Environmental Radiation Monitoring Plan for the DU Impact Area
at Jefferson Proving Ground, Indiana

1. Introduction

The Nuclear Regulatory Commission source material license number SUB-1435 requires environmental radiation monitoring for the DU Impact Area at Jefferson Proving Ground (JPG). The authorized use of the depleted uranium has changed from "possession for decommissioning" to "possession only." As a result, the purpose of environmental radiation monitoring changed from site characterization to effluent monitoring.

The purpose of this environmental radiation monitoring plan (ERMP) is to describe the environmental sampling program to detect depleted uranium (DU) leaving the DU Impact Area. The ERMP explains which environmental pathways require evaluation, which samples will be taken for those evaluations, where these samples will be taken, how often these samples will be taken, and how these samples will be analyzed for DU.

Section 2 describes sampling points and sampling frequencies. Subsequent sections explain why surface water and sediment are sampled while all other media are not sampled.

This ERMP replaces and supersedes "Depleted Uranium Sampling Program, Environmental Radiation Monitoring Program, Jefferson Proving Ground, Madison, IN," dated March 10, 2000 (U.S. Army 2000).

2. Sampling Points and Sampling Frequency (Table 1)

The Army will sample surface water and sediments at locations downstream from the DU Impact Area in Middle Fork Creek (SD-DU-001/SW-DU-001) and Big Creek (SD-DU-002/SW-DU-002) at the JPG installation boundary. Sampling at these points is for detecting any DU that might be leaving JPG.

Similarly, the Army will sample surface water and sediments at locations downstream from the DU Impact Area in Middle Fork Creek (SD-DU-007/SW-DU-007) and Big Creek (SD-DU-008/SW-DU-008) at the boundary of the unexploded ordnance (UXO) area. Sampling at these points is for detecting any DU that might be entering areas at JPG open to the public.

Table 1. Recommended Environmental Radiation Monitoring Sample Locations

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream from the DU Impact Area in Middle Fork Creek (SD-DU-001/SW-DU-001, SD-DU-007/SW-DU-007) and Big Creek (SD-DU-002/SW-DU-002, SD-DU-008/SW-DU-008), as shown in Figure 1 based on the rationale presented in Section 2	Surface water and sediment based on rationale developed from the Environmental Report (U.S. Army 2013a) and site-specific details presented in Section 2	Semi-annual (spring and fall near hydrologic high and low) unless prevented by weather (e.g., dry stream)

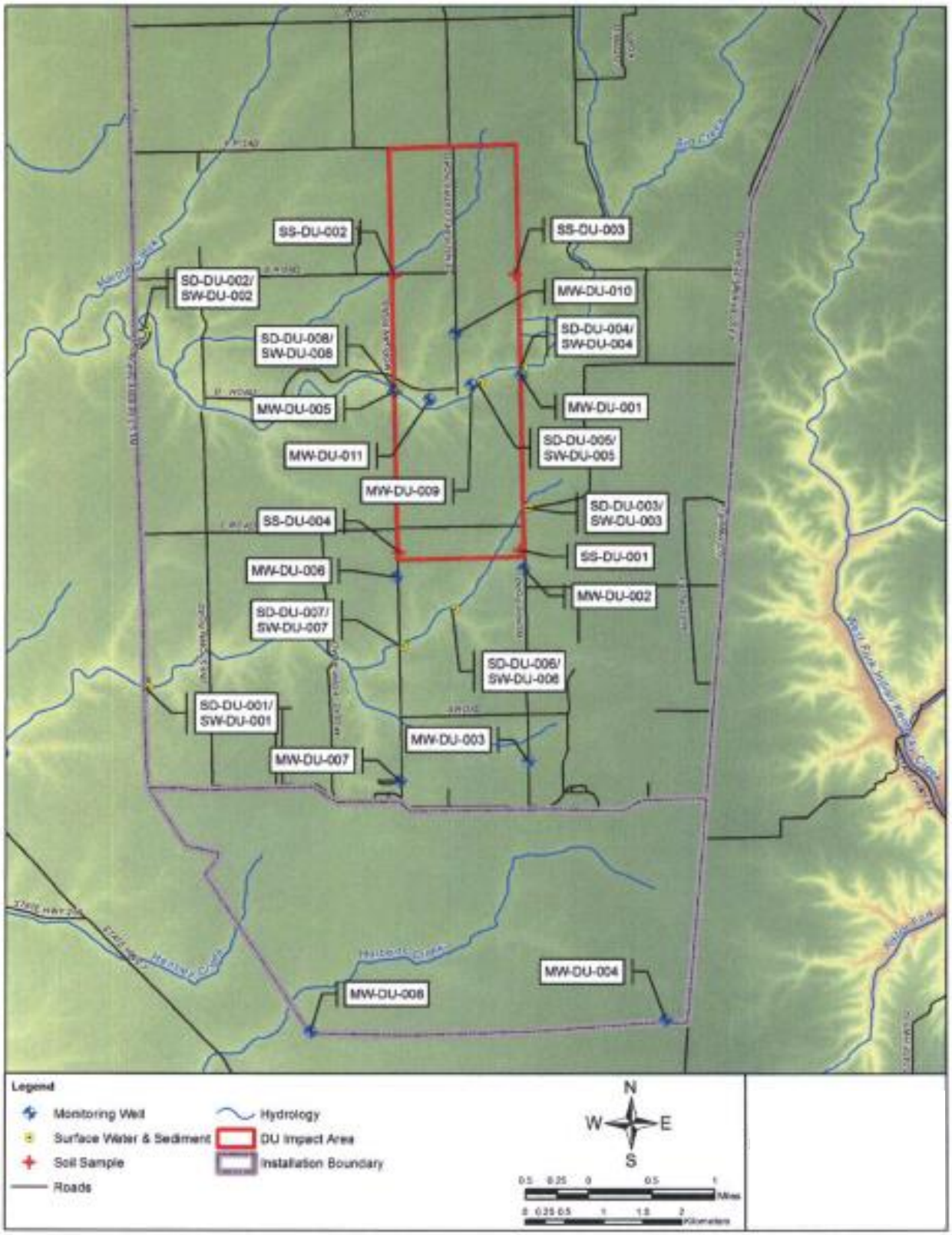


Figure 1 Sampling point locations SW-DU-001, -002, -007, and -008 and SD-DU-001, -002, --007 and -008

3. Historical Information

In addition to the testing of conventional explosive ammunition, the U.S. Army also proof tested large caliber (i.e., 105- and 120-mm) anti-armor DU penetrators under NRC SUB-1435 from 18 March 1984 to 2 May 1994 (U.S. Army 2013). Army personnel fired approximately 220,462 lb (100,000 kg) of DU projectiles into the DU Impact Area. All DU penetrators were test fired from the three fixed-gun positions on the east-west oriented firing line using guns that were aimed in a northerly direction. Since the penetrators were not fired at hard targets (e.g., dismantled tanks, armored personnel carriers), the penetrators traveled through the soft targets, hit the earth/buried itself, or ricocheted/continued traveling until each penetrator lost all kinetic energy and fell to the ground.

