FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN
POHAKULOA TRAINING AREA, HAWAII
ANNEX 17

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

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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

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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
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
HARNG	Hawaii Army National Guard
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
msl	Mean Sea Level
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
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 Pohakuloa Training Area (TA) in Hawaii, 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 Pohakuloa TA. 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 (**ERM-01**) from the 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

Pohakuloa TA is a 131,425-acre installation located on the island of Hawaii, approximately 40 miles west of Hilo and 40 miles east of Kawaihae, Hawaii (Figure 1-1). A public highway, known as Saddle Road, traverses the northern portion of the area and serves as a major land route.

Pohakuloa TA was acquired by the United States from the State of Hawaii and private landowners. The facility is used by the U.S. Army Hawaii, the U.S. Marine Corps, and the Hawaii Army National Guard (HARNG).

Pohakuloa TA consists of a cantonment area, a maneuver area, an impact area, and a safety buffer zone. The cantonment area or Base Camp consists of administrative and logistical buildings, troop billets, Bradshaw Airfield, and the ammunition storage area. The Maneuver Area consists of limited road net and prominent terrain features. The Pohakuloa Impact Area is an area generally bounded on the north by Lava Road, on the east by Redleg Road, on the south by Kona-Hilo Trail, and on the west of Bobcat Trail.

