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**FINAL**

**SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN  
FORT DIX, JOINT BASE MCGUIRE-DIX-LAKEHURST, NEW JERSEY  
ANNEX 16**

**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
BRAC	Base Realignment and Closure Act
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
ft <sup>2</sup> /day	Square Feet per Day
FORSCOM	Forces Command
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
JBMDL	Joint Base McGuire-Dix-Lakehurst
kg	Kilogram
m <sup>2</sup>	Square Meters
mrem/y	Millirem per Year
msl	Mean Sea Level
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
SDZ	Surface Danger Zone
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

## 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 Dix in Joint Base McGuire-Dix-Lakehurst (JBMDL), New Jersey, 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 Dix. 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 ( <b>SWS-13</b> and <b>SWS-14</b> ) from the Frankford Arsenal 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., frozen stream)

### 1.2 INSTALLATION BACKGROUND

Fort Dix is currently the largest military installation in the northeastern United States. It covers 55 square miles in central New Jersey and is located 47 miles east of Philadelphia, Pennsylvania, and 17 miles southeast of Trenton, New Jersey (Figure 1-1).

Fort Dix currently consists of 31,065 acres of land, of which 13,765 acres are range and impact areas and 14,000 are classified as contiguous maneuver areas. The remainder of the installation is the cantonment area. The Fort Dix training areas are bordered by the Lebanon State Forest, Lakehurst Naval Air Engineering Center, and selected Wildlife Management Areas that enable this installation to simultaneously support combat, combat support, and combat service support training. McGuire Air Force Base is on the western edge of Fort Dix, and the Lakehurst Naval Air Engineering Station is on the eastern edge.

