FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN
FORT BENNING, GEORGIA
ANNEX 2

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

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
DZ	Drop Zone
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
GADNR	Georgia Department of Natural Resources
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
PAL	Project Action Level
PCB	Polychlorinated Biphenyl
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
TMDL	Total Maximum Daily Load
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
USACE	U.S. Army Corps of Engineers
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 U.S. Army Installation Fort Benning in Fort Benning, Georgia, 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 Benning. The installation will retain the final version of this Site-Specific ERMP. In accordance with license condition #19, the U.S. Army is required to implement fully this Site-Specific ERMP within 6 months of NRC approval. This Site-Specific ERMP and its implementation is then subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Recommended ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream (**UC2**) from the K-18 Range (Cactus OP) and K-15 Range/Concord OP/DUD Area RCAs, and (**OC2**) from the Hook Range, Buchanan Range, Coolidge Range, Patton Range, Z-4 (Lae Range), and Burma Hill Range (Demo Area) RCAs, as shown in Figures 1-2 and 1-3 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Quarterly unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Benning is approximately 182,000 contiguous acres that span between Muscogee, Chattahoochee, and Russell Counties (Figure 1-1). About 93 percent of the installation is in Georgia, with the remaining portion located in Russell County, Alabama. Fort Benning land is used for military training (e.g., ranges, drop zones [DZs], and landing zones), military administration, and land management activities (Arcadis 2011). The terrain at Fort Benning provides a challenging, realistic training environment for all soldiers who train there. Fort Benning's primary missions are to provide the world's best infantry soldiers and trained units and serve as a power projection platform capable of deploying and redeploying soldiers and units anywhere in the world on short notice (Arcadis 2012).