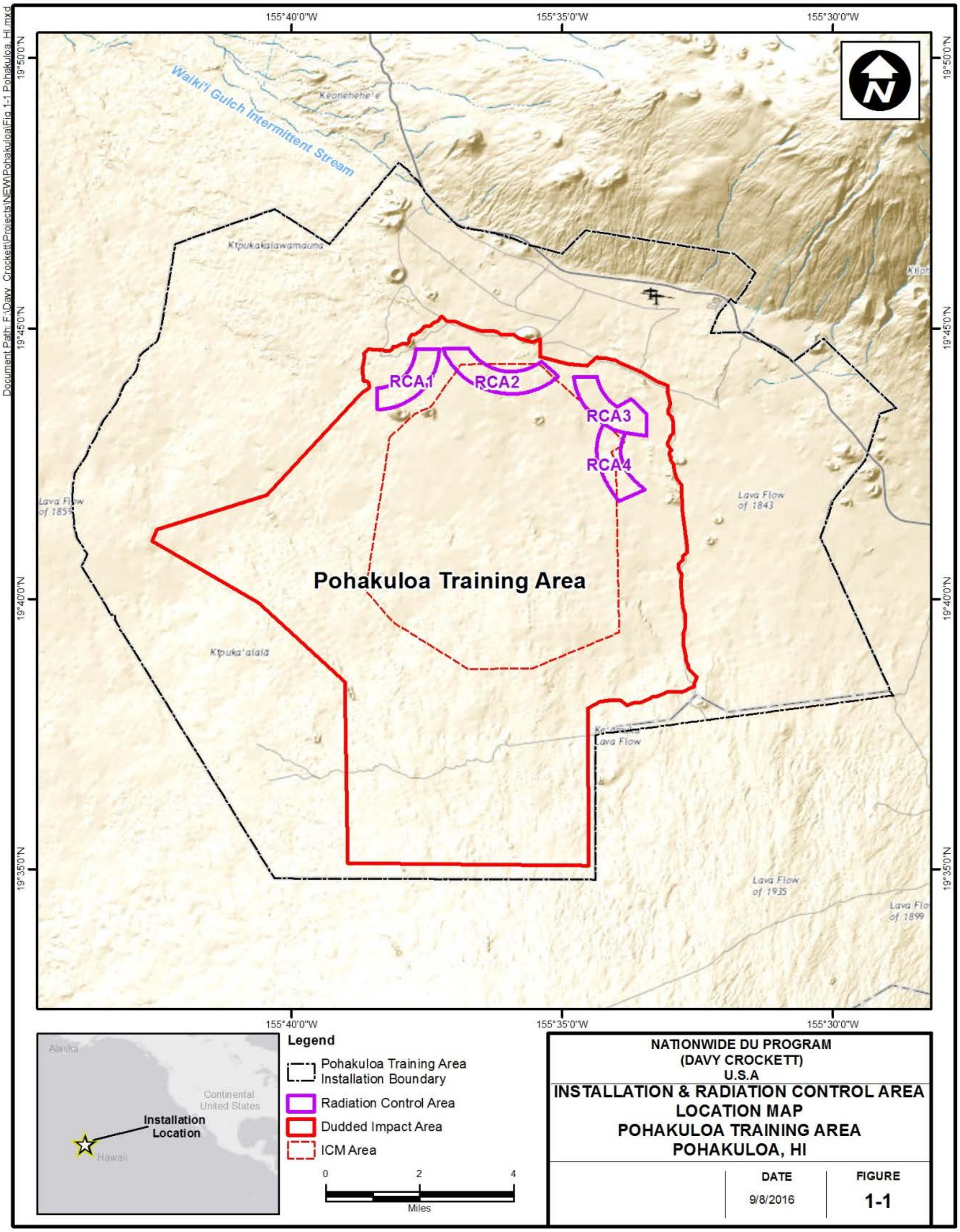

Figure 1-1. Installation and Radiation Control Area Location Map

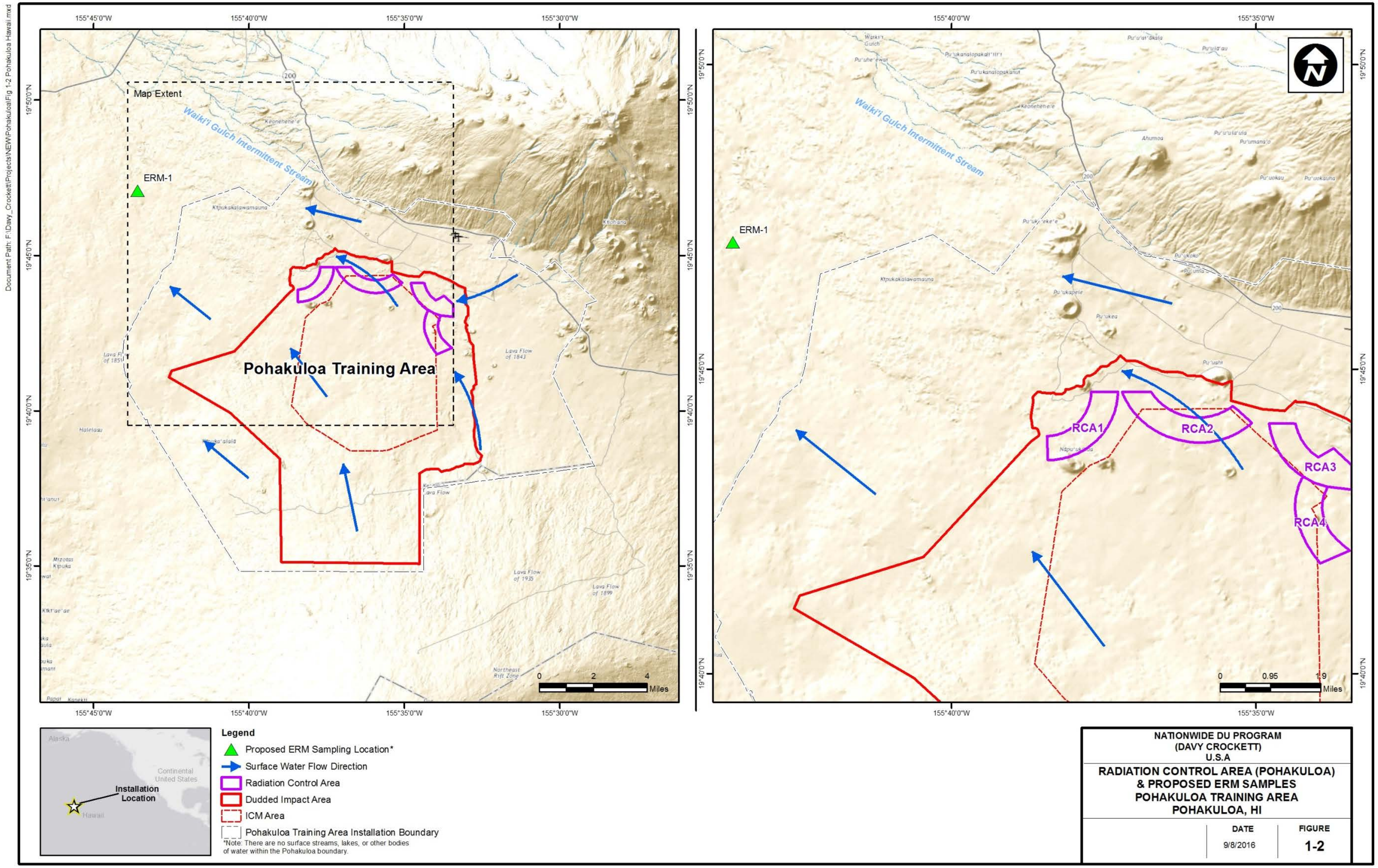

Figure 1-2. Radiation Control Area (Pohakuloa) and Proposed ERM Samples

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The Archives Search Report (ASR) (USACE 2007) confirmed the presence of the Davy Crockett Range at Pohakuloa TA based on range type and use, historical range maps, and range regulations and common practice for the time period of the fielded Davy Crockett Weapon System (i.e., 1961 through 1968). The nearest normally occupied areas to the Davy Crockett Ranges or radiation control areas (RCAs) are 16 miles west-northwest.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of 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 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 Davy Crockett Ranges; therefore, it is assumed that most, if not all, of the 140 kilograms (kg) of DU from the rounds fired into RCAs at Schofield Barracks and Pohakuloa TA remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Pohakuloa TA is in the Humuula Saddle between the two major peaks on the Island of Hawaii; Mauna Kea lies to the northeast and Mauna Loa lies to the south. Elevations within Pohakuloa TA range from 4,030 to 8,650 feet above mean sea level (msl).

Pohakuloa TA lies within the Northwest Mauna Loa and the West Mauna Kea watersheds, which drain to the northern Hualalai and southern Kohala coasts, respectively. There are no surface streams, lakes, or other bodies of water within the Pohakuloa TA boundary due to low rainfall, porous soils, and lava substrates. Rainfall, fog drip, and occasional frost are the main sources of water. Perennial streams are more than 15 miles from Pohakuloa TA on the northeast side of the island.

Rainfall is the primary source of groundwater recharge at Pohakuloa TA, and the geology is characterized by highly permeable lavas from which little or no runoff occurs. Most of the precipitation percolates relatively quickly to the underlying groundwater and then moves seaward, discharging into the coastal waters.

Pohakuloa TA lies above two aquifer systems: the Northwest Mauna Loa and the West Mauna Kea aquifer sectors. The majority of Pohakuloa TA lies within the Northwest Mauna Loa aquifer sector. Based on regional hydrogeological information, it is believed that the groundwater beneath Pohakuloa TA occurs primarily as deep basal water within the older Pleistocene age basalts (U.S. Army 2013).

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

Source data were analyzed along with potential migration pathways and potential off-range human and/or ecological receptors. This information was collected for the RCAs and used to determine if a potential source-receptor interaction existed for each relevant pathway identified. Based on this analysis, the source-pathway-receptor interaction was considered unlikely for the Davy Crockett Ranges.