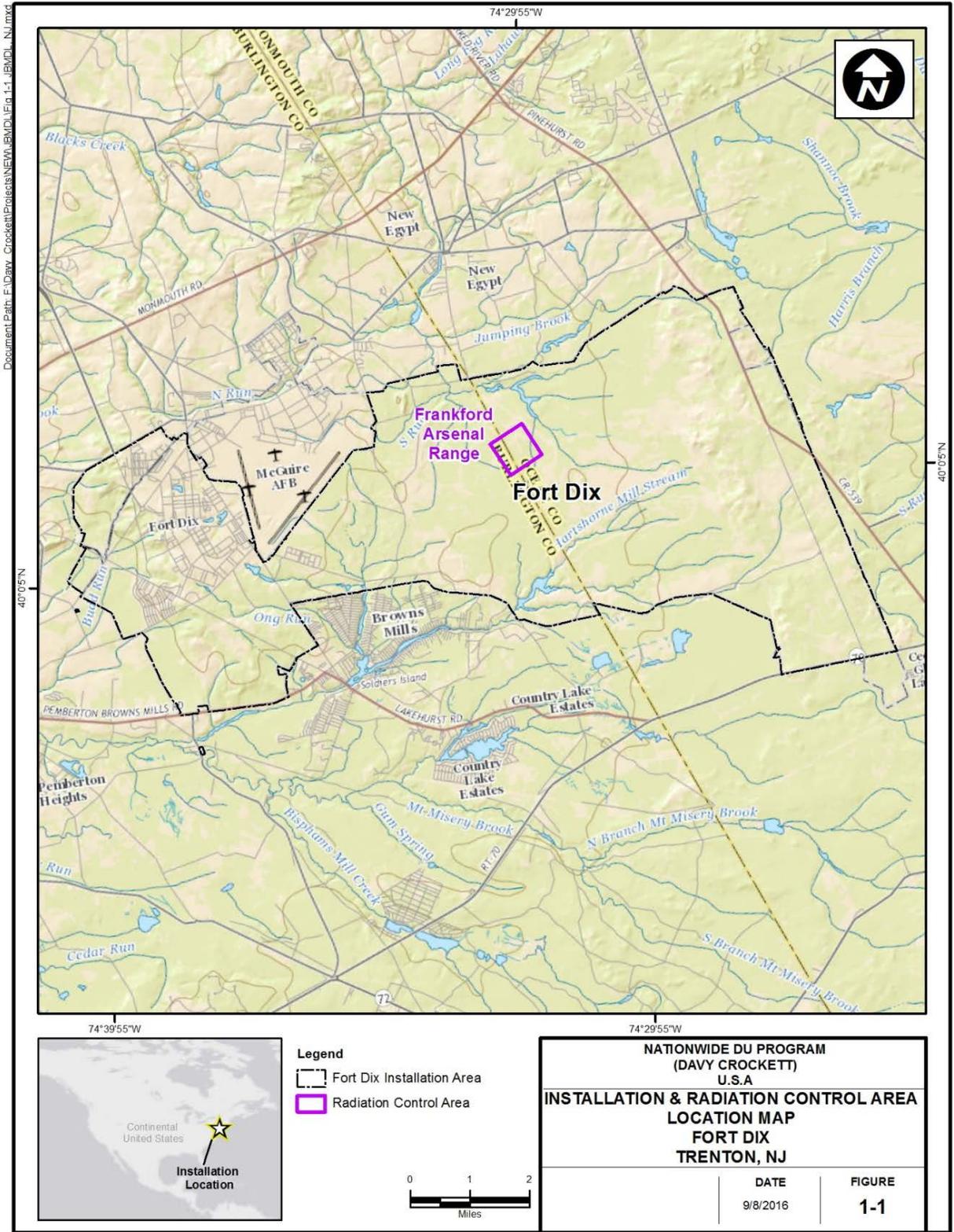


Figure 1-1. Installation and Radiation Control Area Location Map

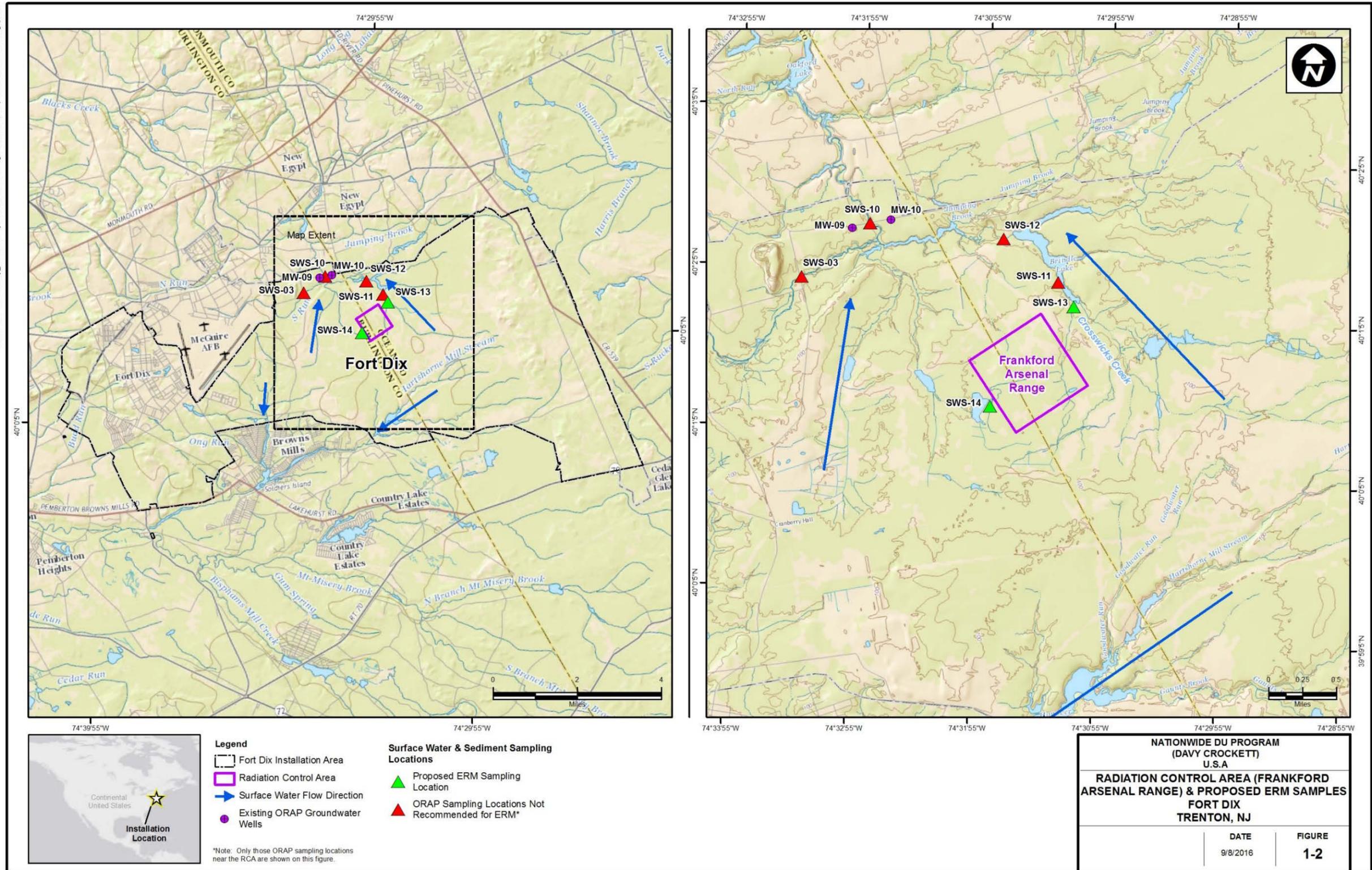


Figure 1-2. Radiation Control Area (Frankford Arsenal Range) and Proposed ERM Samples

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Fort Dix has a long and distinguished history. Construction of Camp Dix began in June 1917 and was used as a training and staging center for units during World War I. Following the end of World War I, the camp was designated as a demobilization center. Prior to World War II, on March 8, 1939, the post became Fort Dix, a permanent U.S. Army installation.

Fort Dix has completed its realignment from an individual training center to a Forces Command (FORSCOM) Power Projection Platform for the northeastern United States under the command and control of the U.S. Army Reserve Command. Primary missions include being a center of excellence for training, mobilizing, and deploying Army Reserve and National Guard units, and providing regional base operations support to on-post and off-post active and reserve component units of all services.

In 2005, the U.S. Department of Defense (DoD) announced that Fort Dix would be affected by a Base Realignment and Closure Act (BRAC) action. It was merged with two neighboring military bases, McGuire Air Force Base and Naval Air Engineering Station Lakehurst, establishing JBMDL, New Jersey. There are currently 140 operational ranges at JBMDL totaling approximately 28,000 acres (EA 2012).

An Archives Search Report (ASR) (USACE 2009) confirmed the presence of one range where the Davy Crockett weapons system was used at Fort Dix. The historical Davy Crockett impact area or radiation control area (RCA) consists of 247.5 acres and was known as the Frankford Arsenal Range (Figure 1-2). While there are Dudded Impact Areas to the southeast of the Frankford Arsenal Range, the Operational Range Assessment Program (ORAP) Phase II report designates the Frankford Arsenal Range as a live-fire range surrounded by Non-Dudded Impact Areas (EA 2012). The nearest normally occupied areas to the Frankford Arsenal Range is located approximately 1.7 miles northwest of the RCA.

### **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 Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), JBMDL (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 JBMDL; therefore, it is assumed that most, if not all, of the 10 kilograms (kg) of DU from the rounds fired remains in the RCA.

### **1.4 PHYSICAL ENVIRONMENT**

JBMDL lies within the northern Atlantic Coastal Plain, which is characterized by generally flat to very gently rolling topography. The maximum topographic relief is approximately 130 feet, varying from above 200 feet above mean sea level (msl) in the northwest to 70 feet above msl in the southeast. The TA, ranges on the western portion of the installation, and the impact area are generally flat with elevations varying between 80 and 100 feet above msl (EA 2012).