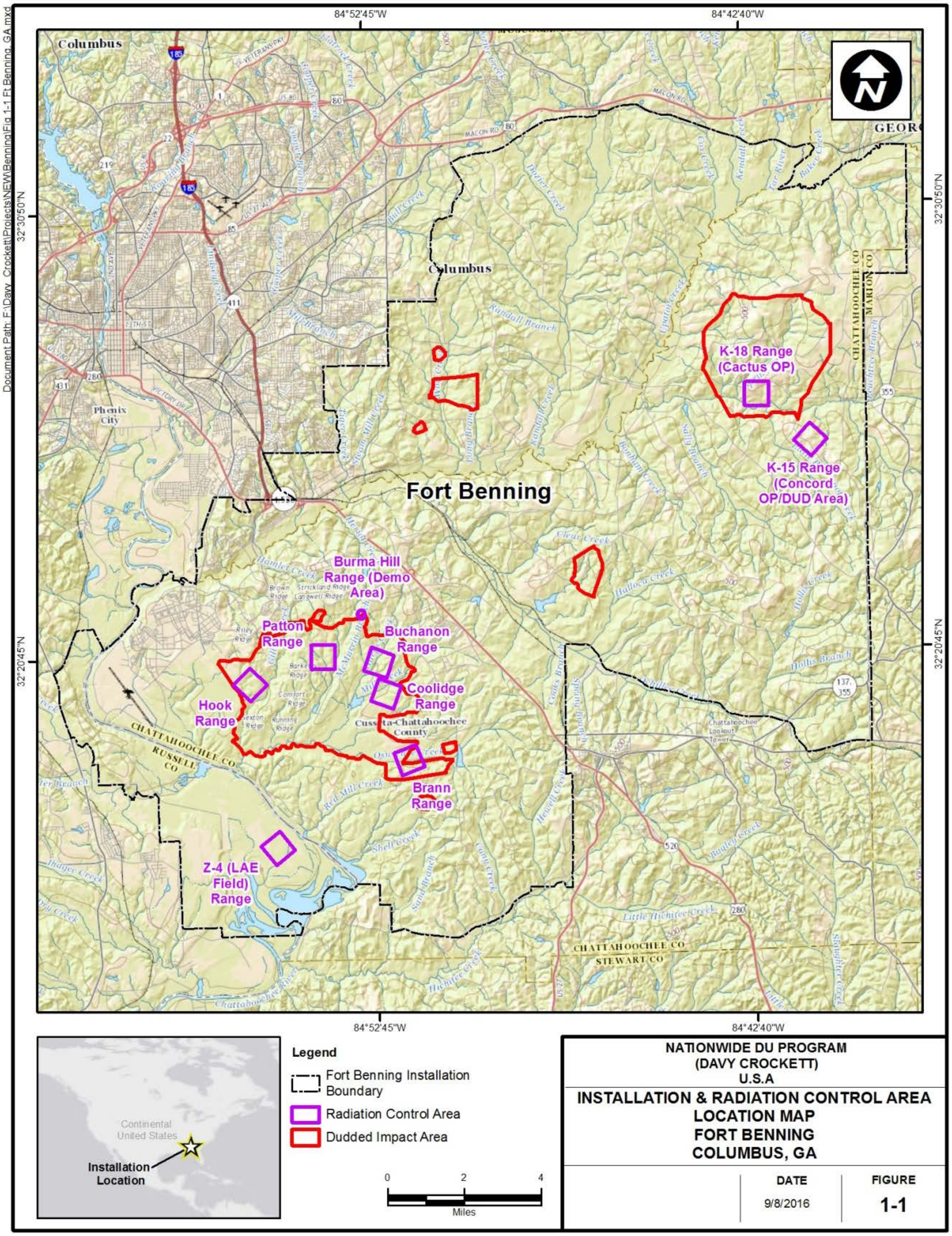

Figure 1-1. Installation and Radiation Control Area Location Map

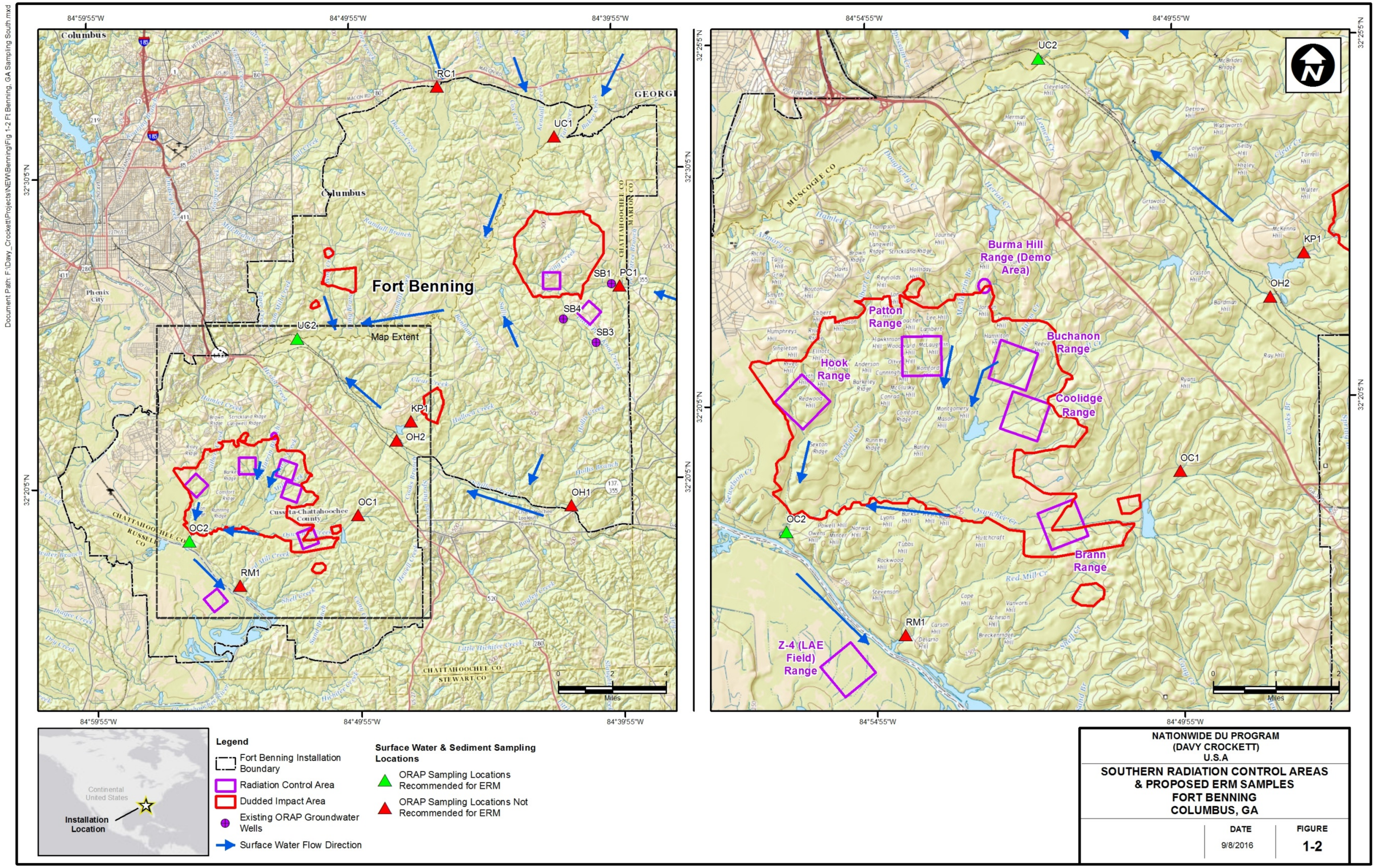

Figure 1-2. Southern Radiation Control Areas and Proposed ERM Samples

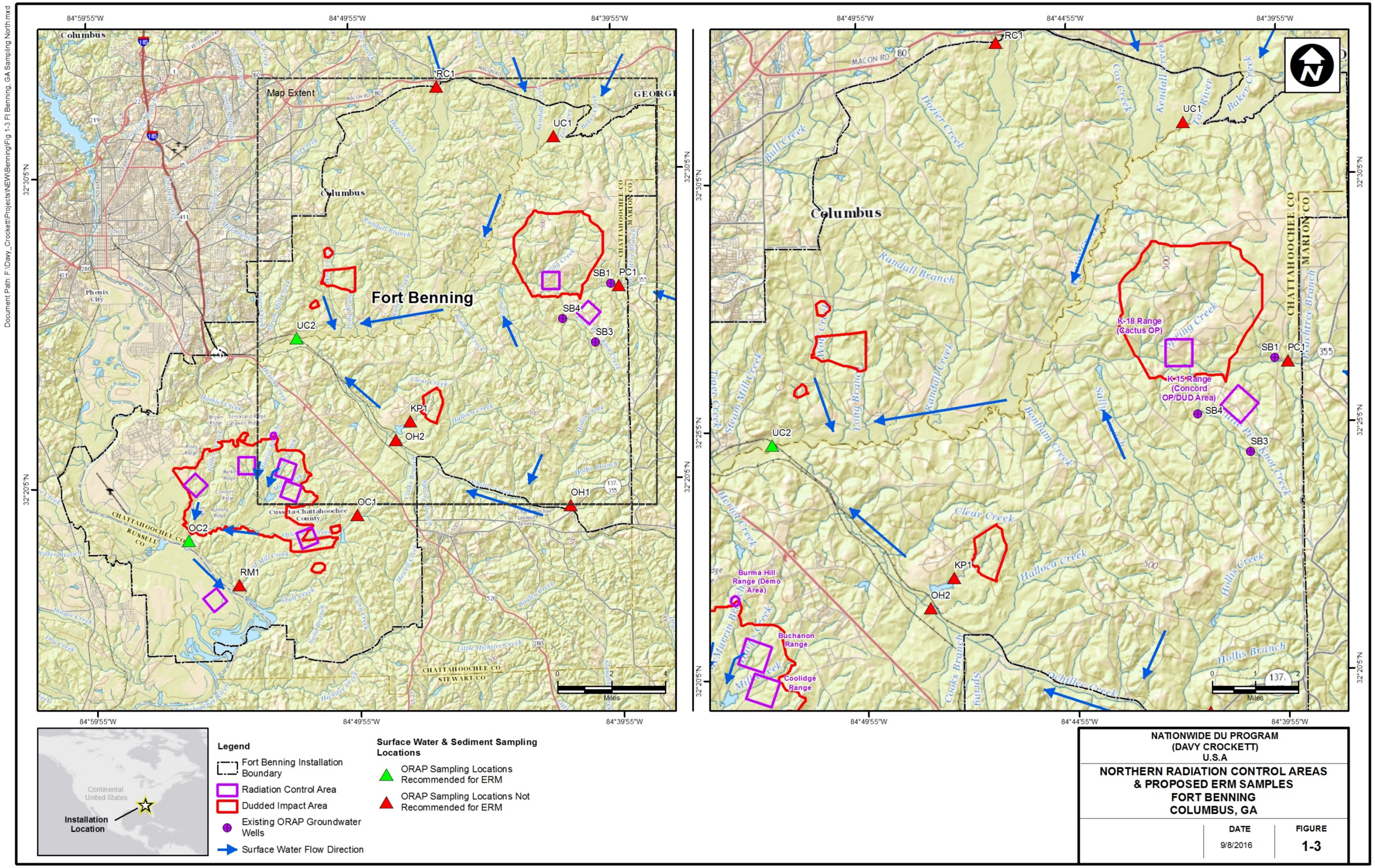

Figure 1-3. Northern Radiation Control Areas and Proposed ERM Samples

Of the 182,000 acres, 141,471 acres (approximately 78 percent of the total land area) are designated for training. The training areas (TAs) consist of 48,171 acres of light maneuver area primarily in the southwestern portion of the installation; 62,958 acres of heavy maneuver area primarily in the northeastern portion of the installation; and 30,342 acres of Nondudded Impact Area. There are also 15,554 acres (9 percent) of permanently Dudded Impact Area. The Dudded and Nondudded Impact Areas are concentrated in the northeastern corner of Fort Benning (Kilo Range Complex), the southern portion (Alpha Range Complex), and near the western installation boundary (Malone Range Complex). US-27/280 divides the northeastern and southwestern sections of Fort Benning.

An Archives Search Report (ASR) (USACE 2008) documented the following eight ranges where the use of the Davy Crockett weapons system is suspected based on historical documentation or confirmed based on physical evidence (i.e., Davy Crockett components or debris) observed during the site inspection:

- Hook Range
- Buchanan Range
- Coolidge Range
- Patton Range
- Z-4 (Lae Range)
- K-18 (Cactus OP)
- K-15 (Concord OP/DUD Area)
- Burma Hill Range (Demo Area).

The ASR concluded demolition operations of the Davy Crockett ammunition is suspected at one range (i.e., Burma Hill Range [Demo Area]) rather than the artillery training activities. Subsequent to the ASR, the Davy Crockett weapons system is suspected of being used at one additional range, the Brann Range. The locations of the impact areas for the nine ranges or radiation control areas (RCAs) for Fort Benning are presented in Figures 1-2 and 1-3. The nearest normally occupied areas to each of the nine RCAs are presented in Table 1-2.

Table 1-2. Summary of Distances to Occupied Buildings

RCA	Occupied Building	Approximate Distance and Direction
Hook Range	Pool Range	0.65 miles (northwest)
Buchanan Range	Buchanan Shoot House	0.60 miles (northeast)
Coolidge Range	Coolidge Left Range	0.30 miles (southeast)
Brann Range	Galloway Range	0.36 miles (north)
Patton Range	Patton Range	0.52 miles (north)
Z-4 (Lae Range)	Griswold Range	0.83 miles (northeast)
K-18 (Cactus OP)	Hartell OP	0.43 miles (southwest)
K-15 (Concord OP/DUD Area)	Ranger Objective	0.25 miles (northwest)
Burma Hill Range (Demo Area)	Porter Range	0.27 miles (northeast)

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 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 Fort Benning; therefore, it is assumed that most, if not all, of the 1,850 kilograms (kg) of DU (SUC-1593) from the rounds fired remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Fort Benning is located in an area characterized by a warm and humid, temperate climate. Average annual precipitation in the area of Fort Benning, primarily rainfall, is approximately 45 to 55 inches per year (Arcadis 2011). Fort Benning lies within the Coastal Plain Physiographic Province of central Georgia and Alabama. It is underlain mostly by Mesozoic, Cretaceous sedimentary rocks from the Bluffton and Tuscaloosa Formations. Floodplains are general undifferentiated stream alluvium from terrace deposits. No major regional structures are on the installation. The closest, the Goat Rock Regional Fault Line, is approximately 15 miles north of the installation in northern Muscogee County and southern Harris County. This area represents the fall line running through much of central Georgia (NRCS 2008).

The rivers and streams are primarily characterized as perennial and free flowing. The streams located in the northern portion of the installation generally flow in a southerly direction on Fort Benning, while streams in the southern portion of Fort Benning generally flow from east to west on the Georgia side and west to east on the Alabama side of the installation. Ultimately, the surface water drains toward the Chattahoochee River, which designates the state line between Georgia and Alabama. The Chattahoochee River dominates the surface water flow regime at Fort Benning.

Three surface water watersheds are at Fort Benning: the Upatoi Creek, the Red Mill Creek, and Oswichee Creek (Arcadis 2011). The watersheds of the Oswichee Creek and Red Mill Creek, both tributaries to the Chattachoochee River, drain the majority of the southern portion of the installation, including the RCAs located in the southern portion of Fort Benning. The Chattachoochee River flows through the southwestern portion of Fort Benning and forms the border between Georgia and Alabama. Several low order streams drain the installation and flow directly into the Chattachoochee River. The Oswichee and Red Mill Creeks are the two largest tributaries. The Upatoi Creek watershed drains 116,448 acres and includes nearly 70 percent of the operational range area on Fort Benning. The watershed is located in the northern portion of the installation and drains southwesterly into the Chattahoochee River. Kings Pond and Ochillee Creek are located within the Upatoi Creek watershed.

Shallow groundwater in the vicinity of Fort Benning is described as mimicking the ground surface topography with shallow groundwater flowing from areas underlying hilltops or ridges to low-lying areas or streams (Arcadis 2011). Shallow groundwater interaction with surface water is prevalent; however, there is potential for shallow groundwater interaction with deep aquifers. The majority of precipitation that infiltrates through soil enters the shallow flow system and discharges to adjacent streams. Several areas on installation are underlain by substantial clay layers that may inhibit downward migration of groundwater. These layers likely promote lateral movement of groundwater as interflow and the discharge of this groundwater to the surface water.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

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

- ***Surface Water Use***—Once the surface water is outside of the installation boundaries, human receptors can interact with surface water and sediment via ingestion (incidental during recreational use and through surface water intakes for potable use), dermal contact, and/or ingestion of fish.

  The Chattahoochee River passes through the installation along the Georgia and Alabama state line. In some areas, the Chattahoochee River is completely surrounded by operational range activity; however, the Chattahoochee River is considered off-range along the entire flow path (Arcadis 2011). The State of Georgia has designated fishing as the sole beneficial use of the Chattahoochee River from Upatoi Creek to the Chattahoochee and Stewart County line at the southern boundary of the installation (GADNR EPD 2010); however, the construction of a surface water intake in the Chattahoochee River will likely add potable water source as a beneficial use. The Chattahoochee River, in this reach, is in violation of the beneficial use standards due to elevated fecal coliform levels potentially caused by urban runoff. Downstream from the installation, the Chattahoochee River has been impounded near Fort Gaines, Georgia, to create Lake Walter F. George, a U.S. Army Corps of Engineers (USACE)-managed recreation resource. Lake W.F. George supports the beneficial use of recreation (GADNR EPD 2010). No violations are currently listed; however, a total maximum daily load (TMDL) assessment was completed for Lake W.F. George and a TMDL has been established for polychlorinated biphenyls (PCBs).

  The Chattahoochee River and Lake W.F. George can be accessed at multiple points for fishing, boating, and swimming. The most upstream access point that is off-range is the Uchee Creek Army Campground, which has a boat ramp and is located within the boundaries of the installation at the confluence of Uchee Creek and the Chattahoochee River in Alabama. Off-installation residents and recreational users of the Chattahoochee River and Lake W.F. George may also gain access at several locations downstream from the installation. River Bend Park is a day use area with a boat ramp and is located on the Chattahoochee River immediately downstream from the installation. Bluff Creek Access Area is approximately 9 miles downstream from the installation. Bluff Creek has a campground and boat ramp. Hatchechubbee Creek Park is 13 miles downstream from the installation and provides camping and a boat ramp to recreational users. Florence Marina State Park is the first recreational area downstream from the installation (approximately 16.5 miles downstream) that officially offers a swimming area, although swimming may occur at other designated and nondesignated recreational areas upstream of the state park. Florence Marina State Park also offers camping, a fishing pier, and a boat ramp to recreational users. The Georgia Department of Natural Resources (GADNR) does not recommend swimming in the Chattahoochee River, as evidenced by the absence of swimming as a beneficial use for the river within the boundaries of the installation; however, recreation, including dermal contact, is a beneficial use within Lake W.F. George (GADNR EPD 2010). The portion of Lake W.F. George with a beneficial use of recreation is more than 16 miles downstream from the installation. Given the long distance from the installation (exceeding 15 miles), this receptor scenario is not evaluated further.