No surface water or groundwater migration pathways were identified. Due to the low mobility of metals in soils and the depth to groundwater (greater than 1,000 feet below ground surface [bgs]), metals were not expected to infiltrate through the soil profile to groundwater. In addition, due to low rainfall, porous soils, and lava substrates, no perennial surface water bodies are located on, or immediately adjacent to, Pohakuloa TA. The closest known surface water body is located 4.5 miles upgradient of Pohakuloa TA. There are no perennial streams within 15 miles of Pohakuloa TA, but there are intermittent streams located northeast of Pohakuloa TA and only one intermittent stream, Popoo Gulch, drains the northern portion of Pohakuloa TA. Despite occasional flow, water in the intermittent stream channels infiltrates rapidly once precipitation stops and the streams become dry (EA 2013).

2.0 ERMP SAMPLE DESIGN

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

2.1 SURFACE WATER AND SEDIMENT

There are no surface water features (i.e., streams, lakes, or other bodies of water) within the Pohakuloa TA boundary, and intermittent streams flow only following heavy rainfall and dry up quickly; therefore, sampling is restricted to sediment collection only. The sediment sampling approach will involve the collection of sediment samples from a location downstream from the RCAs in Pohakuloa TA (Figure 1-2). The sediment sampling location at Pohakuloa TA was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***ERM-01***—The selected sampling point is located at an intermittent stream at the installation's northern boundary, downstream from the RCAs. ERM-01 is accessible using the Lightning Trail or via Saddle Road.

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 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 sediment samples within 30 days of the notification to NRC. The sediment 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).

2.2 GROUNDWATER

Presently, no groundwater monitoring wells are located at or near the RCAs. The depth to groundwater in the vicinity of Pohakuloa TA is approximately 1,000 feet bgs. Although the area within the vicinity of Pohakuloa TA exhibits high soil permeability, the combination of limited precipitation and great depth to groundwater make it unlikely that DU would migrate into the groundwater. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2015), groundwater sampling is not planned for Pohakuloa TA.

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, Pohakuloa TA 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.

3.0 ERMP METHODOLOGY

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

No surface water samples will be collected because of the lack of surface water features (i.e., streams, lakes, or other bodies of water) due to low rainfall, porous soils, and lava substrates within Pohakuloa TA.