The headwaters of four watersheds (Toms River, Assiscunk Creek, Rancocas Creek, and Crosswicks Creek) originate on JBMDL. The streams that exit JBMDL have the following designated uses: maintenance, migration, and propagation of natural and established biota; primary and secondary

contact for recreation; industrial and agricultural water supply; public potable water supply after conventional filtration treatment and disinfection; and any other reasonable uses.

Crosswicks Creek drains 11,400 acres of the northern portion of the Fort Dix cantonment area and range complex, including the northern half of the impact area and ranges where small-, medium-, and large-caliber munitions are fired. Crosswicks Creek flows into Brindle Lake along the northern installation boundary. Frankford Arsenal Range is located to the west and near Brindle Lake. After exiting Brindle Lake, Crosswicks Creek flows onto private forestlands and then into a series of active commercial cranberry bogs. Crosswicks Creek continues north of JBMDL for approximately 6 miles before turning west toward the Delaware River.

The southeastern area of the RCA in Fort Dix is drained to the northeast into Brindle Lake via a small stream (Figure 1-2). The western central portion of the RCA is drained by another small stream that exits the RCA to the west for a short distance before entering a cranberry bog.

Groundwater occurs within the northern Pinelands Section of the New Jersey Coastal Plain. Groundwater yield within the area is known to vary considerably depending on formation. Six major aquifers have been identified in the Coastal Plain: the Kirkwood-Cohansey aquifer (the upper water-bearing unit at JBMDL), Lower Member of the Kirkwood, Mount Laurel-Wenonah, Marshalltown-Wenonah, Englishtown, and Potomac-Raritan-Magothy. Due to the confining units separating the aquifers, water does not tend to move from one aquifer to another.

The depth to groundwater in the Kirkwood-Cohansey aquifer is less than 5 feet below ground surface (bgs) and groundwater flow generally follows topography. The recharge area of the Kirkwood-Cohansey aquifer system covers 2,250 square miles and matches the dimensions of the Cohansey Sand formation. Recharge of the Cohansey and Kirkwood formations is primarily by precipitation falling on exposed portions of the units. Transmissivity rates of the Kirkwood-Cohansey aquifer range from approximately 3,102 to 38,475 square feet per day (ft<sup>2</sup>/day), and vertical hydraulic conductivity rates range from 36 to 420 feet per day, according to the New Jersey Geologic Survey. The Kirkwood-Cohansey aquifer also recharges surface water. Approximately 90 percent of stream flow in the area of JBMDL is from shallow groundwater discharges of the Kirkwood-Cohansey aquifer system (New Jersey Geological Survey 2009).

## 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 Frankford Arsenal Range at Fort Dix are as follows:

- **Surface Water Use**—Surface water in the vicinity of JBMDL is used for drinking water. Approximately 80 percent of the water used at JBMDL is obtained from a surface water intake along the Greenwood Branch of Rancocas Creek. Frankford Arsenal Range does not drain into Rancocas Creek.
- **Recreational Use**—Local off-range surface water bodies within 15 miles are used for recreational purposes.
- **Sensitive Environments**—JBMDL is located within the New Jersey Pinelands, which is the largest area of contiguous, undeveloped forest and wetland on the Atlantic Coastal Plain of the Mid-Atlantic region. The mosaic of globally rare upland and wetland communities and species found here is of national significance and the New Jersey Pinelands is the largest pine barrens complex in the world. The Pinelands overlay one of the largest aquifers in the country, and the wetlands and pristine headwaters arising within the Pinelands support a

unique assemblage of indigenous species and are critical for the water quality and productivity of the New Jersey backbarrier lagoon estuaries (USFWS 2016).