  Five ponds are listed by the Fort Benning Directorate of Family and Morale, Welfare, and Recreation, on its webpage, as on-installation recreational fishing areas. Russ Pond, Victory Pond, Twilight Pond, Weems Pond, and Kings Pond are located completely within the installation and provide opportunities for fishing and subsequent ingestion of fish. The Kings Pond Recreation Area is completely surrounded by operational range area, but is not included in the operational range footprint. Kings Pond is one of the most popular recreational use areas on the installation. Fishing is likely to occur along the Chattahoochee River within and immediately downstream from the installation and at Kings Pond.

The Operational Range Assessment Program (ORAP) Phase II Quantitative Assessment Report concluded that surface water detections within the preferential surface water and sediment sample location did not exceed the project action levels (PALs) and the data were indistinguishable from reference conditions (Arcadis 2012).

- ***Ecological Receptors***—Ecological receptors include sensitive environments (e.g., wetlands) and threatened and endangered species with habitat and/or foraging areas near the Chattahoochee River within 15 miles downstream. The bald eagle (*Haliaeetus leucocephalus*), American alligator (*Alligator mississippiensis*), and wood stork (*Mycteria americana*) are all known to exist within the Chattahoochee River directly south of Fort Benning. Ecological receptors (the Indiana bat [*Myotis sodalis*] and American bald eagle) may contact surface water and/or sediment via both dermal contact and ingestion. The American bald eagle was federally de-listed but is still protected under the Bald and Golden Eagle Protection Act. The American bald eagle can obtain fish from rivers, thus potentially being exposed via direct contact with surface water and indirect contact through ingestion of prey.

Wetlands, which are considered sensitive environments, are considered potential ecological receptors. Wetlands exist throughout Fort Benning and within the 15-mile downstream area of Fort Benning. The wetland areas total approximately 1,235 acres, including the Chattahoochee River, within the installation boundary.

Groundwater Use—The groundwater pathway is a potential concern for the downgradient domestic water supply wells east and south of Fort Benning. Water from these wells is used for drinking (ingestion), and activities leading to dermal contact, such as bathing (Arcadis 2011). However, the ORAP Phase II Quantitative Assessment Report concluded that groundwater that may be impacted by operational range activities does not leave the installation but discharges locally into adjacent surface water bodies (Arcadis 2012).

Potential human receptors include those outside of the installation boundaries that can interact via ingestion (incidental during recreational use and through surface water intakes for drinking), dermal contact, and/or ingestion of fish. Ecological receptors include sensitive environments (e.g., wetlands) and threatened and endangered species with habitat and/or foraging areas near the Chattahoochee River within 15 miles downstream.

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the 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 RCAs at Fort Benning are listed 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 locations downstream from the RCAs at Fort Benning (Figures 1-2 and 1-3) 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 locations at Fort Benning were selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***OC2***—The selected sampling point is located in the Oswichwee Creek downstream from the RCAs located in the southern portion of the installation (i.e., Hook Range, Patton Range, Burma Hill Range [Demo Area], Buchanon Range, Coolidge Range, and Brann Range) and in the Oswichwee Creek watershed.
- ***UC2***—The selected sampling point is in the Upatoi Creek downstream from the RCAs located in the northern portion of the installation (i.e., K-18 Range [Cactus OP] and K-15 Range [Concord OP/DUD Area]) and in the Upatoi Creek watershed.

The Phase II ORAP sample locations (i.e., RM1, KP1, and OH2) were not recommended for the environmental radiation monitoring (ERM) because of lack of hydrologic connection with the RCAs (Figures 1-2 and 1-3). In addition, the upstream reference locations sampled during the ORAP Phase II assessment (OC1, UC1, RC1, PC1, and OH1) will not be sampled during the ERM. Sampling will be conducted on the PAERMP's specified quarterly interval as the sampling locations are within perennial and free flowing areas.

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 RCAs 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).

The recommended downstream sampling locations, UC2 and OC2, for the ERM and the other ORAP Phase II assessment sample locations were sampled in 2011 and 2012. Both surface water and sediment samples were analyzed for uranium (Arcadis 2012). The range of uranium concentrations that resulted from the sampling events in September/October, November, February, and March is presented in Table 2-1.

Table 2-1. Uranium Surface Water and Sediment Analytical Results

Sample Location	Number of Samples	Range of Concentrations (µg/L)
Surface Water		
KP-1 (King's Pond)	4	0.003-0.005
OC-1 (Oswichee Creek)	2	0.070-0.135
OC-2 (Oswichee Creek)	5	0.008-0.026
OH-1 (Ochillee Creek)	4	0.008-0.043
OH-2 (Ochillee Creek)	5	0.009-0.192
PC-1 (Pine Knot Creek)	4	0.009-0.022
RC-1 (Randall Creek)	4	0.005-0.024
RM-1 (Red Mill Creek)	4	0.016-0.059
UC-1 (Upatoi Creek)	4	0.017-0.053
UC-2 (Upatoi Creek)	4	0.007-0.060
Sediment		
KP-1 (King's Pond)	3	0.460-0.590
OC-1 (Oswichee Creek)	3	1.100-2.000
OC-2 (Oswichee Creek)	6	0.130-0.230
OH-1 (Ochillee Creek)	3	0.190-0.240
OH-2 (Ochillee Creek)	2	0.190-0.230
PC-1 (Pine Knot Creek)	~	0.170-0.290
RC-1 (Randall Creek)	3	0.180-3.300
RM-1 (Red Mill Creek)	3	0.250-0.290
UC-1 (Upatoi Creek)	3	0.280-0.290
UC-2 (Upatoi Creek)	3	0.260-0.460

2.2 GROUNDWATER

Uranium was included as an analyte during the ORAP Phase II assessment groundwater sampling in June 2012 (U.S. Army 2014). The uranium concentrations resulting from the October/November/ December 2011 sampling event are presented in Table 2-2. The existing groundwater monitoring wells are shown in Figures 1-2 and 1-3.

Presently, no groundwater monitoring wells are located at or near the RCAs. In addition, groundwater in the shallowest aquifer discharges to the adjacent surface water bodies for the majority of the installation. Since shallow groundwater is known to discharge to surface water, any DU potentially present in 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 Benning.

Table 2-2. Uranium Groundwater Analytical Results

Sample Location	Number of Samples	Detected Concentration (µg/L)
SB1 (36-41 ft bgs)	1	0.008
SB1 (64-69 ft bgs)	1	0.071
SB4 (84-89 ft bgs)	1	0.004
SB4 (100-105 ft bgs)	1	0.007
SB4 (122-127 ft bgs)	1	0.05

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 Benning 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 each of the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support 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 Fort Benning will be coordinated with the Fort Benning Installation Safety Office and Range Control prior to mobilizing for fieldwork.

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

3.1 SURFACE WATER SAMPLING

Surface water samples will be collected from OC2 and UC2 and submitted for laboratory analysis. The grab surface water samples will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

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

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

3.2 SEDIMENT SAMPLING

The collection of sediment samples will coincide with the surface water sampling activities and consist of the compositing of at least 10 subsamples collected from various areas of the stream bed. 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 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 (1,850 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 Benning RCAs

Parameter		Default Value	LAE Field Z-4, Brann, Hook, Coolidge, Patton, Buchanon, K-15, and K-18 Ranges	Burma Hill Range	Justification or Source
Internal Dose Library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone					
Soil concentrations (pCi/g)	U-234	N/A	0.182	2.34×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC Materials License. = DU mass × nuclide specific mass abundance[a] × nuclide specific activity[a] / (CZ area × CZ depth × CZ density) NOTE: 9 DU rounds (~ 2 kg) were associated with the Burma Hill Range Demo Area
	U-235	N/A	1.67×10^{-2}	2.14×10^{-4}	
	U-238	N/A	2.76	0.04	
Area of contaminated zone (m^2)		10,000	1,000,000	84,000	
Depth of contaminated zone (m)		2	0.15	0.15	NRC Radioactive Materials License SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	Depth to groundwater is generally 30 to 75 ft bgs
Length parallel to aquifer flow (m)		100	1,000	330	Length of RCA is approximately 1,000 m; Burma Hill diameter is 330 m
Contaminated zone total porosity		0.4	0.39	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand (Soil is sand with varying amounts of clay and silt)
Contaminated zone hydraulic conductivity (m/y)		10	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Contaminated zone b parameter		5.3	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Average annual wind speed (m/s)		2.0	7.4	7.4	www.usa.com for Fort Benning, GA
Precipitation rate (annual rainfall) (m/y)		1.0	1.1	1.1	www.usa.com for Fort Benning, GA
Saturated Zone					
Saturated zone total porosity		0.4	0.39	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone effective porosity		0.2	0.3	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone hydraulic conductivity (m/y)		100	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Saturated zone b parameter		5.3	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated Zone					
Unsaturated zone 1, thickness (m)		4.0	1.5	1.5	Depth to groundwater is generally 5 ft bgs
Unsaturated zone 1, total porosity		0.4	0.39	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, effective porosity		0.2	0.3	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.9	4.9	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	1,090	1,090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam

[a] See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Benning RCAs

RCA Layout Parameter	Z-4 Range (LAE Field)				Brann Range				Hook Range			
Distance to nearest normally occupied area (m)	1,300				550				1,000			
Bearing of X axis (degrees)	135 (northeast)				90 (north)				45 (northwest)			
X dimension of primary contamination (m)	1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	2,400	2,432	500	531.25	1,650	1,682	500	531.25	2,100	2,132
Leafy vegetables plot	500	531.25	2,434	2,466	500	531.25	1,684	1,716	500	531.25	2,134	2,166
Pasture, silage growing area	500	600	2,616	2,716	500	600	1,866	1,966	500	600	2,316	2,416
Grain fields	500	600	2,466	2,566	500	600	1,716	1,816	500	600	2,166	2,266
Dwelling site	500	531.25	2,300	2,332	500	531.25	1,550	1,582	500	531.25	2,000	2,032
Surface-water body	500	800	2,716	3,016	500	800	1,966	2,266	500	800	2,416	2,716
Atmospheric Transport Parameter												
Meteorological STAR file	GA_COLUMBUS.str				GA_COLUMBUS.str				GA_COLUMBUS.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	1,300				550				1,000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	1,716				966				1,416			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				270				225			

