTENTIONALLY LEFT BLANK

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 the RCA at Fort Sill 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 a location downstream from the RCA (Figure 1-2) in an intermittent creek near the Fort Sill installation boundary. 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 location at Fort Sill was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-06A***—The selected sampling point is located on the East Branch of Wolf Creek downgradient from flow from the part of the West Range where the RCA is located.

Additional locations were sampled during the ORAP Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the FP 182/West Range RCA based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***SWS-01, SWS-02, SWS-03, SWS-04, SWS-09, SWS-09A***—These surface water and sediment sampling points are located in the West Cache Creek watershed. These sampling points are not relevant because the RCA is not within their watershed.
- ***SWS-05***—This surface water and sediment sampling point is located where the West Branch of Wolf Creek exits the installation. This sampling point is not relevant because the RCA is not within its watershed.
- ***SWS-06***—This surface water and sediment sampling point is downstream from SWS-06A where the East Branch of Wolf Creek exits the installation. SWS-06 is located farther downstream and sustains lower flows than SWS-06A.
- ***SWS-07, SWS-08, SWS-10***—These surface water and sediment sampling points are located to the north and east of the RCA in a portion of the East Cache Creek watershed that is upstream where the East Branch of Wolf Creek enters the East Cache Creek. These sampling points are not relevant because the RCA is not within their watershed.

Even though surface water at Fort Sill is intermittent, 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 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 quarterly or every 3 months. If flow is intermittent, then sampling will occur during that flow, but 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 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 (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 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).

Sediment was collected at the recommended environmental radiation monitoring (ERM) sampling point (SWS-06A), the downstream sampling point (SWS-06), and the upstream reference sampling point (SWS-09) during the ORAP Phase II assessment in 2012 and analyzed for uranium (EA 2014). Surface water was not available at these sampling points, so additional sediment sampling was performed. The range of U-238/U-234 activity ratios from the May, June, and September 2012 sampling events is presented in Table 2-1.

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

Sample Location	Number of Samples	Observed Ratios[a]
Sediment		
Downstream (SWS-06A)	3	0.60-1.14
Downstream (SWS-06A)[b]	3 [c]	0.85-1.06
Downstream (SWS-06)	3	0.94-1.05
Downstream (SWS-06)[b]	3[c]	0.94-1.06
Reference (SWS-09)	3	1.51-1.56
Reference (SWS-09)[b]	3 [c]	1.01-1.12

[a] 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).
[b] The ORAP Phase II expanded the sediment investigation due to the lack of surface water.
[c] The three samples include a primary, duplicate, and triplicate.

2.2 GROUNDWATER

Groundwater samples were collected during the ORAP Phase II assessment in 2006; however, the samples were not analyzed for radiological parameters (EA 2014). The existing groundwater monitoring wells are shown in Figure 1-2.

Presently, no groundwater monitoring wells are located at or near the RCA. 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 Sill.

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 Sill 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.

THIS PAGE WAS INTENTIONALLY LEFT BLANK

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 Sill will be coordinated with the Fort Sill 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-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 the weight percentage of U-235 mass 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 quarterly from SWS-06A 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 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 the RCA by multiplying the entire mass of DU listed on the license for the installation (120 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	Mass Abundance[b]
	Ci/g	%
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 Sill RCA

Parameter		Default Value	Fort Sill FP 182/West Range	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	1.18×10^{-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	1.08×10^{-3}	
	U-238	N/A	0.18	
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 140 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	0.45	RESRAD Manual (DOE 2001) Table E-8 for Silt (Soil is cobbly loam from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	1,090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Contaminated zone b parameter		5.3	4.9	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Average annual wind speed (m/s)		2.0	7.3	www.usa.com for Fort Sill, OK
Precipitation rate (annual rainfall) (m/y)		1.0	0.89	www.usa.com for Fort Sill, OK
Saturated Zone				
Saturated zone total porosity		0.4	0.42	RESRAD Manual (DOE 2001) Table E-8 for Clay
Saturated zone effective porosity		0.2	0.06	RESRAD Manual (DOE 2001) Table E-8 for Clay
Saturated zone hydraulic conductivity (m/y)		100	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Saturated zone b parameter		5.3	10.4	RESRAD Manual (DOE 2001) Table E.2 for Silty Clay
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.42	RESRAD Manual (DOE 2001) Table E-8 for Clay
Unsaturated zone 1, effective porosity		0.2	0.06	RESRAD Manual (DOE 2001) Table E-8 for Clay
Unsaturated zone 1, soil-specific b parameter		5.3	10.4	RESRAD Manual (DOE 2001) Table E.2 for Silty Clay
Unsaturated zone 1, hydraulic conductivity (m/y)		10	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay

[a] See Table 4-1.