Under the former site characterization monitoring program (U.S. Army 2000) samples were collected semi-annually in the fall and spring from 23 locations (Figure 1). Samples from different media were collected, including 4 surface soil, 11 groundwater, 8 surface water, and 8 sediment samples (U.S. Army 2000), plus one duplicate sample for each medium during each event.

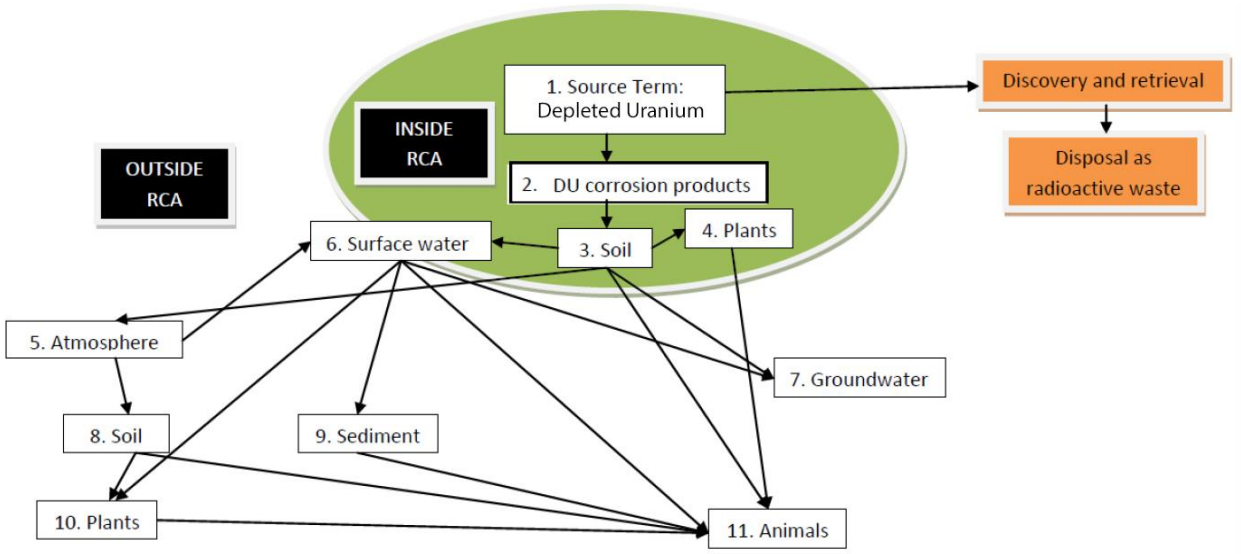
4. Physical Environment

The DU Impact Area is within the Muscatatuck Plateau physiographic region and is characterized by broad uplands covered by glacial till with entrenched valleys (Gray 2001). The glacial deposits overlie Paleozoic bedrock consisting of interbedded limestone, dolomite, and shale, and overburden thicknesses based on previously installed monitoring wells range from 10 to greater than 65 ft thick (U.S. Army 2002). According to Franzmeier, Steinhardt, and Schulze (2004), the glacial till is Pre-Wisconsinan age and thought to be Illinoian age or older and is covered with a thick (>6 ft thick) mantle of Wisconsinan age loess (wind deposited silt). The soil region that encompasses the DU Impact Area is described as “moderately thick loess over weathered loamy glacial till” (USDA NRCS 1999).

The DU Impact Area is incised by two streams (i.e., Middle Fork Creek and Big Creek) and associated tributaries. The surface relief generally is a result of erosion and down cutting associated with the streams and surface water flow to the streams. The surface water drainage is characterized as exhibiting a dendritic pattern that discharges to the streams. The vegetative cover consists of wooded areas containing deciduous trees and open spaces populated with grasses, sedges, and other herbaceous plants. FWS uses controlled burns (management of vegetation by prescribed fires) to manage some of the grassland areas. A wide variety of wildlife inhabits the area, including terrestrial crayfish and other burrowing animals that may cause localized bio-turbation (i.e., reworking of soils and sediments by animals or plants) of the soil.

5. Environmental Pathways and Sample Media

Figure 2 shows generic environmental pathways (depicted by arrows) that DU could follow from inside the DU Impact Area (inside the shaded oval) to outside the DU Impact Area (outside the shaded oval). Rectangles inside the shaded oval depict media in which DU resides inside the DU Impact Area. Rectangles outside the shaded oval depict potential sample media outside the DU Impact Area. For the purposes of Figure 2, the DU Impact Area is the Radiation Control Area (RCA).



Pathway	Comment
1→2	Rate of oxidation (corrosion) depends on environmental conditions in RCA
2→3	Oxidized uranium becomes part of soil matrix in immediate vicinity of DU in RCA
3→4	Plants in RCA uptake oxidized uranium
3→5	Soil windblown from RCA
3→6	Water flowing through RCA erodes soil and carries it outside RCA, or precipitation dissolves oxidized uranium and carries it to surface water flowing away from RCA
3→7	Precipitation dissolves oxidized uranium and seeps into groundwater
3→11 8→11	Animals ingest soil containing oxidized uranium
4→11 10→11	Animals ingest DU-affected plants (or animals ingest other animals that ingested DU-affected plants) and proceed outside the RCA
5→6	Windblown soil deposits on surface water outside RCA
5→8	Windblown soil deposits on soil outside RCA
6→7	Surface water with dissolved oxidized uranium seeps into groundwater
6→9	Surface water carrying oxidized uranium (in suspended soil or in solution) transfers it to sediment
6→10	Plants outside RCA and adjacent to stream uptake dissolved oxidized uranium
6→11	Animals drink surface water containing dissolved oxidized uranium
8→10	Plants outside RCA uptake soil containing oxidized uranium
9→11	Animals ingest sediment that contains oxidized uranium

Figure 2 Environmental pathways and potential sample media (RCA = radiation control area)

6. Risk Assessment

According to the "standardized Army risk matrix" (US Army 2014a), entry into an area known to contain UXO involves "high risk." "High risk" means "… high potential for serious injury to personnel … if hazards occur during the mission. This implies that, if a hazardous event occurs, serious consequences will occur. The decision to continue

must be weighted carefully against the potential gain to be achieved by continuing this [course of action]" (US Army 2014a).