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Benning RCAs (continued)

RCA Layout Parameter	Coolidge Range				Patton Range				Buchanon Range			
Distance to nearest normally occupied area (m)	450				800				950			
Bearing of X axis (degrees)	135 (northeast)				90 (north)				135 (northeast)			
X dimension of primary contamination (m)	1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	1,550	1,582	500	531.25	1,900	1,932	500	531.25	2,050	2,082
Leafy vegetables plot	500	531.25	1,584	1,616	500	531.25	1,934	1,966	500	531.25	2,084	2,116
Pasture, silage growing area	500	600	1,766	1,866	500	600	2,116	2,216	500	600	2,266	2,366
Grain fields	500	600	1,616	1,716	500	600	1,966	2,066	500	600	2,116	2,216
Dwelling site	500	531.25	1,450	1,482	500	531.25	1,800	1,832	500	531.25	1,950	1,982
Surface-water body	500	800	1,866	2,166	500	800	2,216	2,516	500	800	2,366	2,666
Atmospheric Transport Parameter												
Meteorological STAR file	GA_COLUMBUS.str				GA_COLUMBUS.str				GA_COLUMBUS.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	450				800				950			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	866				1,216				1,366			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				270				315			

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Benning RCAs (continued)

RCA Layout Parameter	Burma Hill Range				K-15 Range				K-18 Range			
Distance to nearest normally occupied area (m)	400				400				650			
Bearing of X axis (degrees)	135 (northeast)				45 (northwest)				315 (southwest)			
X dimension of primary contamination (m)	290				1,000				1,000			
Y dimension of primary contamination (m)	290				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	790	822	500	531.25	1,500	1,532	500	531.25	1,750	1,782
Leafy vegetables plot	500	531.25	824	856	500	531.25	1,534	1,566	500	531.25	1,784	1,816
Pasture, silage growing area	500	600	1,006	1,106	500	600	1,716	1,816	500	600	1,966	2,066
Grain fields	500	600	856	956	500	600	1,566	1,666	500	600	1,816	1,916
Dwelling site	500	531.25	690	722	500	531.25	1,400	1,432	500	531.25	1,650	1,682
Surface-water body	500	800	1,106	1,406	500	800	1,816	2,116	500	800	2,066	2,366
Primary Contamination Parameter												
Length parallel to aquifer flow	290				1,000				1,000			
Atmospheric Transport Parameter												
Meteorological STAR file	GA_COLUMBUS.str				GA_COLUMBUS.str				GA_COLUMBUS.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	400				400				650			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	816				816				1,066			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				225				135			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Benning does not exceed 1.0 $\times 10^{-2}$ millisievert per year (mSv/y) (1.0millirem 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

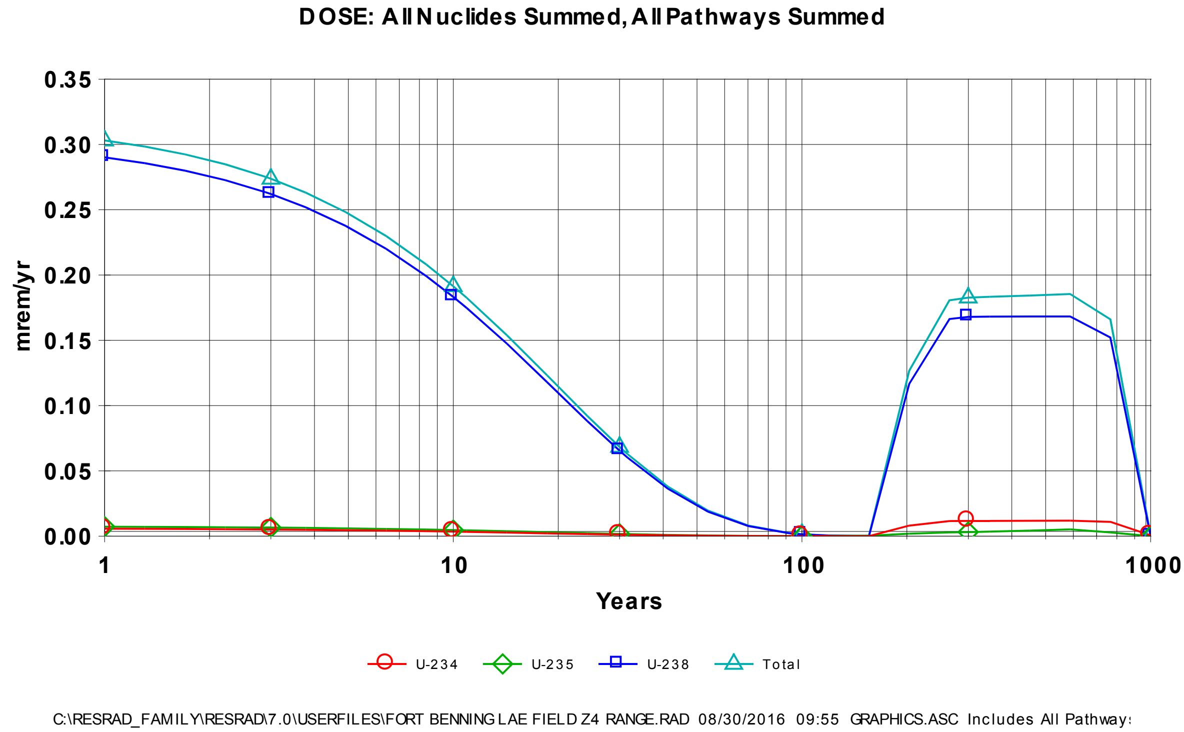
RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Brann Range	0.32	0.33
Buchanon Range	0.32	0.31
Burma Hill Range	0.0045	0.0038
Coolidge Range	0.32	0.32
Hook Range	0.32	0.31
K-15 Range	0.32	0.35
K-18 Range	0.32	0.33
Patton Range	0.32	0.32
Z-4 Range	0.32	0.29

[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.

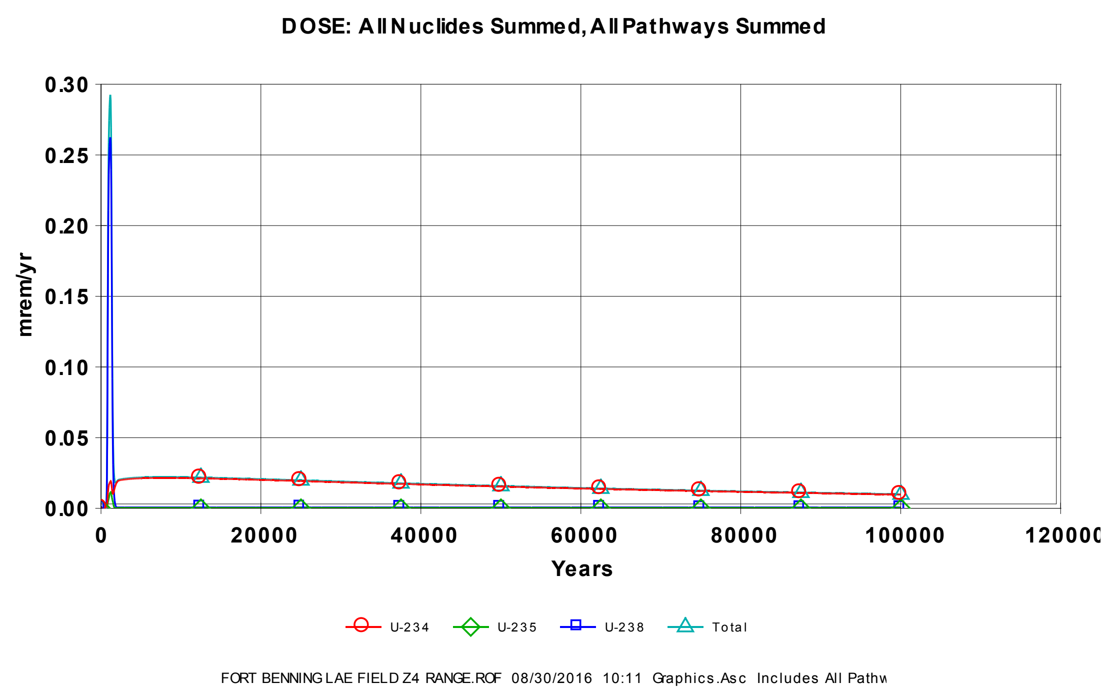
RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

Figure 4-1. Residential Farmer Receptor Dose Graphs for Fort Benning RCAs

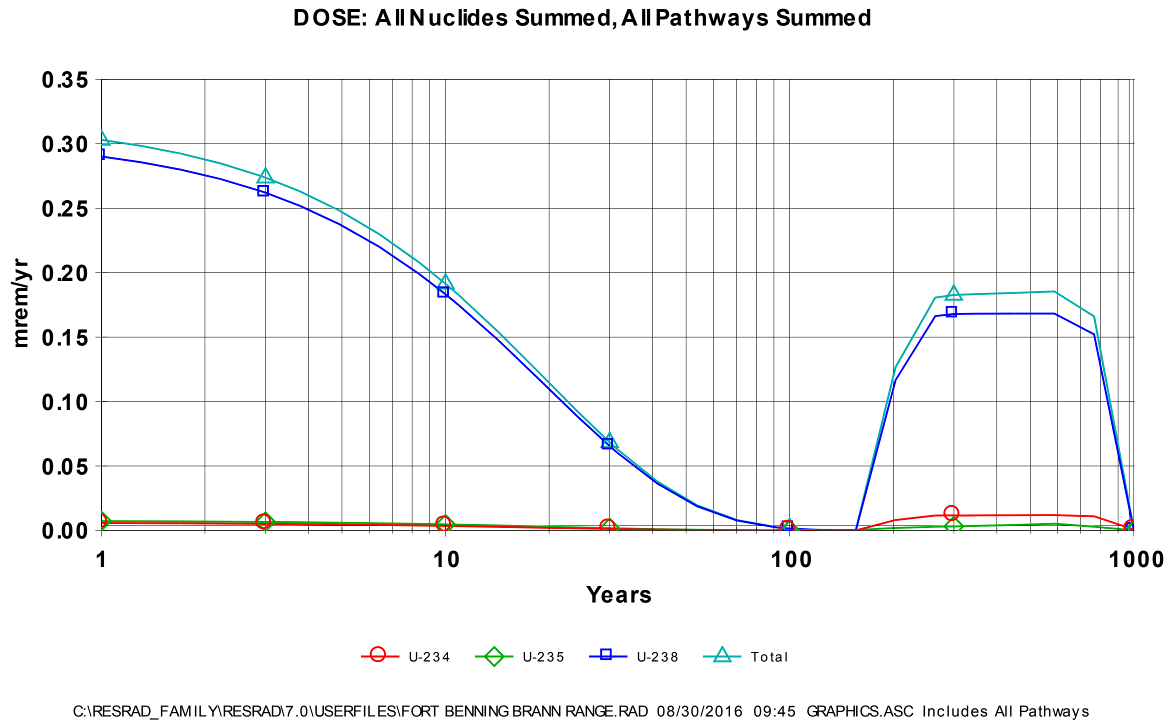
Z-4 Range
RCA Onsite (RESRAD)