3.2 SEDIMENT SAMPLING

The collection of the sediment sample will consist of the compositing of at least 10 subsamples collected from various areas of the stream bed. Sediment samples will be collected from the stream bed using a clean, disposable plastic scoop. Sampling locations within the stream bed should be selected where the intermittent surface water flow is low and/or deposition is most likely. 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 differential global positioning system (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 (140 kg for Schofield Barracks and Pohakuloa TA) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

	Specific Activity	Mass Abundance[b]
Nuclide	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 Pohakuloa Training Area RCAs

Parameter		Default Value	Area 1	Area 2	Area 3	Area 4	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	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	1.38×10^{-2}	1.38×10^{-2}	1.38×10^{-2}	9.19×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC SML (NRC 2016). = DU mass × nuclide specific mass abundance[a] × nuclide specific activity[a] / (CZ area × CZ depth × CZ density)
	U-235	N/A	1.26×10^{-3}	1.26×10^{-3}	1.26×10^{-3}	8.41×10^{-4}	
	U-238	N/A	0.21	0.21	0.21	0.14	
Area of contaminated zone (m^2)		10,000	1,000,000	1,000,000	1,000,000	1,500,000	Area of RCA
Depth of contaminated zone (m)		2	0.15	0.15	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	0	0	Depth to groundwater is approximately 1,000 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	1,000	1,500	Groundwater flows northeast across RCA
Contaminated zone total porosity		0.4	0.43	0.43	0.43	0.43	RESRAD Manual Table E.8 (DOE 2001) for Fine Sand
Contaminated zone hydraulic conductivity (m/y)		10	4,930	4,930	4,930	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	4.38	4.38	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	5.3	5.3	5.3	5.3	U.S. Army 2013
Precipitation rate (annual rainfall) (m/y)		1.0	0.51	0.51	0.51	0.51	U.S. Army 2013
Saturated Zone							
Saturated zone total porosity		0.4	0.43	0.43	0.43	0.43	RESRAD Manual Table E.8 (DOE 2001) for Fine Sand
Saturated zone effective porosity		0.2	0.33	0.33	0.33	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Saturated zone hydraulic conductivity (m/y)		100	4,930	4,930	4,930	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter		5.3	4.38	4.38	4.38	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated Zone							
Unsaturated zone 1, total porosity		0.4	0.43	0.43	0.43	0.43	RESRAD Manual Table E.8 (DOE 2001) for Fine Sand
Unsaturated zone 1, effective porosity		0.2	0.33	0.33	0.33	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.38	4.38	4.38	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	4,930	4,930	4,930	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 Pohakuloa Training Area RCAs

RCA Layout Parameter	Area 1				Area 2				Area 3				Area 4			
Distance to nearest normally occupied area (m)	4,900				3,400				4,400				6,000			
Bearing of X axis (degrees)	135 (northeast)				135 (northeast)				135 (northeast)				135 (northeast)			
X dimension of primary contamination (m)	1,000				1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000				1,500			
Location	X Coordinate (m)		Y Coordinate (m)		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	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	6,000	6,032	500	531.25	4,500	4,532	500	531.25	5,500	5,532	500	531.25	7,600	7,632
Leafy vegetables plot	500	531.25	6,034	6,066	500	531.25	4,534	4,566	500	531.25	5,534	5,566	500	531.25	7,634	7,666
Pasture, silage growing area	500	600	6,216	6,316	500	600	4,716	4,816	500	600	5,716	5,816	500	600	7,816	7,916
Grain fields	500	600	6,066	6,166	500	600	4,566	4,666	500	600	5,566	5,666	500	600	7,666	7,766
Dwelling site	500	531.25	5,900	5,932	500	531.25	4,400	4,432	500	531.25	5,400	5,432	500	531.25	7,500	7,532
Surface-water body	500	800	6,316	6,616	500	800	4,816	5,116	500	800	5,816	6,116	500	800	7,916	8,216
Atmospheric Transport Parameter																
Meteorological STAR file*	CA_SAN_DIEGO.str				CA_SAN_DIEGO.str				CA_SAN_DIEGO.str				CA_SAN_DIEGO.str			
Groundwater Transport Parameter																
Distance to well (parallel to aquifer flow) (m)	4,900				3,400				4,400				6,000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	5,316				3,816				4,816				6,416			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				315				315				315			

* RESRAD Offsite has no meteorological STAR files for Alaska or Hawaii. The selected STAR file is based on nearest available location. The inhalation pathway dose is insignificant to external and groundwater dose pathways.