Entry into a UXO area requires support from explosive ordnance disposal (EOD) personnel. While EOD support mitigates the risk of entry into a UXO area, it does not eliminate the risk.

The "potential gain to be achieved" by collection of environmental radiation samples in a UXO area is knowledge of the concentration of DU in samples of soil, water, air, or biota in the UXO area. However, according to results of RESRAD calculations, it is almost certain that laboratory results from analyses of these samples will indicate DU concentrations (if any DU is detected at all) and implied average annual doses that are far below NRC standards. That is, the potential gain is minimal.

Therefore, collection of environmental radiation samples in UXO areas generally will not occur as the purpose for monitoring changes from site characterization to effluent monitoring..

7. Principles

Although natural uranium is ubiquitous, DU, which is depleted in uranium isotopes uranium-234 (^{234}U) and uranium-235 (^{235}U) relative to natural uranium, does not occur in nature. Hence, background reference areas and background sampling for DU is unnecessary.

When analytical sampling results from locations outside of the DU Impact Area indicate that the ^{238}U/^{234}U activity ratio exceeds three, the Army shall notify NRC within 30 days and collect additional environmental samples within 30 days of the notification of NRC, unless prohibited by the absence of sampling media.

8. Inside the DU Impact Area

Given the purpose of the ERMP, we usually will not perform sampling inside the DU Impact Area.

a. Depleted uranium penetrators

The original source of DU contamination is DU penetrators fired at soft targets into an impact area, which is now the DU Impact Area. Upon impact, these rounds remained intact or mostly intact.

Any DU removed from the DU Impact Area in accordance with the guidance in the Radiation Safety Plan will be held for proper disposition as radioactive waste.

No conditions require collection or sampling of DU metal alloy in the DU Impact Area.

b. Pathway: DU penetrators → DU corrosion products

The rate of corrosion of the DU in the DU- tungsten-carbide alloy in the DU penetrators left in the environment is not known. A contractor working at Schofield Barracks in 2012

found both contaminated soil and solid DU-molybdenum alloy fragments (Cabrera 2013).

An Army contractor working on the Jefferson Proving Ground (JPG) decommissioning project for DU penetrators consisting of DU-tungsten-carbide alloy reported (SAIC 2013):

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> Corrosion of DU penetrators and subsequent dissolution of the corrosion products is the primary mechanism for introducing DU into the soil and for subsequent transport to the media (e.g., surface runoff to surface water and sediment). The rates of corrosion and dissolution were determined based on laboratory testing and field observations for conditions similar to those experienced by the DU penetrators at the DU Impact Area. Based on this information, the most likely time to complete corrosion and dissolution of a JPG penetrator was calculated to be approximately 107 years.

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Since DU munition testing began at JPG in 1983 and ended in 1995 it is unlikely that any DU penetrators have corroded completely since the Army fired them.

c. DU corrosion products

Corrosion products initially will be on the surfaces of DU penetrators that are then subject to spalling. Sampling of corrosion products in the DU Impact Area is unnecessary.

No conditions require collection or sampling of DU corrosion products in the DU Impact Area.

d. Pathway: DU corrosion product → Soil

Corrosion products attach loosely to DU penetrator surfaces. They gradually will leave those surfaces (spalling). Therefore, corrosion products will be present near the DU penetrators in the DU Impact Area.

e. Soil

The contractor at JPG observed (SAIC 2013), "… each penetrator or portion thereof served as a point source rather than forming a homogeneous mixture of DU in site soils."

Analysis … of data obtained at Schofield Barracks during a characterization survey [(Cabrera 2008a)] showed that DU contamination was concentrated in specific locations in the surveyed area and that the rest of the surveyed area was at background concentrations of natural uranium.

An Army contractor reported (Cabrera 2008b), "The mobility and persistence of DU in the environment is influenced by the amount, form, and oxidation state of the metal, as

well as by the composition and physicochemical properties of the affected media. In the metal form, DU tends to persist in the soil, and undergo few chemical changes other than oxidation due to weathering and exposure. [Figure 3] illustrates the appearance of Davy Crockett round fragments found at [Schofield Barracks]. Note the oxidized state (bright yellow) of the fragments. … The nature of the underlying soils, coupled with the relatively dry climate favors the retention and reduced solubility of metals, thereby reducing their mobility."

Durante and Pugliese wrote (Durante and Pugliese 2003), "… studies of radiological contamination in the soil from impacted DU rounds [in Bosnia in 1994 and 1995] suggest that dispersion and deposition are localized within 10 m from the hit target." The Director of the NRC's Office of Nuclear Material Safety and Safeguards wrote, regarding environmental sampling in Vieques, Puerto Rico (Kane 2001):

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> From May 29 to June 12, 2000, the U.S. Navy performed radiological surveys of the [Live Impact Area (LIA)]. … The surveys conducted by the U.S. Navy, and independently observed by the NRC, concluded that there were no elevated exposure rates or count rates indicative of radioactive contamination on areas of the LIA exclusive of the North Convoy Site, where the DU was fired during the February 19, 1999, incident. While observing the U.S. Navy survey activities between May 31 and June 12, 2000, the NRC staff also performed numerous surveys and collected soil samples. Soil samples were collected from the areas where DU penetrators had already been excavated. In addition, soil samples were collected downhill of areas known to have been impacted by the DU penetrators. … [A] purpose was … to determine whether the surrounding environment and members of the public had been exposed to DU.
>
> … The NRC Inspection Reports dated July 13, 2000, and September 28, 2000, document the performance and results of the environmental samples taken in June 2000. Copies of these reports are available in ADAMS (ML003767608 and ML003755565). The NRC samples demonstrated that there was no spread of DU contamination to areas outside of the LIA and that contamination from the DU inside the LIA was limited to the soil immediately surrounding the DU penetrators. With the exception of the soil samples taken from holes where the Navy had recovered DU penetrators, neither the direct measurement nor the environmental sample results identified the presence of radioactive materials exceeding those associated with naturally occurring radioactive materials routinely found in the environment.