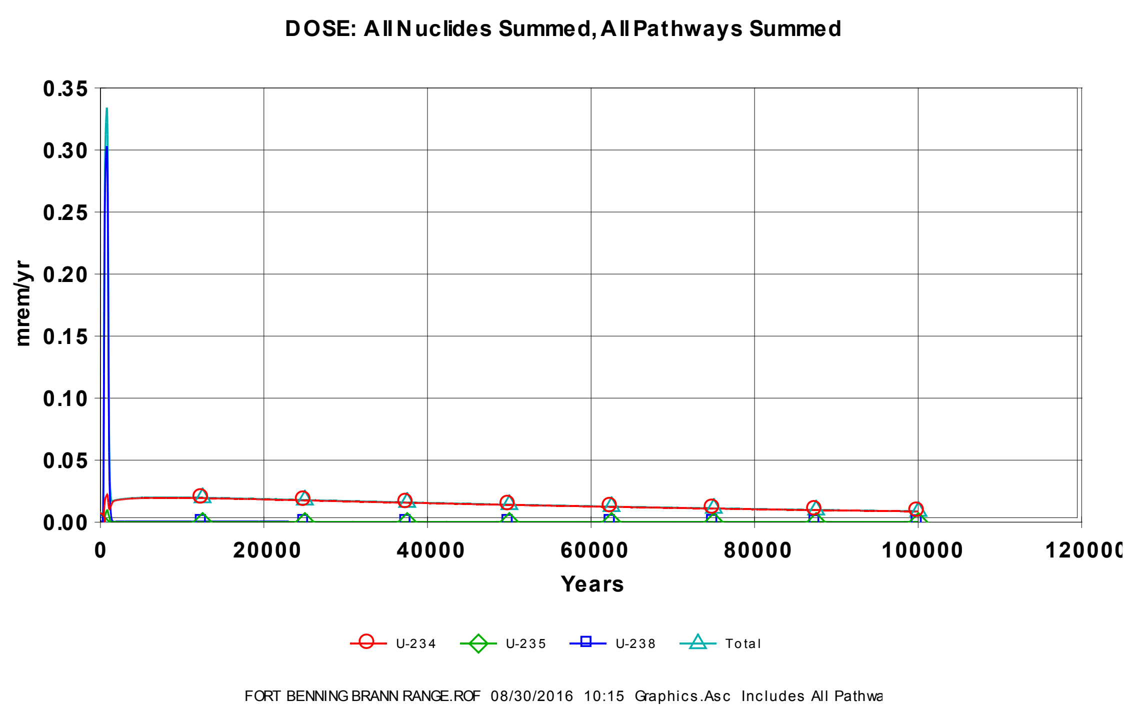
RCA Offsite (RESRAD-OFFSITE)



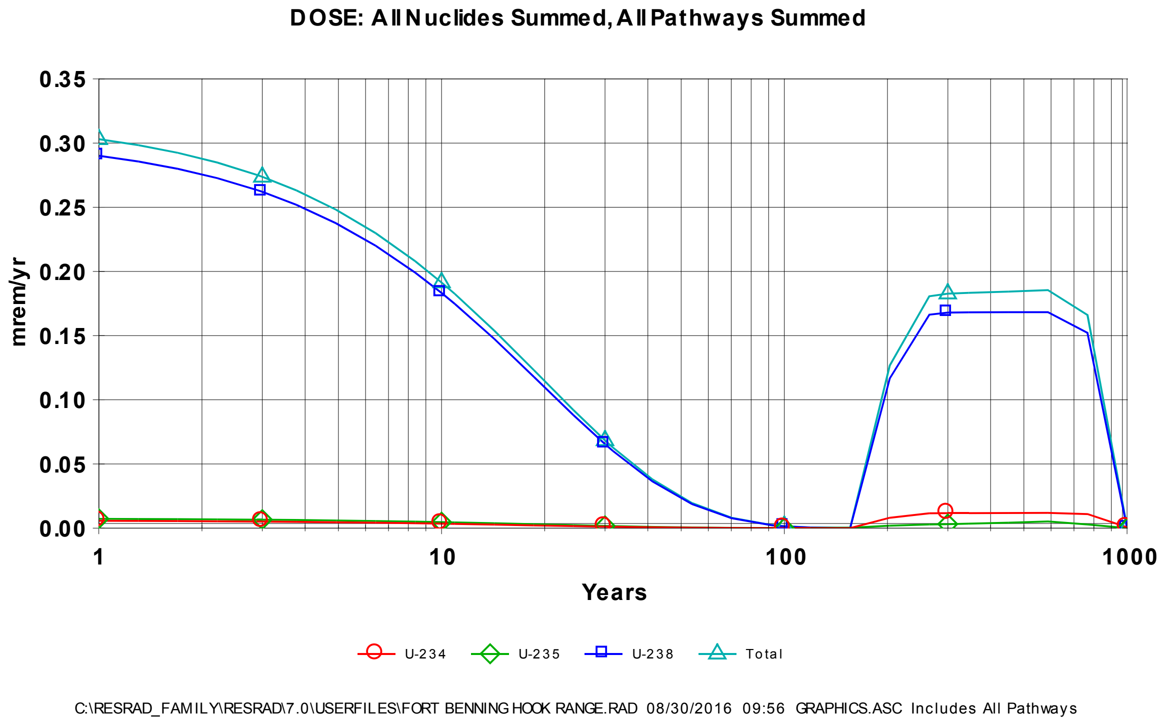
Brann Range
RCA Onsite (RESRAD)



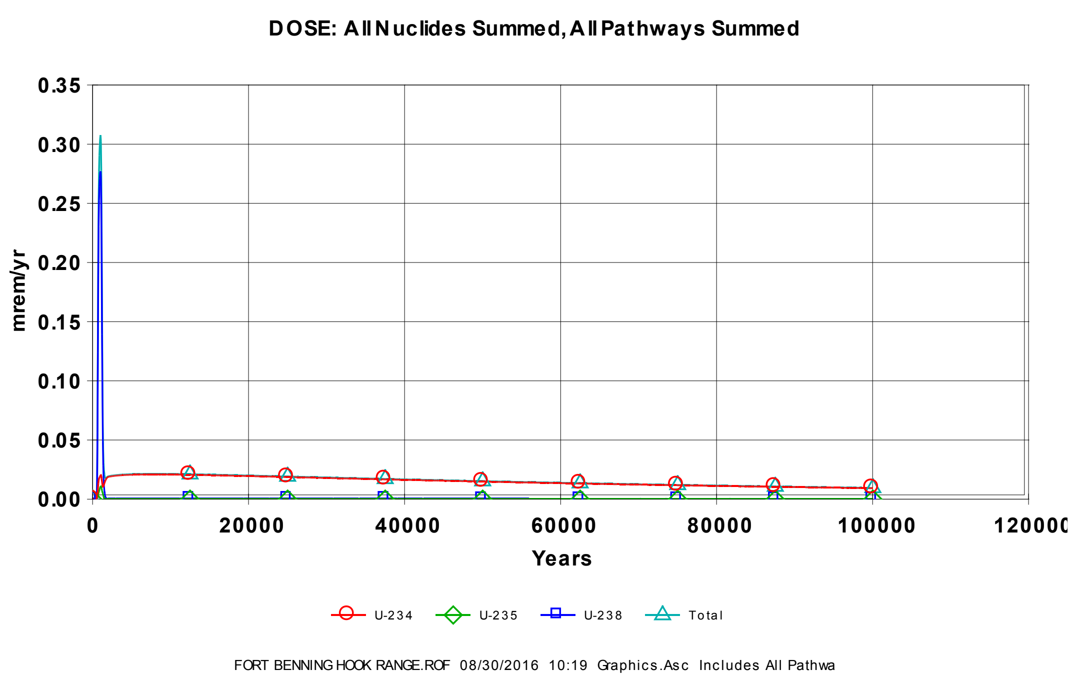
RCA Offsite (RESRAD-OFFSITE)