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 Pohakuloa TA 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

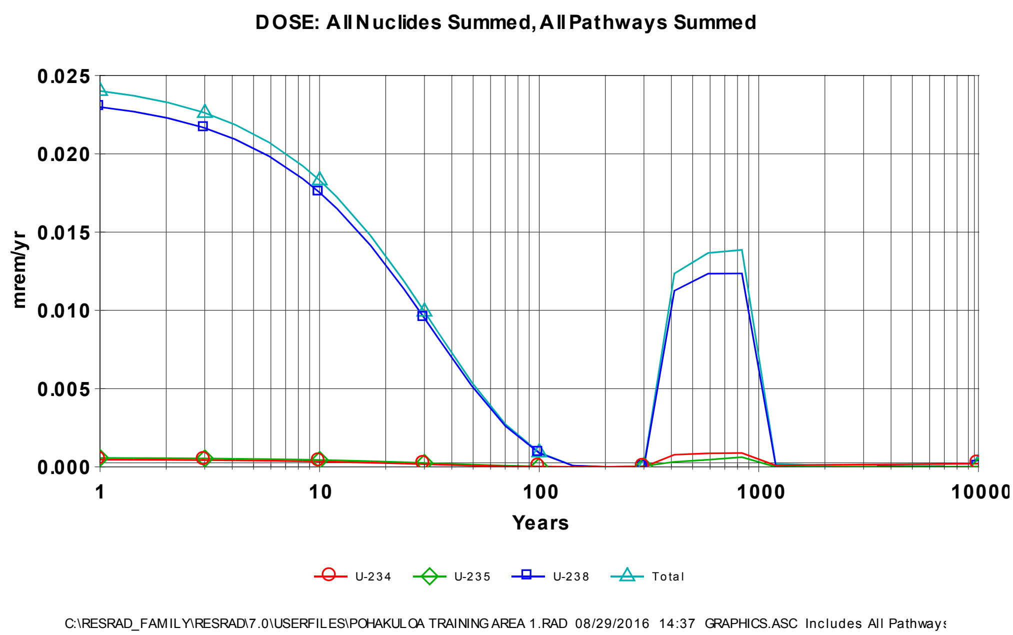
RCA	RCA Onsite[a] (RESRAD)	RCA Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Davy Crockett Range Area 1	0.025	0.012
Davy Crockett Range Area 2	0.025	0.013
Davy Crockett Range Area 3	0.025	0.012
Davy Crockett Range Area 4	0.017	0.0074

[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.

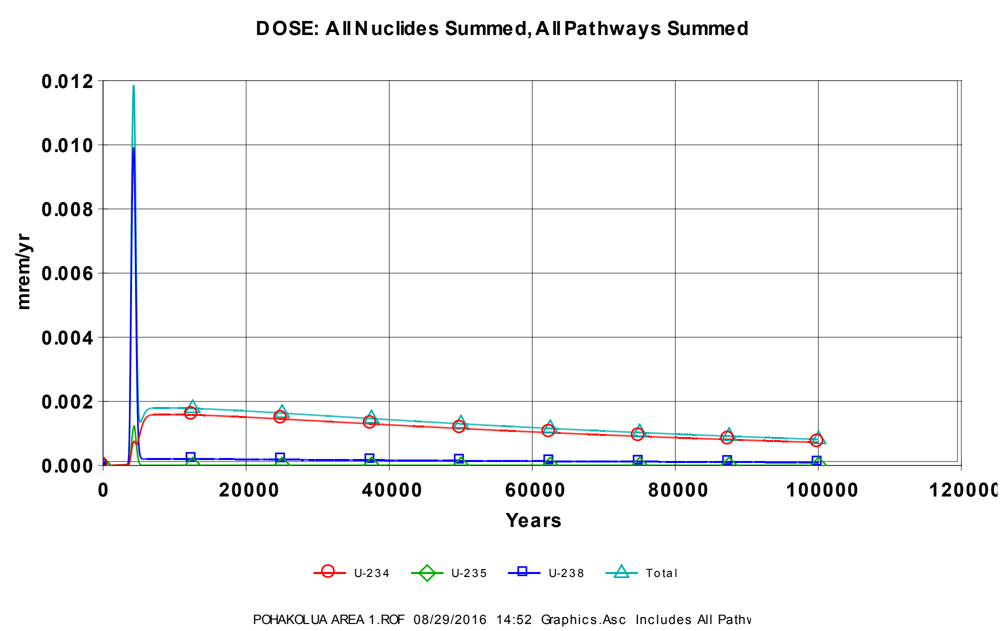
RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

