DEPARTMENT OF THE ARMY
US ARMY INSTALLATION MANAGEMENT COMMAND
2405 GUN SHED ROAD
JOINT BASE FORT SAM HOUSTON, TX 78234-1223

REPLY TO
ATTENTION OF

January 27, 2014

Safety

ATTN: Document Control Desk
Director, Office of Federal & State Materials and Environmental Management Programs
US. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Director:

This letter responds to your November 20, 2013 letter, subject: Acceptance Review of a License Amendment Request for the Decommissioning of the Jefferson Proving Ground Facility, License SUB-1435. In that letter, "the staff identified one area in the application where additional information is needed ... to complete [their] review." I have enclosed the additional information you requested.

You may reach me at (210) 466-0368 or robert.n.cherry.civ@mail.mil.

Sincerely,

Robert N. Cherry
Radiation Safety Staff Officer

Enclosure

FSME20

REQUEST FOR ADDITIONAL INFORMATION (RAI)

BASIS

In Section 3.6.2 of the *Decommissioning Plan* (DP), the Army provides exposure rate measurements from site characterization. This exposure rate data indicates numerous locations where penetrators were detected in the top 46 cm (18 inches) of soil. In Section 3.4.2 of the DP, the Army indicates that it is expected to take at least 100 years for a depleted uranium (DU) penetrator to corrode completely. Because the Army expects penetrators to persist onsite for years after license termination, the Army should evaluate the dose to an individual who discovers and handles a penetrator on site if institutional controls fail. The U.S. Nuclear Regulatory Commission staff expects that relevant exposure pathways will include, but not necessarily be limited to, inadvertent ingestion and inhalation of corrosion products transferred from the penetrator.

REFERENCES

ANL (Argonne National Laboratory). 2000. *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, ANL/EAD/TM-98, NUREG/CR-6697, prepared for the U.S. Nuclear Regulatory Commission, November.

ANL. 2002. *Technical Basis for Calculating Radiation Doses for the Building Occupancy Scenario Using Probabilistic RESRAD-BUILD 3.0 Code*, ANL/EAD/TM/02-1, NUREG/CR-6755, prepared for the U.S. Nuclear Regulatory Commission, February.

ICRP (International Commission on Radiological Protection). 2012. *Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119.* Ann. ICRP 41(Suppl.)

U.S. Army. 2013a. *Decommissioning Plan for NRC Source Material License SUB-1435, Depleted Uranium Impact Area, Jefferson Proving Ground, Madison, Indiana.* July.

U.S. Army. 2013b. *Army's Environmental Report for NRC Source Material License SUB-1435, Depleted Uranium Impact Area, Jefferson Proving Ground, Madison, Indiana.* July.

USACHPPM (U.S. Army Center for Health Promotion and Preventative Medicine). 2004. *Depleted Uranium Aerosol Doses and Risks: Summary of U.S. Assessments.* October.

Yu, C. 2009. RESRAD-BUILD 3.5 Version History (http://web.ead.anl.gov/resrad/home2/bldhstry.cfm). 30 October.

RESPONSE

The U.S. Nuclear Regulatory Commission's (NRC's) Request for Additional Information (RAI) requested the Army to evaluate the residual radiation dose to an individual who discovers and handles a penetrator onsite if institutional controls fail. The dose to an individual, who contacts depleted uranium (DU) corrosion products in the soil onsite, if institutional controls fail, was evaluated in three scenarios in the Army's *Decommissioning Plan for NRC Source Material License SUB-1435, Depleted Uranium Impact Area, Jefferson Proving Ground, Madison, Indiana* (DP) (U.S. Army 2013a): resident farmer with irrigation, onsite industrial worker, and onsite sportsman/recreationalist. In all three scenarios, the pathways considered, at a minimum, external gamma, inhalation, and ingestion of DU corrosion products. In addition, external exposure to intact DU penetrators was discussed in Section 3.9, Appendix C of the

2013 Jefferson Proving Ground (JPG) DP where external exposure to an onsite residential farmer from all JPG DU penetrators was 19 millirems per year (mrem/y).

The evaluation presented in this response to NRC's RAI contains a conservative modeled dose assessment for an individual who discovers, handles, and removes a DU penetrator from the JPG site. The modeled assessment uses RESRAD-BUILD (Version 3.5) to estimate dose. This scenario conservatively assumes 100 hours of exposure to the intact DU penetrator and its corrosion products from three pathways: external gamma, inhalation, and ingestion. Additional dose calculations address the same receptor aggressively handling the DU penetrator during and after removal from the site. Aggressive handling is conservatively defined as 12 hours of hands-on contact with the DU penetrator per year. Although the scenarios presented above are very conservative and unlikely to occur, they are designed to be inclusive of other potential scenarios where a DU penetrator is removed from the site. Further details about this evaluation are presented below. Also, to account for the possibility of mechanical disturbance of the DU penetrator (e.g., use of a grinder), a discussion of personnel exposure to aerosolized DU from studies conducted by the Army is provided below.