- **Habitat**—JBMDL is located at the northern end of the New Jersey Pinelands and can be provisionally divided into three forest communities: pine-oak, oak-hickory, and white cedar-type forests. The base contains approximately 24,200 wooded acres; 14,000 acres deemed commercial forest; and 10,200 acres for impact use.
- **Ecological Receptors**—There are 223 species of special emphasis in the New Jersey Pinelands, incorporating 84 species of plants and 75 species of birds (USFWS 2016).
- **Groundwater Use**—Groundwater in the vicinity of JBMDL is used for drinking water. Public groundwater supply wells have been identified in the Crosswicks Creek watershed. The bulk of these wells are screened in deep, confined aquifers that are not likely to be impacted by activities directly linked to the water table.

Potential human receptors include those within Fort Dix and off-range relying on surface water downgradient from the RCA for potable water. Ecological receptors include sensitive environments (e.g., wetlands) and species of special emphasis in the New Jersey Pinelands potentially present at Fort Dix.

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## 2.0 ERMP SAMPLE DESIGN

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

Very limited sampling is recommended for the RCA. While a few ORAP Phase II samples have been collected downstream from the Frankford Arsenal Range (EA 2012), they were not analyzed for total/isotopic uranium and their placement was used to determine the presence/absence of munitions constituents other than DU. The ORAP Phase II assessment does not specify why total/isotopic uranium was not part of the analytical suite. However, it should be noted that there was limited usage of DU at the Frankford Arsenal Range. No units were authorized to field the Davy Crockett Weapon System at Fort Dix during the Davy Crockett M28 era (1958-1968). Less than 50 Cartridges, 20mm Spotting M101 were fired at Fort Dix. While the amount of additional XM101 20mm cartridges potentially fired at Fort Dix could not be determined, minimal Davy Crockett weapon and/or M101/XM101 20mm spotting rounds debris is expected to be found on the Frankford Arsenal Range at Fort Dix. This was confirmed during a range inspection in 2009 when no Davy Crockett weapon or ammunition debris was found.

### 2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the collection of two collocated samples from locations downstream from the RCA in Fort Dix (Figure 1-2) where it is assumed surface water flows throughout the year. If surface water is not flowing when a quarterly sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a quarterly basis unless sediment is inaccessible when a quarterly sampling event is planned (e.g., frozen stream, flooding).

The surface water and sediment sampling locations at Fort Dix were selected based on the surface water hydrology and potential for DU contribution and are located as follows:

- **SWS-13**—The selected sampling point is located just upstream of Brindle Lake on a stream that drains the southeastern portion of the RCA. SWS-13 is downstream from the northeastern boundary of the RCA.
- **SWS-14**—The selected sampling point is located just outside the western boundary of the RCA on a stream that drains the west-central portion of the RCA.

Historical surface water and sediment sample locations SWS-03, SWS-10, SWS-11, and SWS-12 will not be sampled during the environmental radiation monitoring (ERM). The proposed ERM is focused on surface water features downstream of the Frankford Arsenal Range and locations SWS-03, SWS-10, SWS-11, and SWS-12 are located on surface water features inapplicable to the RCA. In addition, the historical samples were not analyzed for total/isotopic uranium during the ORAP Phase II (EA 2012).

Surface water and sediment samples will be analyzed for total/isotopic uranium using the 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).

Surface water and sediment samples will 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, sampling of the surface water will occur every 3 months. If flow is intermittent, then sampling will occur during or after that flow, but no less than 3 months apart.

## **2.2 GROUNDWATER**

Presently, no ORAP groundwater monitoring wells are located at or near the RCA and the groundwater samples collected as part of the ORAP Phase II were not analyzed for total/isotopic uranium. As noted previously, the Kirkwood-Cohansey aquifer is the upper water-bearing unit at JBMDL, which is less than 5 feet bgs, and also recharges surface water. Approximately 90 percent of stream flow in the area of JBMDL is from shallow groundwater discharges of the Kirkwood-Cohansey aquifer system (New Jersey Geological Survey 2009). As a result, any surface water and sediment sampling downstream from the RCA should cover both direct migration from overland flow into streams and migration from groundwater to surface water. For this reason and additional rationale included in the PAERMP (U.S. Army 2015), groundwater sampling is not planned for JBMDL.