Figure 4-1. Residential Farmer Receptor Dose Graphs for Pohakuloa Training Area RCAs

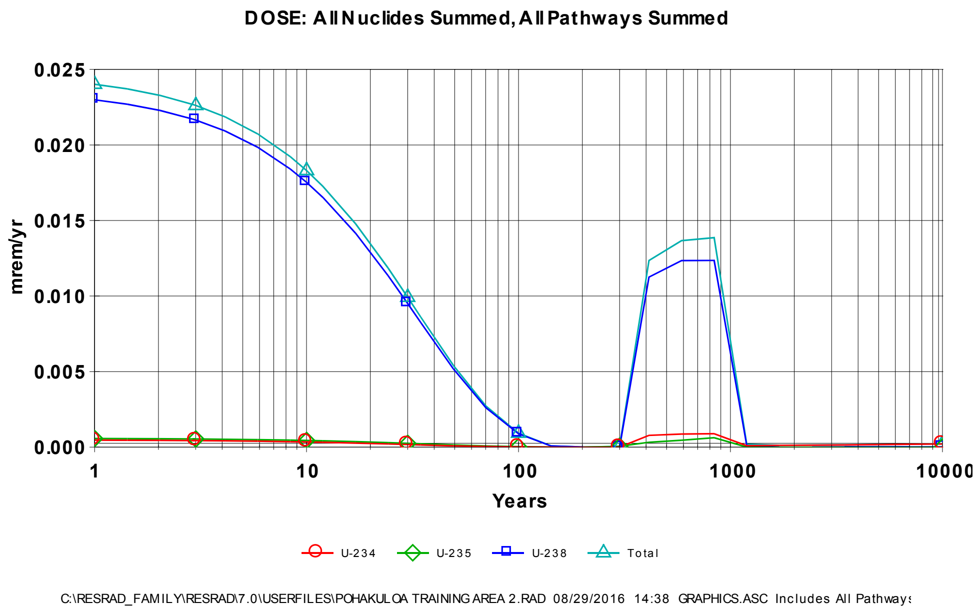
Davy Crockett Range Area 1
RCA Onsite (RESRAD)



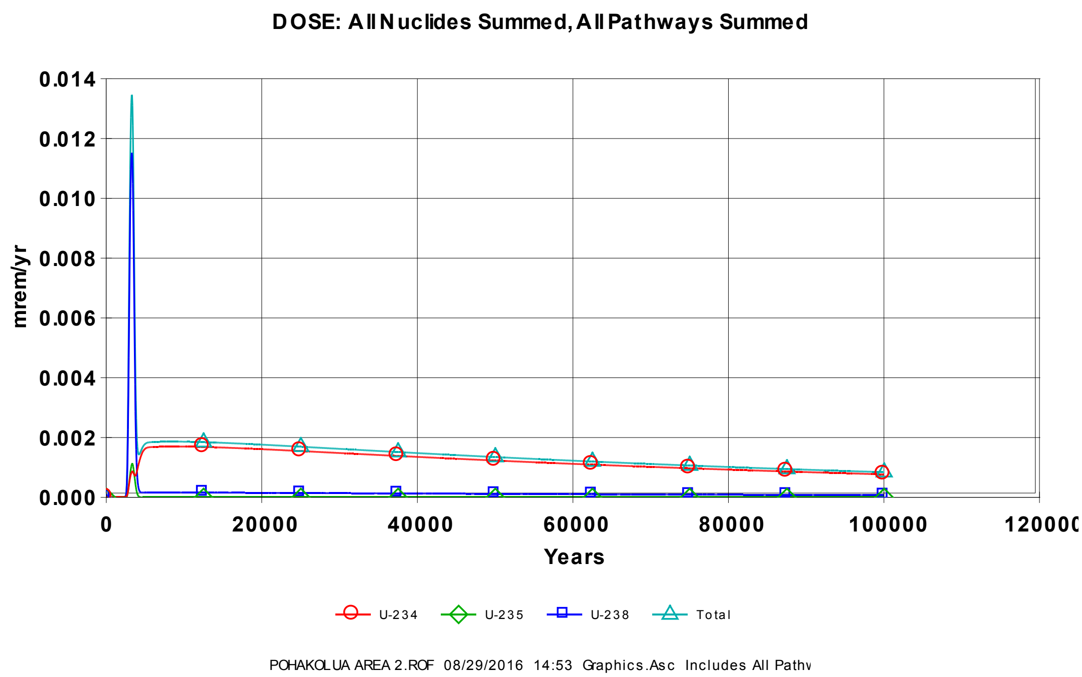
RCA Offsite (RESRAD-OFFSITE)