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Figure 3a Typical form of DU at Schofield Barracks (Cabrera 2008b)

Figure 4b Penetrator from the Avonburg/Cobbsfork soil type grouping (JPPAC-005) as it appeared when discovered (JPG Environmental Report 2013b)

A review of United Nations Environment Programme (UNEP) reports [(UNEP 2001) (UNEP 2002) (UNEP 2003)] (Papastefanou 2002) summarized those reports, “There was no detectable widespread contamination of the ground surface by depleted uranium. This was in such low levels that it could not be detected or differentiated from

the natural uranium existing in soil globally. Detectable ground surface contamination by depleted uranium is limited to areas around and below penetrators and the associated points of concentrated contamination."

Uyttenhove et al. reported on independent measurements in Kosovo (Uyttenhove, Lemmens and Zizi 2002) and wrote, "Based on our [minimum detectable activity (MDA)]-considerations (and the experimental confirmation with calibration samples), we can state with good confidence that there is no DU present at our 50 sampling points in Kosovo, with MDA values as low as 15 Bq [corresponding approximately to a milligram of DU in a typical sample (100–150 g)]. Some samples, taken near places where DU ammunitions were used, have been re-examined very carefully with extra-long measuring times (27.8 h), always with negative results."

The Air Force did not find DU outside range boundaries at Eglin Air Force Base. As an NRC staffer (Spitzberg 2005) wrote, "The licensee sampled the environs of the site as part of the site characterization process. Radioactive material in excess of the NRC-approved [derived concentration guideline limits] was not identified offsite during … site characterization studies suggesting that the DU material, a heavy metal, was not migrating outside of the site boundary."

The US Army Environmental Policy Institute wrote (USAEPI 1995), "Investigations of DU migration at U.S. test sites have not identified significant migration in the environment."

An Army contractor that has performed environmental monitoring for DU at JPG for many years has never detected DU in soil or sediment samples outside the DU impact area. Reports dating back to 2005 are available on the NRC ADAMS website.

The US Department of the Army Soldier and Biological Chemical Command (USASSBC) took sediment samples at JPG and reported (USASSBC 2002), "Sediment samples were collected at the same locations where surface water samples were obtained during the scoping survey. The total uranium concentration in sediment samples ranged from 0.88 to 1.09 pCi/g within the DU Impact Area. Along the firing line trajectories, the total uranium concentration in sediment was measured at 2 and 3 pCi/g along two different streams south of the DU Impact Area. The U-238 to U-234 activity ratio in the sediment samples collected during the scoping survey indicates that the uranium is naturally occurring."

Also for JPG in 1995, an Army contractor (Scientific Ecology Group 1995) reported that all results of samples taken in the impact area showed $^{238}U/^{234}U$ ratios less than three.

In 2010, the current License RSO performed an analysis of results in a contractor's characterization survey report for the Radiation Control Area in the Battle Area Complex at Schofield Barracks (Cabrera 2008a). The results of his analysis (see Appendix) showed that unbiased soil samples taken contained only natural uranium. The contractor's report showed that biased samples contained both natural uranium and DU.

A conclusion is that DU remains close to its point of original deposition and is not likely to move outside the DU Impact Area in appreciable amounts.

An implication of the above is that DU does not migrate readily in soil in many, if not almost all, cases. Once it becomes part of the soil matrix, it remains in the same soil matrix for many years.

Sampling of soil in the DU Impact Area is unnecessary. We expect DU to be in DU Impact Area soil.

No conditions require deliberate collection or sampling of soil within the DU Impact Area.

f. Pathway: Soil → Plants in DU Impact Area

Table 2 is an extract from Table 6.4 in Till and Grogan (Whicker and Rood 2008).

Some plants, such as lichens, concentrate uranium in their tissues more than most plants do. For example, The USASSBC took vegetation samples at JPG and reported (USASSBC 2002), "Twenty vegetation samples were collected during the scoping survey using the same methods for soil sampling. Fourteen samples were obtained from within the DU Impact Area, and six samples were obtained along the firing line trajectories. The total uranium concentration in vegetation samples was less than 0.7 pCi/g in all samples. Two lichen samples from the south-central portion of the DU Impact Area had U-238 to U-234 activity ratios of 2.3 and 2.6, which indicate DU contamination."

Table 2 Typical plant/soil concentration ratios for selected elements and crops, adapted from the International Atomic Energy Agency (IAEA 1994)

Element	Crop	Concentration Ratio (dry mass basis)	
		Expected	Range (95%)
Uranium	Cereal grains	0.001	
	Fruits, tubers	0.01	0.0008 to 0.14
	Grass	0.02	0.002 to 0.2

The UNEP also detected DU in lichen in the three areas it surveyed [(UNEP 2001) (UNEP 2002) (UNEP 2003)]. According to UNEP, "This indicates that at least some of the penetrators at these sites hit hard targets and surfaces, partly aerosolized into dust, and dispersed into the air" (UNEP 2003). The DU penetrators hit no such hard targets and surfaces at JPG, therefore no aerosolization occurred.

The above indicates that plant uranium concentrations are expected to be no more than about two percent of the uranium concentration in the soil where the plant is growing, except for plants such as lichens. However, the uranium concentrations in a plant could be as high as about 20 percent of the uranium concentration in the soil where the plant is growing.

g. Plants in DU Impact Area

Sampling of plants in the DU Impact Area is generally unnecessary.

The Army allows livestock (beef cattle) to graze in a Radiation Control Area at Fort Hood. RESRAD calculations showed that the maximum annual total dose to a resident farmer on the Radiation Control Area at Fort Hood is about 0.13 millirem. The consumption of meat contributes less than 3 percent of that dose, or less than 0.004 millirem.

The calculations assumed that all meat that the resident farmer consumes derives from livestock grazing only in the Radiation Control Area. In the case of Fort Hood, the livestock graze over a much larger area that includes the Radiation Control Area, and consumers of that meat consume meat from numerous other sources. The conclusion is that sampling plants in the DU Impact Area will provide little or no useful information.