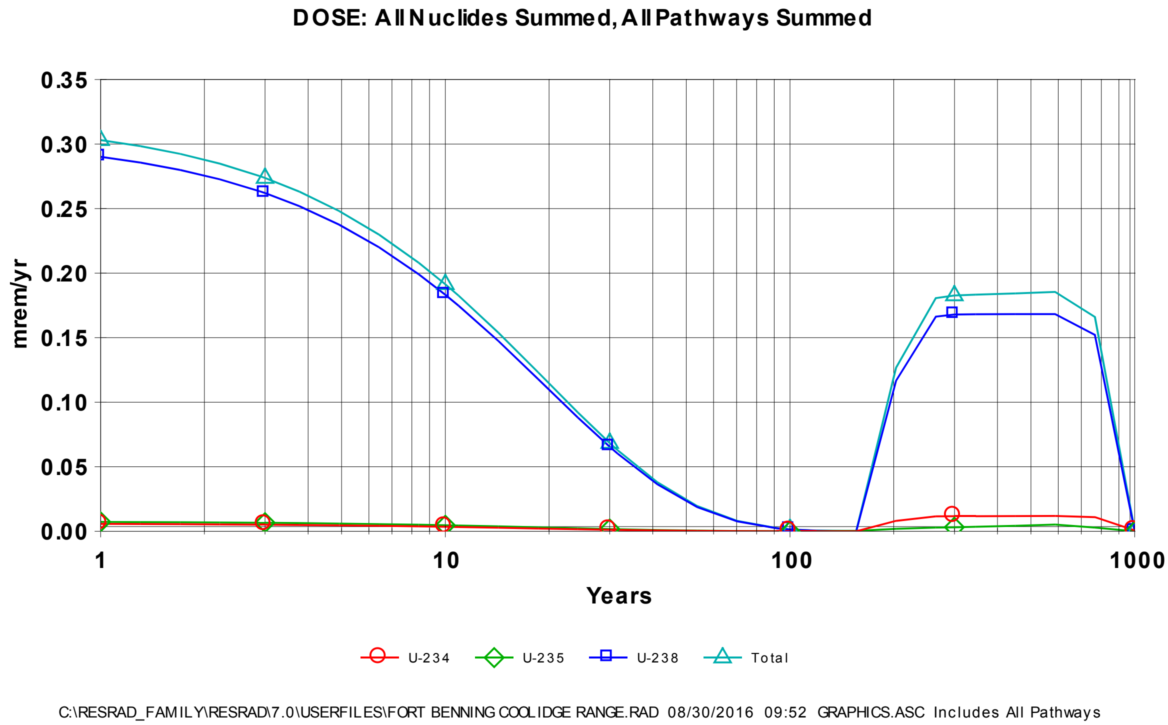
Hook Range
RCA Onsite (RESRAD)



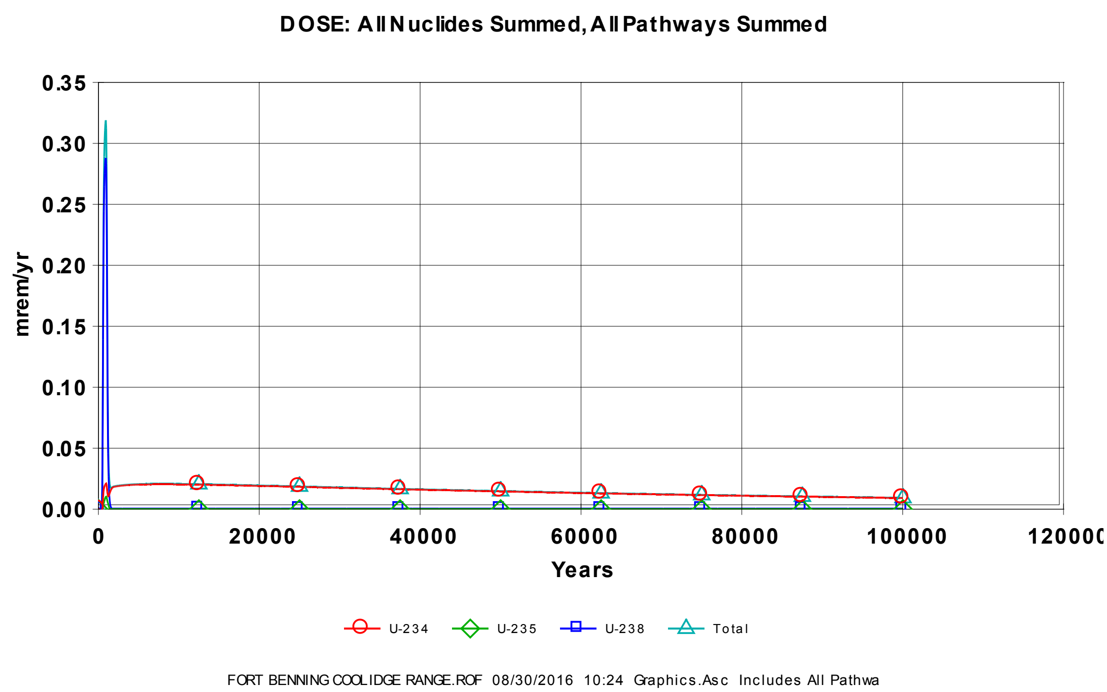
RCA Offsite (RESRAD-OFFSITE)



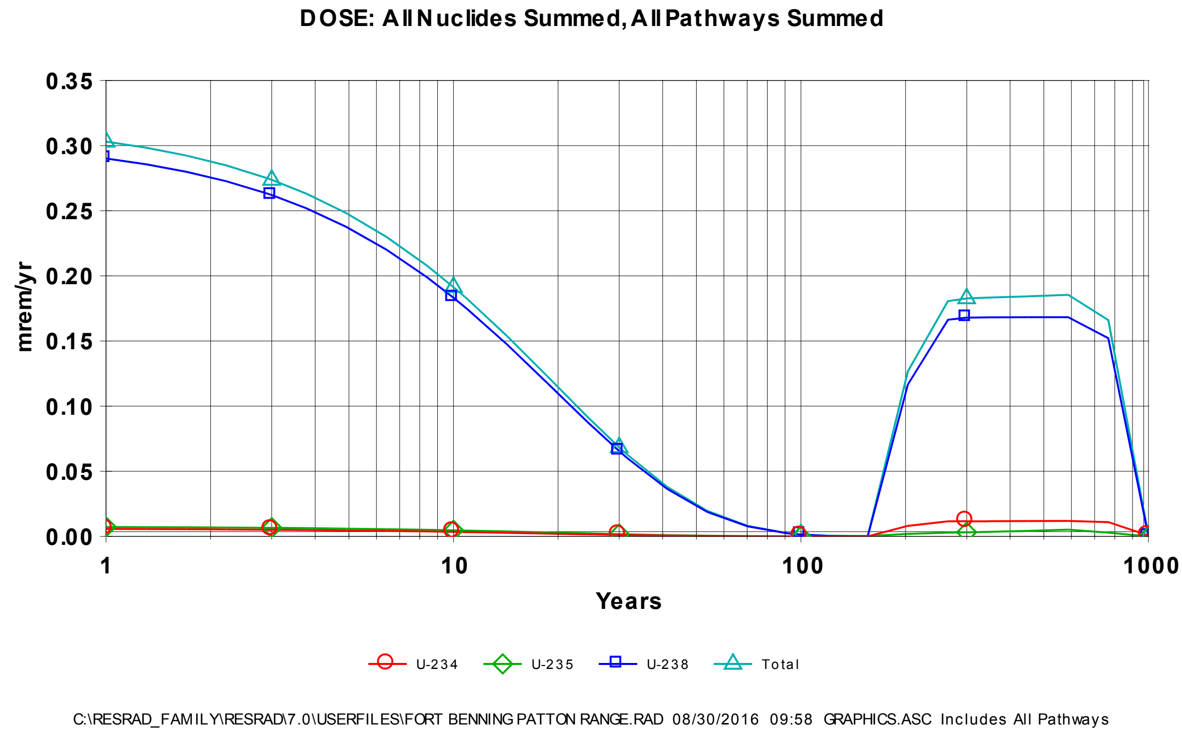
Coolidge Range
RCA Onsite (RESRAD)



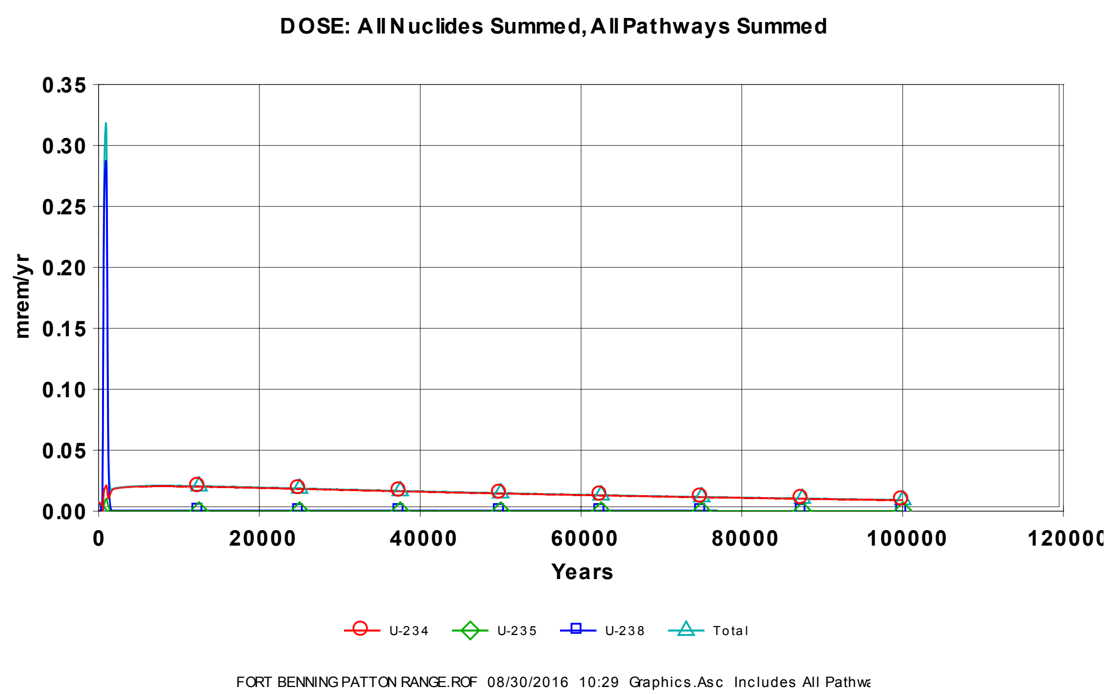
RCA Offsite (RESRAD-OFFSITE)