## **2.3 SOIL**

If an area of soil greater than 25 square meters (m<sup>2</sup>) 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<sup>2</sup> unless the soil erosion is located in a UXO area. The collection of environmental radiation 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 Dix 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 JBMDL will be coordinated with the JBMDL 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 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**

Surface water samples will be collected from two stream locations (SWS-13 and SWS-14) that drain the RCA 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 the 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 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<sup>®</sup>).
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 the 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 (10 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 <sup>b</sup>
	Ci/g	%
U-234	$6.22 \times 10^{-3}$	$3.56 \times 10^{-4}$
U-235	$2.16 \times 10^{-6}$	0.0938
U-238	$3.36 \times 10^{-7}$	99.9058
Depleted uranium <sup>a</sup>	$3.6 \times 10^{-7}$	100

<sup>a</sup> 10 CFR 20, Appendix B, Footnote 3.

<sup>b</sup> 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 Joint Base McGuire-Dix-Lakehurst RCA**

Parameter	Default Value	Frankford Arsenal Range	Justification or Source
Internal dose library	DCFPK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
<b>Contaminated Zone</b>			
Soil concentrations (pCi/g)	U-234	N/A	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance <sup>a</sup> × nuclide specific activity <sup>a</sup> / (CZ area × CZ depth × CZ density)
	U-235	N/A	
	U-238	N/A	
Area of contaminated zone (m <sup>2</sup> )	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 5ft bgs
Length parallel to aquifer flow (m)	100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity	0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand (Soil is clayey course sand)
Contaminated zone hydraulic conductivity (m/y)	10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter	5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)	2.0	8.9	<a href="http://www.usa.com">www.usa.com</a> for Fort Dix, NJ
Precipitation rate (annual rainfall) (m/y)	1.0	1.2	<a href="http://www.usa.com">www.usa.com</a> for Fort Dix, NJ
<b>Saturated Zone</b>			
Saturated zone total porosity	0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Saturated zone effective porosity	0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Saturated zone hydraulic conductivity (m/y)	100	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter	5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
<b>Unsaturated Zone</b>			
Unsaturated zone 1, thickness (m)	4.0	1.5	Depth to groundwater is generally 5ft.
Unsaturated zone 1, total porosity	0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Unsaturated zone 1, effective porosity	0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Unsaturated zone 1, soil-specific b parameter	5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)	10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand

<sup>a</sup> See Table 4-1.

**Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for  
Joint Base McGuire-Dix-Lakehurst RCA**

RCA Layout Parameter		Frankford Arsenal Range			
Distance to nearest normally occupied area (m)		2,700			
Bearing of X axis (degrees)		45 (northwest)			
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	3800	3832
Leafy vegetables plot		500	531.25	3834	3866
Pasture, silage growing area		500	600	4016	4116
Grain fields		500	600	3866	3966
Dwelling site		500	531.25	3700	3732
Surface-water body		500	800	4116	4416
<b>Atmospheric Transport Parameter</b>					
Meteorological STAR file		NJ_WRIGHTSTOWN_MCGUI.str			
<b>Groundwater Transport Parameter</b>					
Distance to well (parallel to aquifer flow) (m)		2,700			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)		3,116			
Distance to well (perpendicular to aquifer flow) (m)		0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)		-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)		150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)		225			

## 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 JBMDL does not exceed  $1.0 \times 10^{-2}$  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**