No conditions require deliberate collection or sampling of plants within the DU Impact Area.

h. Pathway: Soil → Surface water in the DU Impact Area

The most common forms of uranium oxide are U_3O_8 and UO_2. Both oxide forms are solids that have low solubility in water and are relatively stable over a wide range of environmental conditions (Argonne National Laboratory n.d.). Triuranium octaoxide (U_3O_8) is the most stable form of uranium and is the form most commonly found in nature. Uranium dioxide (UO_2) is the form in which uranium is most commonly used as a nuclear reactor fuel. At ambient temperatures, UO_2 will gradually convert to U_3O_8.

i. Surface water in DU Impact Area

Sampling of static surface water, such as water in a pond, entirely in the DU Impact Area is unnecessary.

No conditions require deliberate collection or sampling of surface water within the DU Impact Area.

9. Outside the DU Impact Area

a. Pathway: Soil → Atmosphere

The Army has found many DU penetrators in the DU Impact Area that seem to be mostly intact with corrosion products in or on the soil in the immediate area adjacent to the round. This means that not all the DU in the DU Impact Area is available for suspension into the atmosphere.

The NRC did not require the Air Force to perform air sampling during DU remediation at a range at Eglin Air Force Base (Spitzberg 2005): "… perimeter sampling was only required at the discretion of the on-site radiation safety officer. The permittee planned to establish environmental controls to prevent erosion, to manage storm water runoff, and to minimize dust emissions. The permittee subsequently discontinued some of

these environmental controls because reclamation activities had a minimal impact on the environment."

The NRC has never required the Army to perform air sampling at Jefferson Proving Ground since test operations ceased there in 1995.

The Army provided a contractor-prepared report to the NRC (Shia 2005), which said "The assessments at [Jefferson Proving Ground], [Los Alamos National Laboratory], and [Aberdeen Proving Ground], among other sites indicate that risks associated with potential transport of DU in the air from controlled burns are negligible. The benefit/cost ratio of an air sampling program is extremely low (i.e., the benefits are small and the costs of the program high). Therefore, an air monitoring program is not recommended given the low probability of DU release and transport and the negligible effects on receptors."

The Enewetak Cleanup Project (1977-1980) was a joint DOD-Department of Energy (DOE) project to remove debris and radioactive contamination (mostly uranium and plutonium, not fission products) from the islands and lagoon of the atoll. Since both are actinides, uranium and plutonium behave similarly in the environment. The DOD operated air samplers whenever contaminated soil movements were underway. The report of the project (Defense Nuclear Agency 1981) concluded, "Throughout the cleanup project, over 760,000 cubic meters of air were sampled on the controlled islands plus more than 211,000 cubic meters at Lojwa. Nearly 5,200 air samplers [sic] filters were analyzed by the lab. No significant airborne radioactivity of any type (including beta) was detected. It is clear from these results – as it was from resuspension experiments performed during early [Radiation Safety Advisory and Inspection Team] visits to the atoll – that the Enewetak contamination situation was not conducive to creation of a resuspension hazard."

The Environmental Protection Agency (USEPA 2006) says, "The amount of uranium in the air is usually very small and effectively insignificant for remedial operations. … The high density of DU in most particulate forms limits the air transport of DU to relatively small particles. … It is reported that most of the DU dust will be deposited within a distance of 100 meters from the source."

b. Atmosphere

Air sampling is generally unnecessary. Remedial actions, discussed above and which did not produce significant air concentrations, are not underway at any DU Impact Area. In addition, the NRC allowed high explosive testing throughout the JPG impact area, to include the DU impact area, without a requirement for air sampling.

No conditions require air sampling.

c. Pathway: Soil → Surface water flowing from the DU Impact Area

The most common forms of uranium oxide are U_3O_8 and UO_2. Both oxide forms are solids that have low solubility in water and are relatively stable over a wide range of

environmental conditions (Argonne National Laboratory n.d.). The most stable form of uranium is U_3O_8, which is the form most commonly found in nature. At ambient temperatures, UO_2 will gradually convert to U_3O_8.

d. Pathway: Atmosphere → Surface water

As discussed above, "The amount of uranium in the air is usually very small and effectively insignificant [even] for remedial operations" (USEPA 2006). Therefore, transfer from the atmosphere to surface water outside the DU Impact Area is also "effectively insignificant."

e. Pathway: Surface water in DU Impact Area → Surface water outside the DU Impact Area

The DU concentration in surface water outside the DU Impact Area that has flowed from the DU Impact Area should be about the same as that the concentration in the flowing water at the DU Impact Area boundary.

f. Surface water

Flowing surface water traversing the DU Impact Area is a potential pathway for the environmental mobilization of DU out of the DU Impact Area.

The purpose of sampling flowing surface water is to monitor for the potential transport of DU out of the DU Impact Area. If we identify DU in a sample, we must then assess the risk that is implied. Minimizing these risks is the relatively low solubility of uranium in water and the typically low concentration of DU in soil in the DU Impact Area compared to the concentration of natural uranium.

The Army and its contractors have sampled surface water extensively at JPG over the last twenty years (SAIC 2013). Detection of DU in surface water at JPG occurred, albeit rarely and always well within NRC effluent limits and USAEPA drinking water standards.

Sampling of surface water routinely flowing from the DU Impact Area will occur.

g. Pathway: Soil → Groundwater

The DU concentration in groundwater depends on several factors, including distance of the groundwater from the soil surface, acidity/alkalinity of the soil and leaching water, soil porosity, amount of precipitation, and so on. The Army has not measured most of the influencing factors for this pathway for the DU Impact Area.

h. Pathway: Surface water → Groundwater

The low solubility of uranium oxide in water and the low concentration of DU in soil in the DU Impact Area make it improbable that surface water contributions to DU in groundwater are significant.

i. Groundwater

Groundwater flow beneath the DU Impact Area is a potential pathway for the environmental mobilization of DU out of the DU Impact Area. However, as

demonstrated in the RESRAD analyses for this license, the groundwater pathway contributes no significant increase in risk to maximum reasonably exposed individuals. This includes RESRAD evaluation using the conservative “resident farmer” scenario.