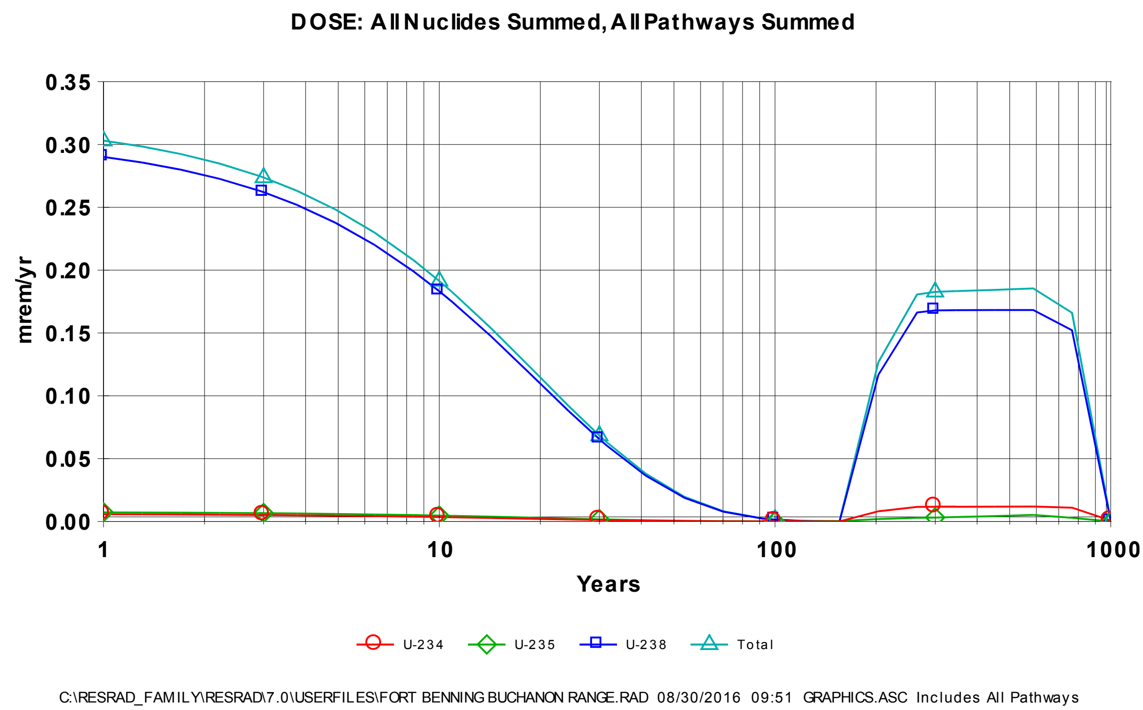
Patton Range
RCA Onsite (RESRAD)



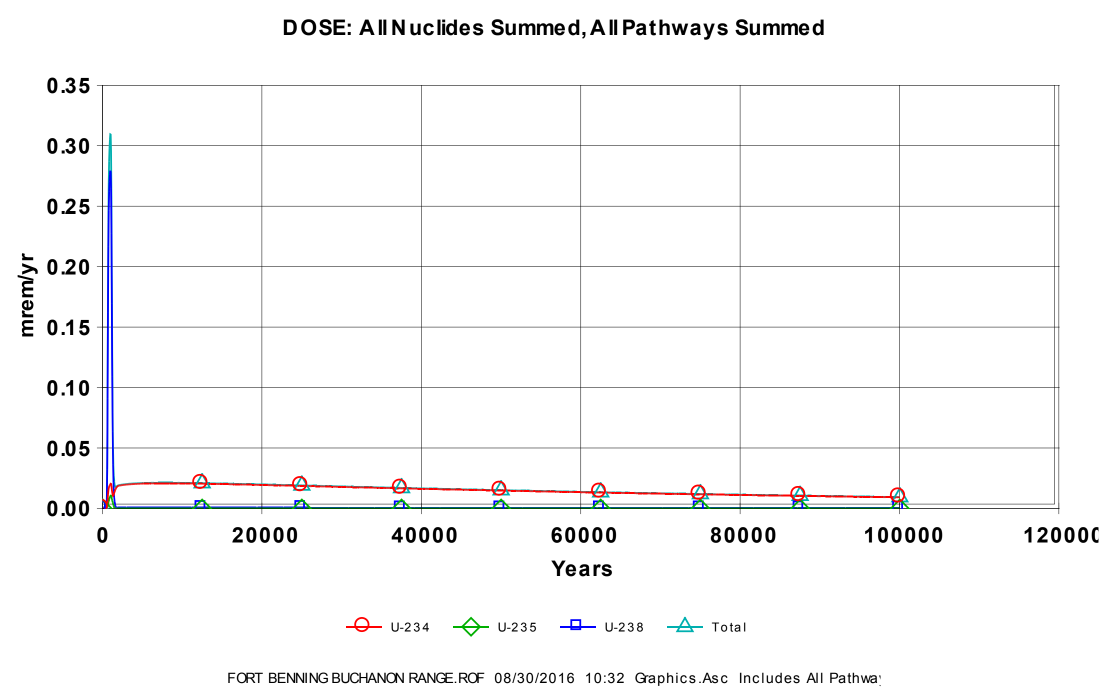
RCA Offsite (RESRAD-OFFSITE)



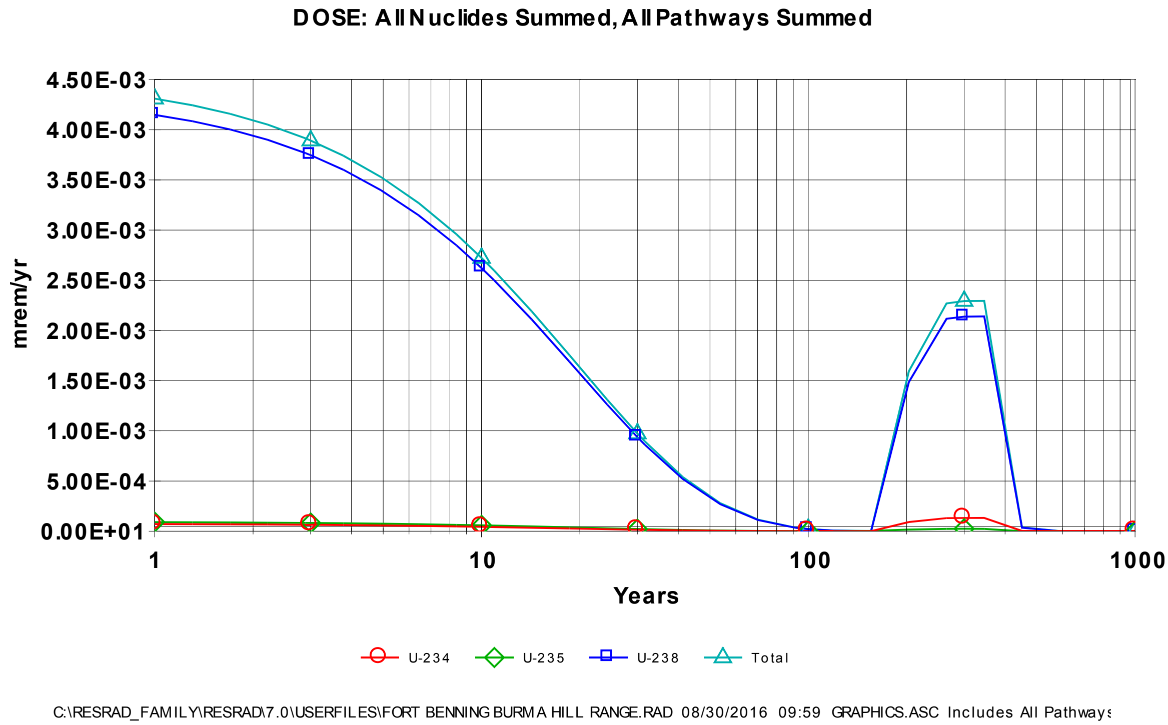
Buchanon Range
RCA Onsite (RESRAD)



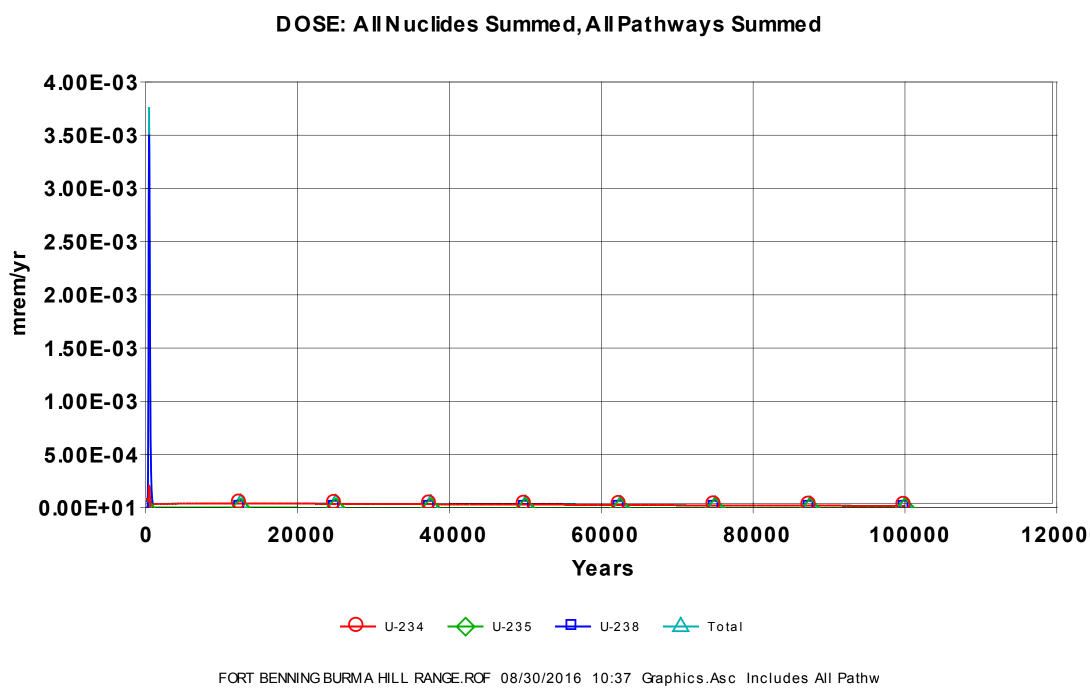
RCA Offsite (RESRAD-OFFSITE)