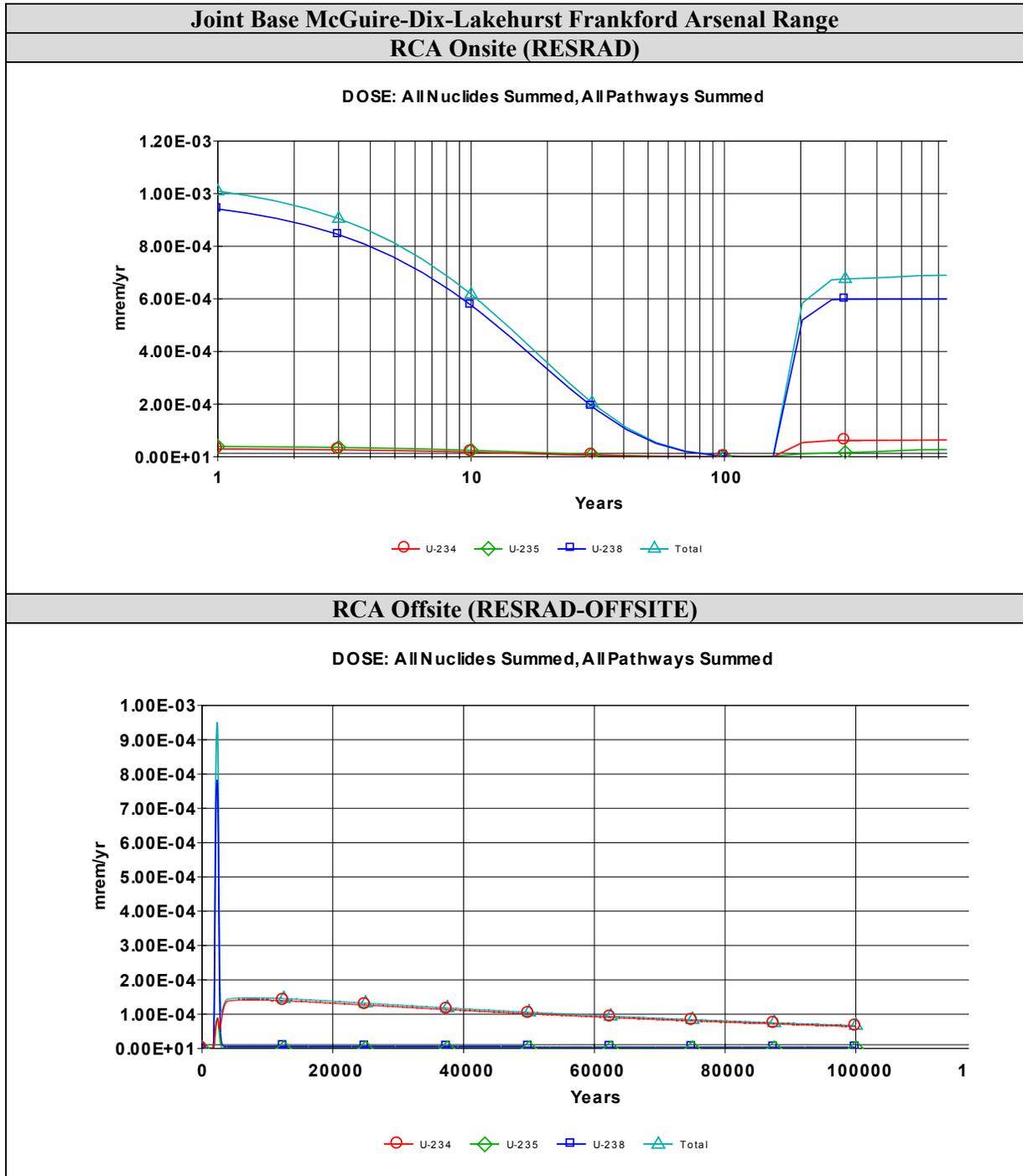
RCA	Onsite <sup>a</sup> (RESRAD)	Offsite <sup>b</sup> (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Joint Base McGuire-Dix-Lakehurst Frankford Arsenal Range	$1.2 \times 10^{-3}$	$9.6 \times 10^{-4}$

<sup>a</sup> The onsite residential farmer receptor resides on the RCA.