These evaluations using conservative assumptions of source strength, soil and geologic transport characteristics, and exposure scenarios establish reasonable bases for concluding the groundwater pathway is an extremely low-risk pathway. For this reason, groundwater sampling for DU will occur only when groundwater sampling is being performed for other reasons. See Section 16 below.

j. Pathway: Atmosphere → Soil

Since the atmosphere is unlikely to carry more than barely detectable amounts of DU from inside to outside the DU Impact Area, this pathway will contribute virtually immeasurable amounts of DU to soil outside the DU Impact Area.

k. Soil

Soil sampling is generally unnecessary because DU contamination tends to remain in place in the DU Impact Area (see paragraph 6e). However, if a local condition indicates that massive erosion of soil from the DU Impact Area to areas outside the DU Impact Area has occurred, sampling the soil deposited due to that erosion will occur (following risk assessment if UXO or other hazards are present).

As a minimum, the following threshold criteria for soil erosion will require semi-annual soil sampling outside the DU Impact Area:

- General erosion rate for the DU Impact Area greater than 2 tons per acre per year.
- Localized erosion rate in an area of 25 m^2 exceeds a volume of 3.75 m^3 per year

l. Pathway: Surface water → Sediment

Water flowing out of the DU Impact Area could carry DU-contaminated sediment. Sediment sampling at JPG has occasionally detected small amounts of DU in sediment inside the DU Impact Area, but never outside the DU Impact Area.

m. Sediment

If surface water sampling occurs, sediment sampling will also occur at the same time and near the same place. No other conditions require sediment sampling.

n. Pathway: Surface water → Plants

The DU concentration in surface water will be low if it is even detectable. However, some plants, such as lichens discussed above, can concentrate DU above ambient levels.

o. Pathway: Soil → Plants

The DU concentration in soil outside the DU Impact Area will be much lower than it is in the DU Impact Area, if it is even detectable. However, some plants, such as lichens discussed above, can concentrate DU.

p. Plants

No condition requires plant sampling.

q. Pathway: Soil → Animals

The DU concentration in soil outside the DU Impact Area will be much lower than that in the DU Impact Area, if it is even detectable. However, some animals could concentrate DU in their bodies above ambient levels.

Table 3 is an extract from Table 6.8 in Till and Grogan (Whicker and Rood 2008) that demonstrates this possibility.

Table 3 Expected values for transfer coefficients (day/kg–1) in various animal food products (IAEA 1994)

Element	Beef	Pork	Poultry
Uranium	3×10^{-4}	6×10^{-2}	1

[a] The transfer coefficient TC is defined as TC = $C_{prod}(eq)/R$, where $C_{prod}(eq)$ is the measured equilibrium (activity per unit mass) in the product of interest at equilibrium and *R* is the radionuclide ingestion rate (activity per unit time), in this case the rate of entry into the mouth.

[b] See original source for other data and ranges of values

r. Pathway: Plants in DU Impact Area → Animals

Plants that herbivorous and omnivorous animals normally consume do not concentrate uranium above ambient levels, and neither do the herbivorous, carnivorous, and omnivorous animals themselves.

s. Pathway: Surface water → Animals

Depleted uranium concentrations in any water that animals consume are orders of magnitude less than the uranium concentrations that NRC effluent standards and EPA drinking water regulations limit. As shown in paragraph 7q, animals generally do not concentrate uranium above ambient levels.

t. Pathway: Soil → Animals

Depleted uranium concentrations in any DU Impact Area soil that animals consume are, on the average, less than the default derived concentration guideline limits. The DU concentration in soil outside the DU Impact Area is less than that for soil in the DU Impact Area. As shown in paragraph 7q, animals generally do not concentrate uranium above ambient levels.

u. Pathway: Sediment → Animals

Depleted uranium concentrations in DU Impact Area sediments that animals consume are, on the average, less than the default derived concentration guideline limits. The

average DU concentration in sediments outside the DU Impact Area is less than that for sediments in the DU Impact Area. As shown in paragraph 7q, animals generally do not concentrate uranium above ambient levels.

v. Animals

The USASSBC took biological samples at Jefferson Proving Ground and reported (USASSBC 2002), "A total of eight biological samples were collected from deer, freshwater clams, fish, and a soft-shelled turtle. All of the biological samples from Big Creek were collected from the area adjacent to the DU Impact Area. The total uranium concentrations ranged from 0.091 pCi/g in deer liver to a maximum of 0.774 pCi/g in a freshwater clam. … The U-238 to U-234 activity ratio ranged from 0.4 to 1.2 and does not indicate the presence of DU contamination."

An Army contractor working at Jefferson Proving Ground wrote (SAIC 2013), "To evaluate the total effective dose equivalent (TEDE) associated with consumption of deer meat, a total of 132 tissue samples from 30 deer were collected and analyzed during the winter of 2005/2006. DU was not detected in any tissue sample during laboratory analysis."

No conditions require animal sampling.

10. Radiochemistry

Only accredited laboratories will perform radiochemical analyses for the purposes of NRC license compliance. The laboratories will use alpha spectroscopy to analyze samples for ^{234}U and ^{238}U activities and concentrations.

The NRC's criterion is that a $^{238}U/^{234}U$ concentration or activity ratio less than 3 is assumed representative of natural uranium, whereas higher ratios are potentially indicative of the presence of DU.

All samples with a $^{238}U/^{234}U$ concentration or activity ratio greater than 3 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their ^{235}U and ^{238}U content in an effort to identify samples with DU content.

11. Evaluation of Potential Source-Receptor Interactions

Surface Water Use - Surface water is not used as a domestic drinking water supply near JPG; its primary use is for recreation and livestock watering (MWH 2002).

Recreational Use - The FWS established the Big Oaks NWR in the area north of the firing line including the DU Impact Area. However, access to many areas within the refuge is restricted primarily because of the occurrence of UXO, but also because of the occurrence of both UXO and DU in and near the DU Impact Area. Figure 2-2 (U.S. Army 2013b) shows areas where public access is allowed and where restrictions are emplaced. Within the Big Oaks NWR, fishing is permitted only at the 165-ac (0.67-km2) Old Timbers Lake (FWS 2001) created by the damming of Little Otter Fork which is several miles north northeast of the DU Impact Area.