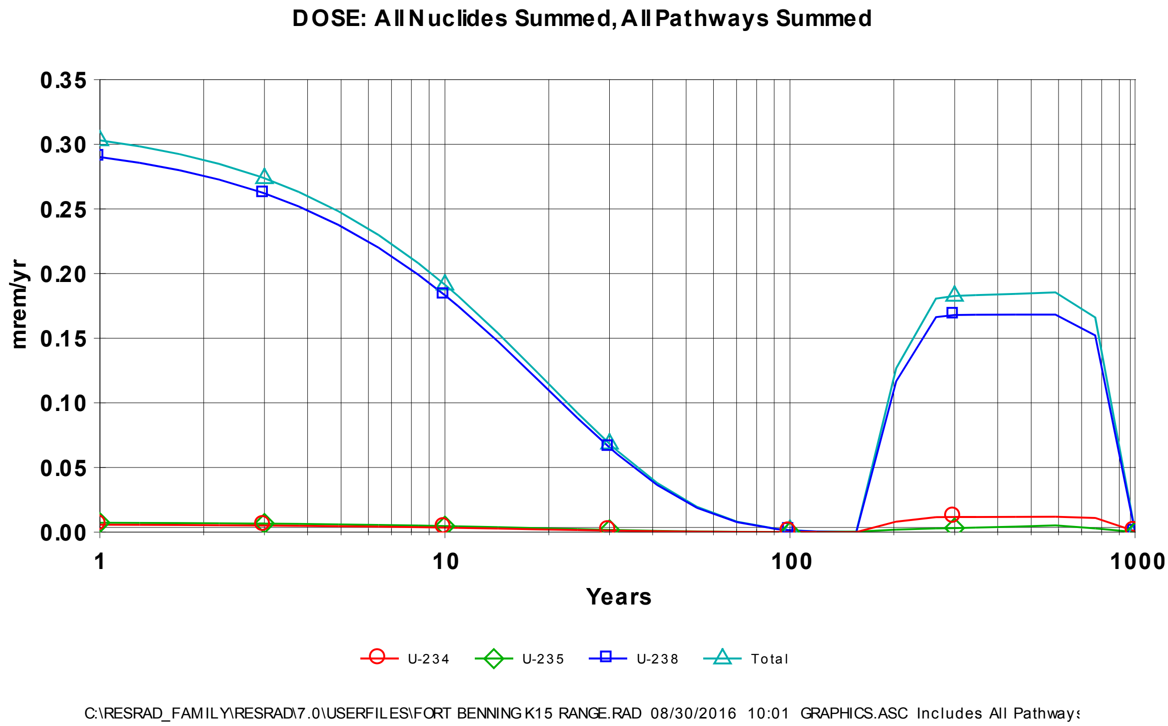
Burma Hill Range
RCA Onsite (RESRAD)



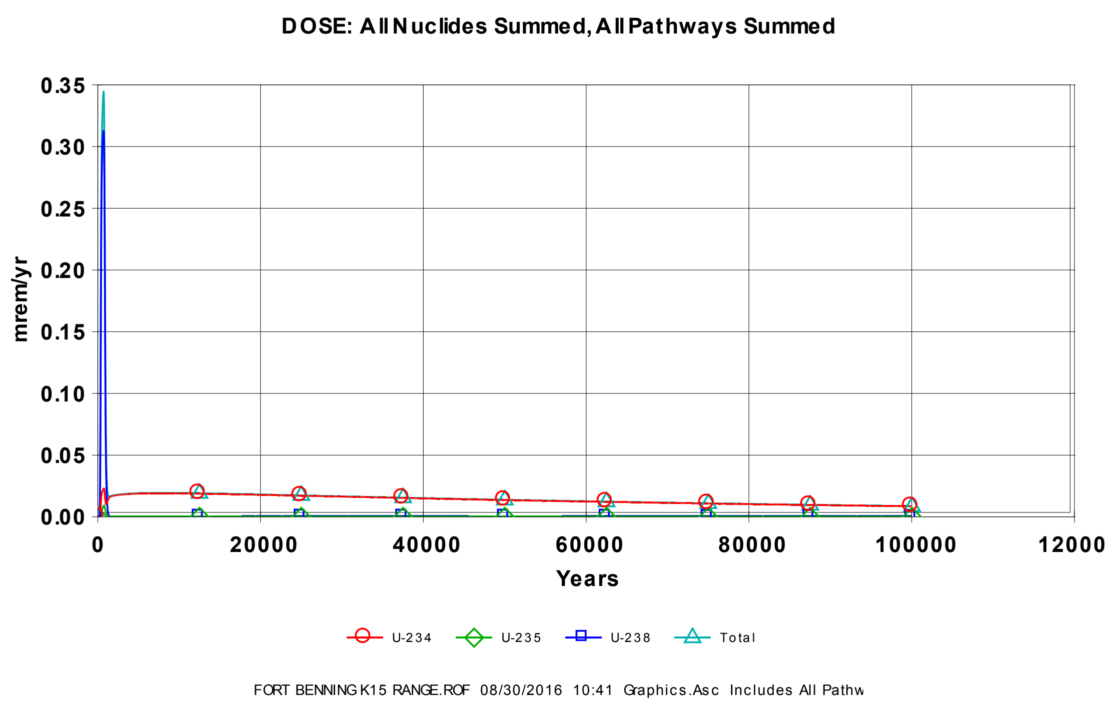
RCA Offsite (RESRAD-OFFSITE)



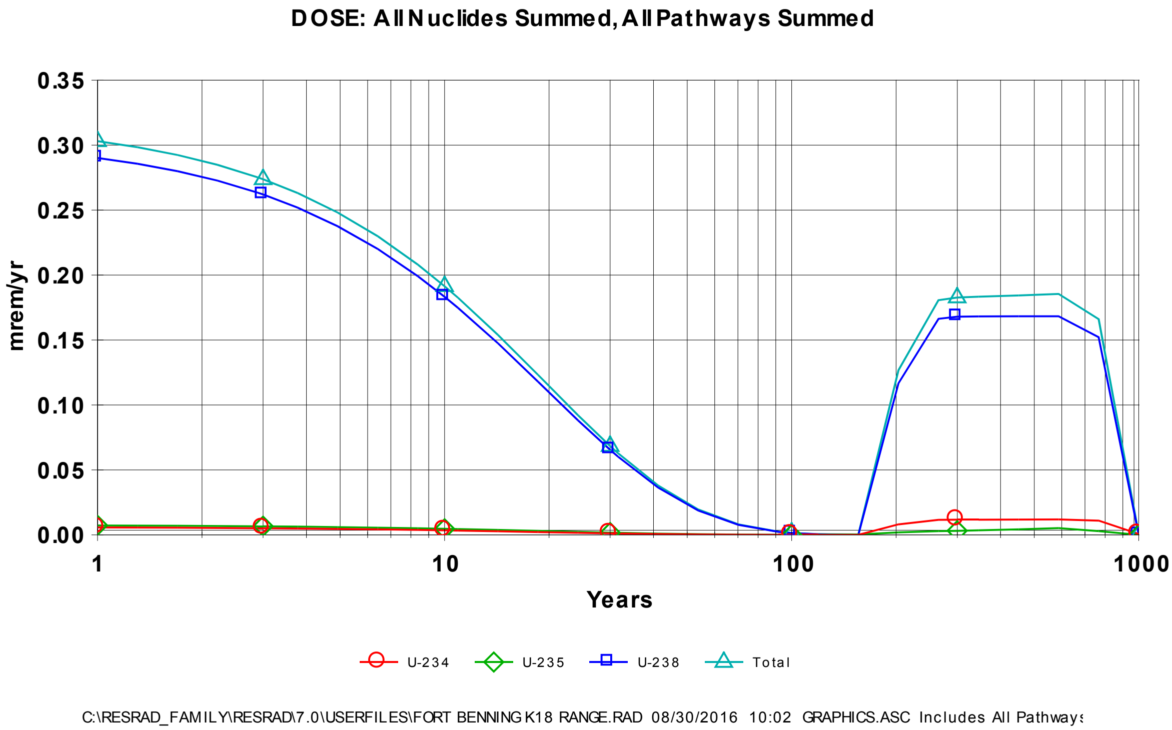
K-15 Range
RCA Onsite (RESRAD)



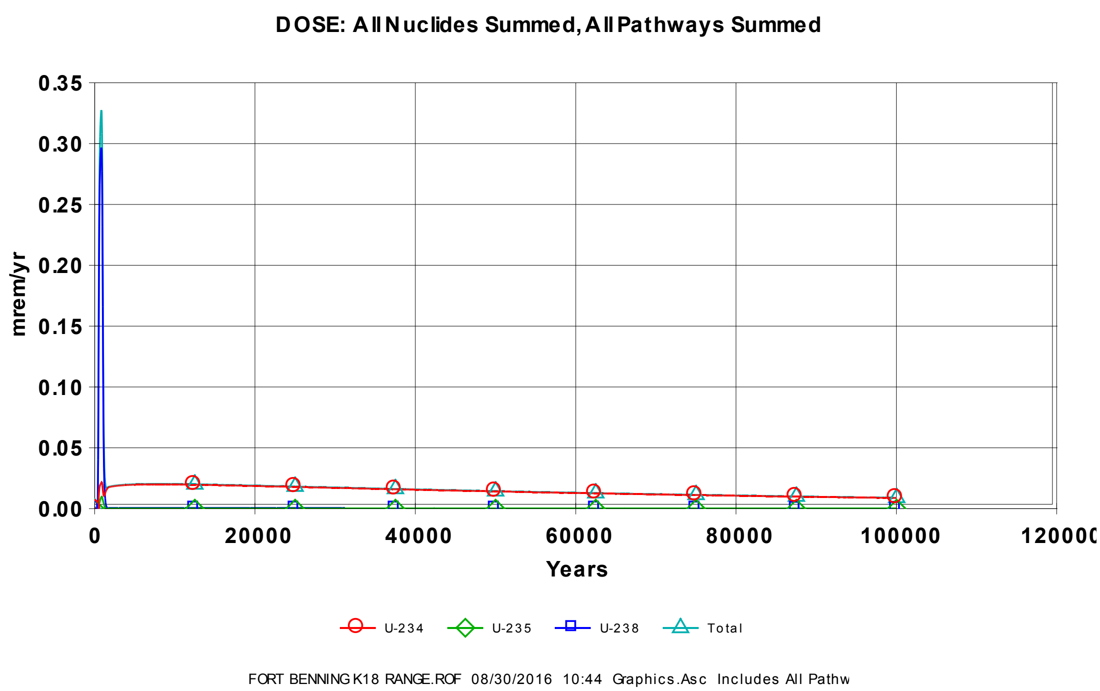
RCA Offsite (RESRAD-OFFSITE)



K-18 Range
RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



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Attachment 1

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

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

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

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

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

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

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

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

$$A_i = \lambda_i N_i$$

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

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