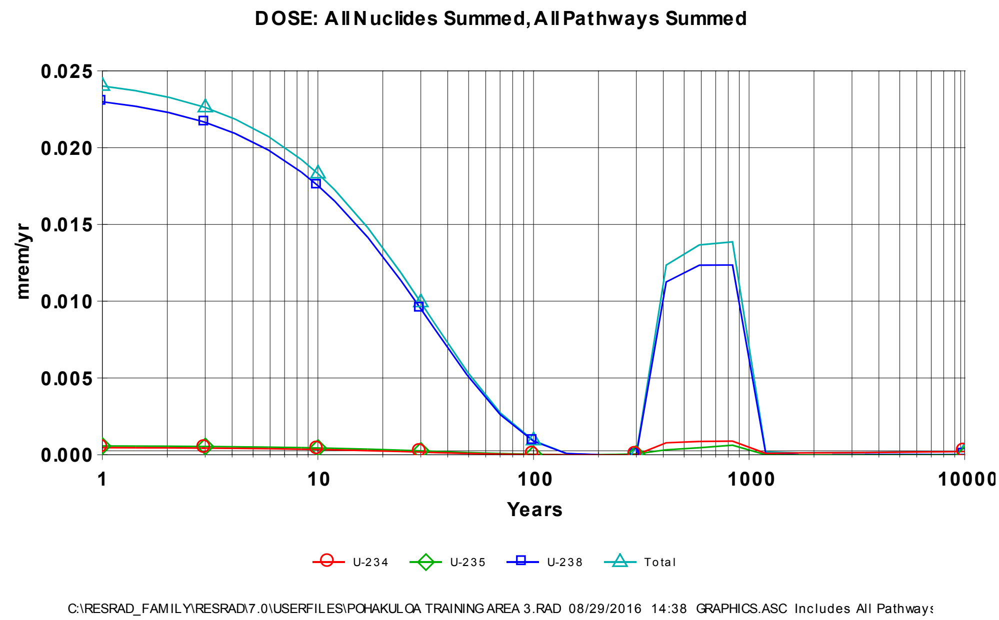
Davy Crockett Range Area 2
RCA Onsite (RESRAD)



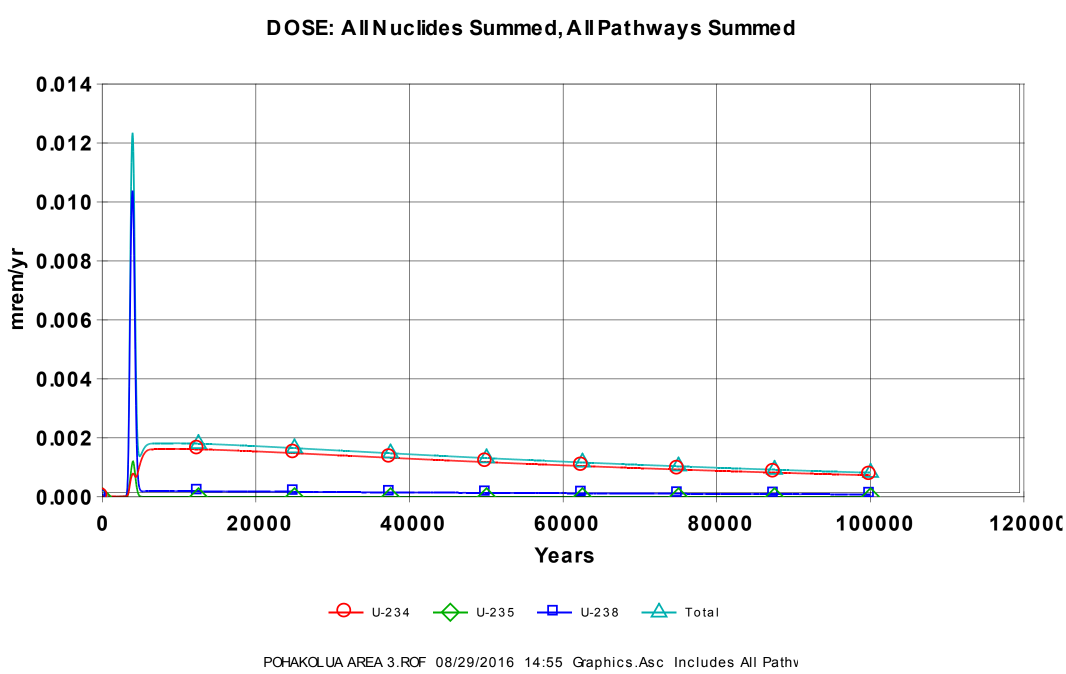
RCA Offsite (RESRAD-OFFSITE)