Habitat – Section 2.5 in the U.S. Army's Decommissioning Plan for NRC Materials License SUB-1435 (U.S. Army 2013b) describes the characteristics of wetlands and habitats for plants and wildlife at JPG. The JPG vegetation habitat types were derived from 1995 and 1997 aerial photographs and photographic interpretation completed in 1998 (FWS 2006). Upland forests make up 27,400 ac (111 km2) or 55 percent of the JPG acreage. The second most abundant habitat at the JPG is grasslands. This habitat type comprises 8,400 ac (12.14 km2 or 17 percent). Other habitat types at JPG include 5,200 ac (21 km2 or 10 percent) of palustrine wetland, 3,000 ac (12.14 km2 or 6 percent) of woodland, 6,200 ac (25 km2 or 12 percent) of early successional, and less than 250 ac (1 km2) each of open water and bare soil areas.

Ecological Receptors - The Indiana bat (Myotis sodalis) has been documented at JPG (Rust E&I 1998). Ten bird species have been documented at JPG that are listed as USEPA Region 3 Federal species of concern (INANG 2013). In addition, 29 State of Indiana-endangered species (1 mammal, 17 birds, 2 amphibians, 1 reptile, 3 crustaceans, 2 butterflies, 2 arachnids, and 1 millipede) and 4 State of Indiana-threatened species (1 bird, 1 butterfly, 1 crustacean, and 1 springtail) also have been identified as potentially occurring at JPG. Fifteen of these species (13 birds, 1 amphibian, and 1 reptile) have been documented at JPG. The Henslow's sparrow (Ammodramus henslowii) has been identified as a breeding species at JPG. The U.S. Army's Decommissioning Plan for NRC Materials License SUB-1435 (U.S. Army 2013b), Table 2-7 identifies Federal and State of Indiana endangered and threatened species and species of special concern.

Groundwater Use - The groundwater under JPG generally is of poor quality and is not used for drinking purposes or for other purposes in any significant capacity. The drinking water at JPG is obtained from the city of Madison Municipal Supply Systems and the Canaan Deposits in the Ohio River Valley, approximately 5 mi (8 km) from JPG (MWH 2002). In addition, there are no sole source aquifers on or near JPG based on a review of USEPA Region 5 sole source aquifer designations.

12. Surface Water and Sediment Sample Design

The surface water and sediment sampling approach will involve biannual collection of collocated samples from four locations downstream from the DU Impact Area and where surface water flows throughout the year. All four are current monitoring locations along Big Creek and Middle Fork Creek downstream from the DU Impact Area. Two are at the JPG boundary and two are closer to the DU Impact Area boundary.

If surface water is not flowing when a quarterly sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Surface water sampling locations situated downstream from the DU Impact Area were selected based on the surface water hydrology and potential for DU contribution. The rationale for each selected location follows:

- SW-DU-001/SD-DU-001 — This selected collocated sampling point is located where West Perimeter Road meets Middle Fork Creek prior to exiting the JPG property and outside UXO areas.
- SW-DU-002/SD-DU-002 — This selected collocated sampling point is located prior to the point where Big Creek exits the JPG property and outside UXO areas.
- SW-DU-007/SD-DU-007 — This selected collocated sampling location point is located where Morgan Road intersects with Middle Fork Creek after approximately 1 mile after exiting the DU Impact Area. SW-DU-006/SD-DU-006 was not selected because though closer to the DU Impact Area boundary, it is deeper into the UXO area.
- SW-DU-008/SD-DU-008 — This selected collocated sampling location is situated where Morgan Road intersects with Big Creek on the western boundary of the DU Impact Area.

Surface water samples will be analyzed for total/isotopic uranium using American Society for Testing and Materials (ASTM) Method D3972-90M (alpha spectrometry). Further details on analytical procedures and QA/QC information are presented in the annex. When analytical sampling results indicate that the 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 ICP-MS for their U-234, uranium-235 (U-235), and U-238 content to calculate the weight percentage of U-235 specified in 10 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).

13. ERMP Methodology

The sampling and laboratory analysis procedures to be utilized during the environmental radiation monitoring (ERM) are described below. This ERMP is to be used in conjunction with a quality assurance project plan 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. All entry to JPG will be coordinated with the FWS and INANG 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/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.

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).

When analytical sampling results indicate that the U-238/U-234 activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media.

The ICP-MS results for U-234, U-235, and U-238 will be summed to calculate a total mass of uranium present, which will be used to establish the weight percent 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).

14. Surface Water Sampling

The Army will sample surface water at locations downstream from the DU Impact Area in Middle Fork Creek (SD-DU-007/SW-DU-007) and Big Creek (SD-DU-008/SW-DU-008) at the boundary of the unexploded ordnance (UXO) area. The Army will sample surface water at locations downstream from the DU Impact Area in Middle Fork Creek (SW-DU-001) and Big Creek (SW-DU-002) at the JPG installation boundary. Sampling at these points is for detecting any DU that might be entering areas at JPG open to the public 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.

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.

15. Sediment Sampling

The Army will sample sediments at locations downstream from the DU Impact Area in Middle Fork Creek (SD-DU-007) and Big Creek (SD-DU-008) at the boundary of the unexploded ordnance (UXO) area. The Army will sample surface water at locations downstream from the DU Impact Area in Middle Fork Creek (SD-DU-001) and Big Creek (SD-DU-002) at the JPG installation boundary. Sampling at these points is for detecting any DU that might be entering areas at JPG open to the public.

The collection of sediment samples will coincide with the surface water sampling activities and from the same locations sampled historically. 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:

- The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
- Use a disposable scoop to remove the loose upper sediment uniformly. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
- Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
- Remove rocks, large pebbles, large twigs, leaves, or other debris.
- Remove excess water from the sediment. This may require allowing the sample to settle.
- Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
- Fill the appropriate sample containers.
- Mark the sample location with a stake and log its coordinates using a DGPS unit.
- Collect digital photographs and document data in the field logbook.

Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis.

16. Wells Selection

To maximize data value from the lengthy historical sampling record, the continued sampling of wells from the ERM Program is preferable to the sampling of wells from the Range Study wells (designated as MW-RS1 to MW-RS8) and site characterization (designated as JPG-DU-xxy). In light of the prevailing west-southwest direction of groundwater flow, the preferred wells for sampling under the ERM Program include MW-DU-005, MW-DU-006, and MW-DU-011. Since U-238/U-234 activity ratios have exceeded 3.0 in MW-DU-001, that well will also continue to be monitored.