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

RCA Layout Parameter	FP 182/West Range			
Distance to nearest normally occupied area (m)	3,200			
Bearing of X axis (degrees)	270 (south)			
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	4300	4332
Leafy vegetables plot	500	531.25	4334	4366
Pasture, silage growing area	500	600	4516	4616
Grain fields	500	600	4366	4466
Dwelling site	500	531.25	4200	4232
Surface-water body	500	800	4616	4916
Primary Contamination Parameter				
Length parallel to aquifer flow* (m)	142			
Atmospheric Transport Parameter				
Meteorological STAR file	OK_OKLAHOMA_CITY_TIN.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	3,200			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	3,616			
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 (m)	90			

* Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

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 Sill 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

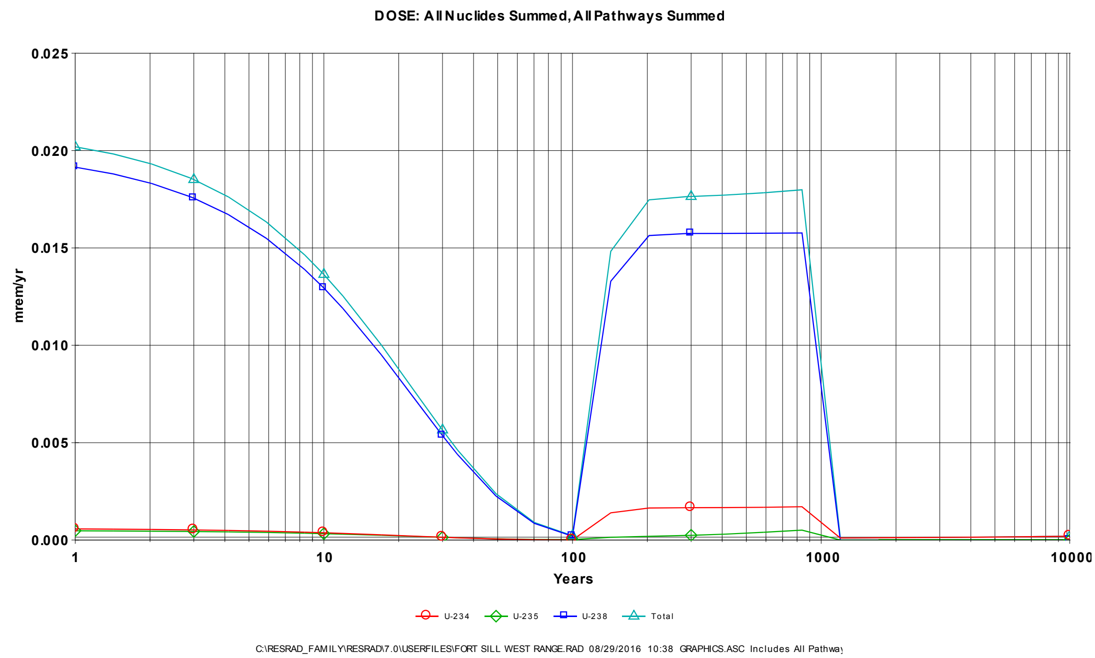
RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Sill FP 182/West Range	0.021	0.013

[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.

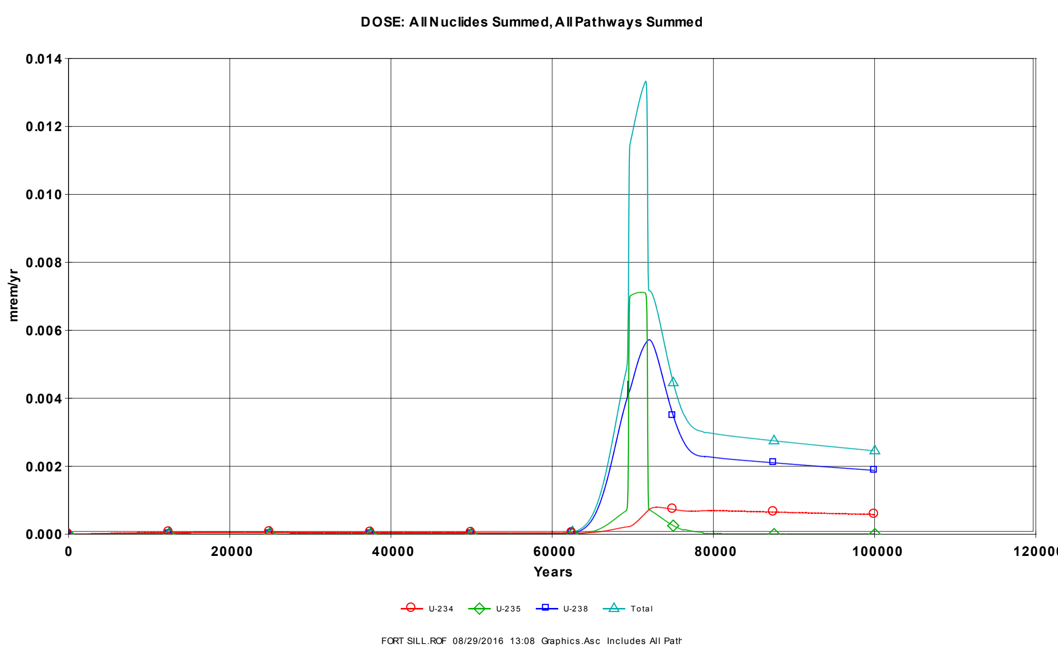
RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Sill FP 182/West Range
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 ($N = 6.02 \times 10^{23}$),[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

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

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,

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

The NRC provides in 10 CFR 20:

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

Returning to the first equation above, then

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

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]

$a_{\text{U-234}} = 0.00000356$
$a_{\text{U-235}} = 0.00093806$
$a_{\text{U-238}} = 0.99905838$

[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.

EA (EA Engineering, Science, and Technology, Inc.). 2014. Final Operational Range Assessment Program, Phase II Quantitative Assessment Report, Fort Sill, Oklahoma

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. 2014. 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).

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.

THIS PAGE WAS INTENTIONALLY LEFT BLANK