<sup>b</sup> 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



## **Attachment 1**

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

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

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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<sup>1</sup>:

$$S = \sum_i S_i a_i$$

$S$  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 (<sup>234</sup>U), <sup>235</sup>U and <sup>238</sup>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:

$$A_i = \lambda_i N_i$$

$\lambda_i$  is the decay constant and  $N_i$  is the number of atoms of uranium isotope  $i$  in the sample with mass  $m_i$ . Thus,

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

$\lambda_i$  is related to the half-life  $t_{1/2i}$  as follows:

$$\lambda_i = \frac{\ln 2}{t_{1/2i}}$$

If  $N_i$  is set to Avogadro's number ( $N = 6.02 \times 10^{23}$ ),<sup>2</sup> 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,

$$S_i = \frac{N \ln 2}{t_{1/2i} M_i}$$

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<sup>1</sup> Although contaminants, including <sup>236</sup>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.

<sup>2</sup> 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.<sup>3</sup> 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 <sup>4</sup>	
				(Bq g <sup>-1</sup> )	(Ci g <sup>-1</sup> )
<sup>234</sup> U	0.000054	$7.75 \times 10^{12}$	234.04	$2.30 \times 10^8$	$6.22 \times 10^{-3}$
<sup>235</sup> U	0.007204	$2.22 \times 10^{16}$	235.04	$7.99 \times 10^4$	$2.16 \times 10^{-6}$
<sup>238</sup> U	0.992742	$1.41 \times 10^{17}$	238.05	$1.24 \times 10^4$	$3.36 \times 10^{-7}$

By definition:

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

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

$$a_{U-234} = a_{0,U-234} D_{U-234}$$

$$a_{U-235} = a_{0,U-235} D_{U-235}$$

$D_{U-234}$  is the depletion of <sup>234</sup>U in depleted uranium and  $D_{U-235}$  similarly for <sup>235</sup>U, with

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

Kolafa<sup>5</sup> estimated the depletion of <sup>234</sup>U relative to the depletion of <sup>235</sup>U as follows:

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

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

$\varepsilon$  is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of <sup>238</sup>U and is much less than one.  $n$  is the number of enrichment stages.

For large  $n$ :

$$D_{U-234} \rightarrow e^{-4n\varepsilon}$$

$$D_{U-235} \rightarrow e^{-3n\varepsilon}$$

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

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

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

<sup>3</sup> For example, see <http://atom.kaeri.re.kr/nuchart/>.

<sup>4</sup> 1 curie (Ci) =  $3.7 \times 10^{10}$  becquerels (Bq)

<sup>5</sup> <http://www.ratical.org/radiation/vzaiic/u234.html>

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{U-235}$$

Substituting for  $n\varepsilon$

$$\ln D_{U-234} = \frac{4}{3}\ln D_{U-235}$$

Finally, exponentiating both sides of the equation,

$$D_{U-234} = D_{U-235}^{(4/3)}$$

So,

$$a_{U-234} = a_{0,U-234}D_{U-235}^{(4/3)}$$

Thus,

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

The NRC provides in 10 CFR 20:

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

Returning to the first equation above, then

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

Dividing by  $10^{-7} \text{ Ci g}^{-1}$  and collecting terms,

$$3.36D_{U-235}^{(4/3)} + 0.131D_{U-235} - 0.239 = 0$$

Solving,  $D_{U-235} = 0.13$ , and<sup>6</sup>

$\begin{aligned} a_{U-234} &= 0.00000356 \\ a_{U-235} &= 0.00093806 \\ a_{U-238} &= 0.99905838 \end{aligned}$
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<sup>6</sup> The values for <sup>234</sup>U and <sup>235</sup>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  $a_{U-234} = 0.000004$ ,  $a_{U-235} = 0.0009$ , and  $a_{U-238} = 0.9991$ . For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are  $a_{U-234} = 0.000007$ ,  $a_{U-235} = 0.0020$ , and  $a_{U-238} = 0.9980$  (DOE-STD-1136-2009), which corresponds to a specific activity of  $S = 3.8 \times 10^{-7} \text{ Ci g}^{-1}$ . I note that the derived DOE value for  $D_{U-234}$  is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for  $D_{U-235}$ :  $D_{U-234}^{(4/3)} = (0.28)^{(4/3)} = 0.18$ .

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