As will be discussed in further detail below, the dose estimate from the RESRAD-BUILD evaluation was 2.7 mrem/y. The additional ingestion dose from aggressive handling of the DU penetrator was 2.4 mrem/y. When summed, the total estimated dose to the receptor was 5.1 mrem/y. This dose is about 5 percent of the 100 mrem/y standard and is about 20 percent of the 25 mrem/y dose standard mandated in Title 10 Code of Federal Regulations (CFR) Part 20, Subpart E for restricted release license termination. The Army's maximum dose estimate for an individual exposed to aerosolized DU for 100 hours in a burned out tank was 40 mrem. This is a conservative comparison to someone exposed to mechanical disturbance of a DU penetrator and is 40 percent of the 100 mrem/y dose standard mandated in 10 CFR 20, Subpart E for restricted release license termination.

RESRAD-BUILD SCENARIO

The residual radiation dose to an individual who handles a DU penetrator (i.e., DU metal with surface oxidation) is equal to the sum of the internal and external dose. The external dose is a function of the dose rate and duration of exposure whereas the internal dose is dependent on a number of factors, including the amount of DU available for intake/uptake, the route of entry into the body (e.g., inhalation or ingestion), the chemical form of DU, the particle size distribution, and the rate of elimination from the body.

This technical evaluation provides a conservative dose assessment for a receptor that not only discovers and handles a DU penetrator but also removes it from the JPG site. The modeled dose assessment includes doses from inhalation, ingestion, and external radiation due to incidental exposure (occupying the same room where the DU penetrator is stored).

The scenario conservatively assumes an individual removes a single DU penetrator from the site, takes it home, stores it in a single room, and spends 100 hours near the DU penetrator over the course of a year. Because the DU penetrator is very similar to stock metal (e.g., smooth rebar), it is unlikely that the item would be stored in the living quarters of a house out in the open. It is likely that the penetrator would be stored in a shop or garage. Addressing a DU penetrator stored in a shop/garage versus the house is more conservative because the living area of the house is likely cleaned more often, has a greater air exchange

rate, and has a larger breathing air volume. All of these conditions would result in a smaller source term and, therefore, a smaller dose due to exposure.

The amount of activity available for intake (i.e., inhalation and indirect ingestion) is a function of the surface area of the penetrator and the penetrator corrosion rate. Section 4.3 in Appendix C of the *Army's Environmental Report for NRC Source Material License SUB-1435, Depleted Uranium Impact Area, Jefferson Proving Ground, Madison, Indiana* (ER) (U.S. Army 2013b) states that the largest piece of the penetrator expected to remain intact after impact was 40.1 centimeters (cm) (15.8 inches [in]) long with a 2.1 cm (0.83 in) diameter. These dimensions equate to a surface area of 273 square centimeters (cm^2). Section 5.2 in Appendix C of the ER provides an average corrosion rate of 0.25 grams per square centimeter per year (g/cm^2-y). Based on the surface area and corrosion rate, the largest piece of an intact penetrator would provide 68.3 grams of corroded DU per year. The remainder of the penetrator would be unavailable for internal exposures. Not all corroded DU is available for intake because some of the corroded DU is dissolved into the surrounding soil. Section 5.3 in Appendix C of the ER provides a dissolution rate of 60 percent per year (i.e., 60 percent of the total corroded mass is dissolved into the surrounding soil). In addition, the ER states that "penetrators on the surface of the soil or buried in waterlogged soil will likely experience considerably lower corrosion rates than those measured in the column tests." Once the DU penetrator is removed from the soil and placed in the shop/garage, it will likely corrode at a much slower pace, which will generate less activity for a source term and, therefore, a smaller dose due to exposure. Therefore, for this evaluation, the corrosion mass generated in a single year less the mass dissolved into surrounding soil, 27.3 g, is taken to be the potential activity available for intake.