The groundwater sampling approach will involve semiannual collection of samples from four groundwater-monitoring wells: MW-DU-001, MW-DU-005, MW-DU-006, and MW-DU-011. All four are current monitoring wells within and downgradient from the DU Impact Area. Groundwater sampling locations were selected based on the prevailing west-southwest direction of groundwater flow and potential for DU contribution. The rationale for each selected location follows:

- MW-DU-001—This well is located on the eastern (upgradient) side of the DU Impact Area near the intersection of D-Road and Wonju Road. This well is selected because of elevated historical U-238/U-234 activity ratios during previous ERM Program sampling.

- MW-DU-005. This well is located on D-Road near Morgan Road (across Bridge No. 13) in the western interior portion of the DU Impact Area. This well was selected because it is located in the shallow carbonate unit near Big Creek where a karst flow system may be recharged in part from areas with smaller thicknesses of overlying till or through more permeable parts of the till. It also is located near the boundary where Big Creek exits the DU Impact Area.
- MW-DU-006. This well is located on Morgan Road south of C-Road. It was selected because it is situated outside of and downgradient from the DU Impact Area. In addition, results from the groundwater age study conducted by the U.S. Geological Survey (USGS) concluded, based on tritium sampling, that groundwater from this well was substantially modern (post-1953 and possibly post-1972). Consequently, water is representative of the age that could see potential impacts from DU. Lastly; MW-DU-006 often exhibits total uranium concentrations exceeding those of the other wells.
- MW-DU-011. This well is located on D-Road between Morgan Road and Center Recovery Road. It was selected due to its close proximity to Big Creek in the central part of the DU Impact Area and it is situated downgradient from the DU trenches.

17. Groundwater Sampling and Analysis

The U.S. Army will sample groundwater at locations up-gradient of the DU Impact Area (MW-DU- 001), within the DU Impact Area (MW-DU-011), and downgradient from the DU Impact Area (MW- DU-005 and MW-DU-006). Sampling at these points is for detecting any DU that might be migrating through groundwater to potential public receptors.

The collection of groundwater samples will coincide with the surface water and sediment sampling activities. The groundwater sampling procedure is as follows:

- The individual performing the purging or sampling will don clean gloves and prepare a hand bailer.
- Purging will be accomplished no later than the Friday preceding sampling and no earlier than 14 days prior to the scheduled start date of the sampling visit.
- Sample will be collected using a new hand bailer for each sample. Care will be taken when lowering the bailer into the well to prevent unnecessary aeration or contamination of the sample.
- A portion of the first bailer full of water will be placed into a clean beaker, or other suitable container, and an evaluation of radiation level, temperature, pH, and conductivity will be conducted and recorded.
- Document sample information in the field logbook and sampling forms similar to records from previous sampling events.

- A total quantity to be collected will include 2 × 1-liter polypropylene bottles to allow a sufficient volume of groundwater for QA/QC and potential re-analysis with ICP-MS.
- Place groundwater into a disposable tray or sealable plastic bag (e.g., Ziploc®).
- Samples will not be filtered or preserved (either with chemicals or ice) in the field.

Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis.

18. Summary

The U.S. Army has opted to continue monitoring groundwater in existing monitoring wells that were originally installed for the ERM Program and have been sampled for more than two decades, including MW-DU-001, MW-DU-005, MW-DU-006, and MW-DU-011. In order to maintain consistency with previous events, ERM sampling is planned to occur two times per year during the hydrologic high (spring) and low (fall).

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Appendix

The following table was produced in 2010 from laboratory data with the purpose of demonstrating whether the background reference area for a characterization survey in the RCA in the Battle Area Complex at Schofield Barracks (Cabrera 2008a) was chosen appropriately. The assumption was made that the results of analyzing 416 unbiased samples from the RCA were indicative of background radionuclide concentrations and did not contain depleted uranium contamination. The resulting ^{234}Th (surrogate for ^{238}U) concentration in soil in the RCA was less than that in the chosen background reference area (calculated from 12 samples) and, therefore, supported the assumption. This also indicates that DU has not migrated far from the M101 spotting round points of impact in the more than fifty years since it was deposited.

Table — Calculation of background soil concentrations from laboratory results for the Davy Crockett impact area and for the background reference area at Schofield Barracks

Matrix	Activity Concentration (pCi/g)[a b]																	
	^{40}K		^{232}Th Progeny								^{238}U Progeny						^{235}U	
			^{208}Tl		^{212}Bi		^{212}Pb		^{228}Ac		^{214}Bi		^{214}Pb		^{234}Th[c]			
	BRA	DCIA	BRA	DCIA	BRA	DCIA	BRA	DCIA	BRA	DCIA	BRA	DCIA	BRA	DCIA	BRA	DCIA	BRA	DCIA
Surface soil	3.16 ± 0.15	5.2 ± 0.2	0.278 ± 0.013	0.293 ± 0.016	0.60 ± 0.07	0.62 ± 0.07	0.96 ± 0.02	0.85 ± 0.04	1.02 ± 0.05	0.94 ± 0.05	0.87 ± 0.03	0.79 ± 0.04	0.95 ± 0.03	0.79 ± 0.04	1.47 ± 0.11	1.09 ± 0.12	0.01 ± 0.04	0.04 ± 0.03
Subsurface soil	3.31 ± 0.18	4.3 ± 0.2	0.350 ± 0.017	0.303 ± 0.016	0.78 ± 0.09	0.66 ± 0.06	1.07 ± 0.03	0.91 ± 0.04	1.18 ± 0.06	0.99 ± 0.05	0.88 ± 0.04	0.60 ± 0.06	0.95 ± 0.03	0.66 ± 0.03	1.77 ± 0.13	1.19 ± 0.13	0.05 ± 0.04	0.06 ± 0.03
Combined	3.22 ± 0.11	4.70 ± 0.16	0.307 ± 0.010	0.298 ± 0.012	0.67 ± 0.05	0.65 ± 0.05	1.00 ± 0.02	0.88 ± 0.03	1.09 ± 0.04	0.96 ± 0.04	0.87 ± 0.02	0.67 ± 0.03	0.95 ± 0.02	0.72 ± 0.02	1.60 ± 0.08	1.14 ± 0.09	0.02 ± 0.03	0.05 ± 0.02

[a] pCi/g = picocurie/g; BRA = background reference area; DCIA = Davy Crockett impact area. The background reference area is more than seven miles from the Schofield Barracks Davy Crockett impact area.

[b] Activity concentrations are weighted means of laboratory results for unbiased samples from the DCIA and from the background reference area. Uncertainties are two standard deviations.

[c] ^{234}Th is a surrogate for ^{238}U.