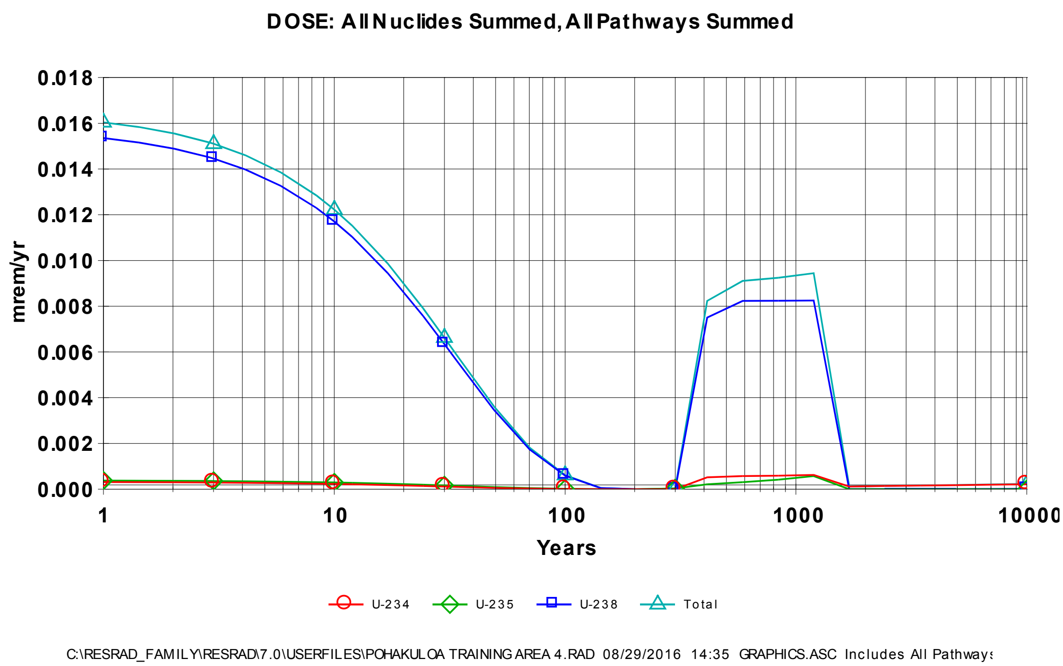
Davy Crockett Range Area 3
RCA Onsite (RESRAD)



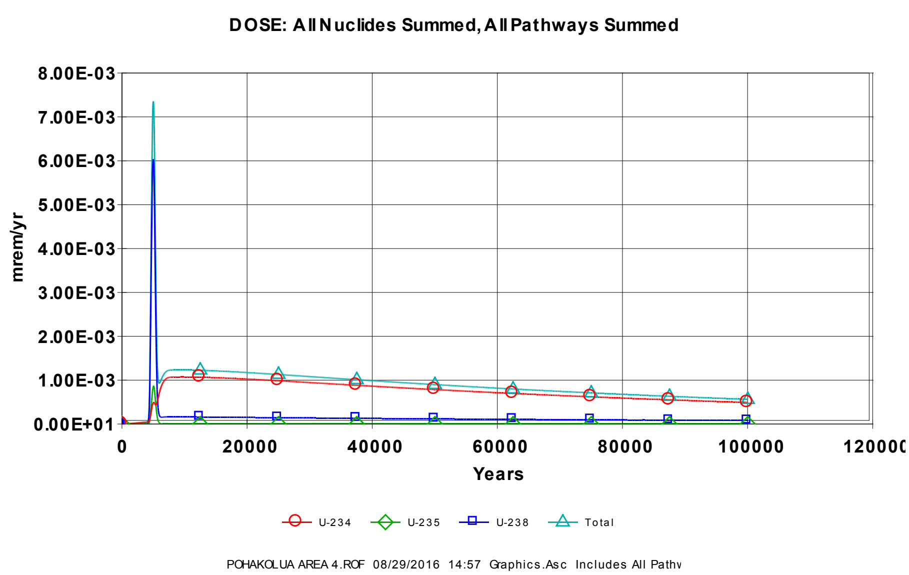
RCA Offsite (RESRAD-OFFSITE)



Davy Crockett Range Area 4
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,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

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[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:

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

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

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

$D_{U\text{-}234}$ is the depletion of ^{234}U in depleted uranium and $D_{U\text{-}235}$ 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:

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

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:

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

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

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

[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]

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

[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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