RESRAD-BUILD (Version 3.5) was used to conduct a deterministic radiation dose assessment for the penetrator in a garage/shop scenario listed above to address the NRC's RAI. The scenario assumed an individual spent 100 hours per year (0.114 indoor fraction) in the shop standing directly above the DU penetrator. The shop was established as an average sized 16 square meters (m^2) room (4 m by 4 m [13 feet {ft}]) with 2.5 m (8.2 ft) high walls (i.e., 13 ft by 13 ft by 8 ft). The shop was assumed to have a poorer than average air exchange rate of 0.4 air changes per hour. This air exchange rate is one half the RESRAD-BUILD default value and approximately the same as the mean distribution value listed in Attachment C of NUREG/CR-6697 (ANL 2000) for this parameter. The receptor's breathing rate was taken to be 31.2 cubic meter (m^3) per day. This equates to 1.3 m^3 per hour (NUREG/CR-6697, Attachment C, Table 5.1-2) and is the same breathing rate used for the Fish and Wildlife Service worker (onsite industrial worker) and sportsman in the residual dose assessment in the DP (U.S. 2013b). The receptor's indirect ingestion rate was 0.0001 m^2 per hour (NUREG/CR-6697, Attachment C low average indirect ingestion rate and RESRAD-BUILD default value). The receptor's whole body dose position was 1 m directly above the DU penetrator. The DU penetrator was modeled as a rectangular volumetric source with an X value of 0.41 m (40.1 cm) and a Y value of 0.021 m (2.1 cm or 0.83 in) and the material type was uranium (U). The source had one layer region (i.e., the penetrator is homogenous DU throughout the entire volume) with a thickness of 2.1 cm, a density of 19 grams per cubic centimeter (g/cm^3), and an erosion rate of 5.75×10^{-5} cm per day. The erosion rate equates to 0.021 cm per year or 1 percent of the total mass, which is the approximate amount of average corrosion per DU penetrator generated annually as determined by the ER corrosion study. The geometry of the source is a volumetric rectangle instead of a cylindrical rod; however, the rectangle contains more source volume than the cylindrical rod because the rectangle width and height dimensions are the same as the diameter of the

cylinder. The source layer region had an air release fraction (ARF) of 3×10^{-5}. Attachment C of NUREG/CR-6697 states that the Department of Energy (DOE) handbook lists "The bounding ARF for plutonium metal formed by oxidation at elevated temperature at 3×10^{-5}." The ARF for plutonium was used because of limited ARF data for uranium and uranium oxides are approximately the same mass as plutonium oxides. Direct ingestion was set at zero grams per hour because the receptor is not likely to have direct mouth contact with the source, but rather to touch the source with hands which then may touch the mouth (i.e., indirect ingestion). The source concentration was set at 3.00×10^{5} picocuries per gram (pCi/g) of U-238, 3.87×10^{3} pCi/g of U-235, and 5.57×10^{4} pCi/g of U-234. This is equivalent to a DU specific activity of 3.6×10^{5} pCi/g separated into individual nuclide specific activity percentages as listed in the DP.

The dose to the receptor in the garage/shop scenario is 2.7 mrem/y consisting of 2.3 mrem/y from external radiation, 0.41 mrem/y from inhalation, and 0.0014 mrem/y from indirect ingestion. This dose is about 3 percent of the 100 mrem/y standard and is about 11 percent of the 25 mrem/y dose standard mandated in 10 CFR 20, Subpart E for restricted release license termination.

ADDITIONAL INGESTION CALCULATIONS – AGGRESSIVE HANDLING

Because the garage/shop scenario only includes exposure from incidental touching of the source while the receptor is in the shop, a more conservative evaluation was conducted to determine the potential radiation dose from indirect ingestion while the receptor is handling the DU penetrator more often. For the purposes of this evaluation, it was assumed that the receptor handled the DU penetrator for 1 hour each month in the course of a year. The ingestion dose was calculated by determining an intake activity and multiplying that value by a dose conversion factor. The intake mass assumed the same initial amount of mass available for intake as calculated above, 27 grams of DU. All of the corroded DU is not easily removed from the penetrator (e.g., 60 percent of the annual corroded mass was dissolved into the soil prior to the removal of the penetrators from JPG; only a percentage of the available corrosion products, when contacted, transfer to the item contacting the surface). As a result, a removable fraction of 10 percent was applied. This value is the most likely value listed in NUREG/CR-6755 (ANL 2002) for the removable fraction.

The next step was to determine how much of the removable mass would be transferred to the receptor's hand and then to the mouth. The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), predecessor organization to the U.S. Army Public Health Command, has published several detailed documents related to health effects from exposure to DU aerosols (USACHPPM 2004). Although the DU penetrator corrosion products are different from aerosolized DU, it is conservative to use the aerosolized DU data for calculations of ingestion dose due to intake of DU corrosion products. The actual amount of DU available for transfer to the hands would be less because the modeled surface-to-hands transfer rate was based on aerosolized DU versus corroded DU. Aerosolized DU is much finer than corroded DU and therefore is more likely to adhere to the gloves used in the USACHPPM 2004 evaluation. The USACHPPM 2004 DU dose evaluation studies calculated dose by determining a surface-to-glove rate (0.384 m^2 per hour), a glove-to-hand factor (20 percent – represents the mass that adhered to the glove would adhere to a hand), and a hand-to-mouth fraction (10 percent – represents the surface area of the fingertips, which are most likely to be placed in/near the mouth). The rate of mass intake

associated with one hour of continuous contact with a DU penetrator is calculated in the following equation:

$$Intake\ Mass(g/hr) = Available\ Mass * RF * SGTR * HGF * HMR / \mathrm{AC}$$

Where:

Available Mass	=	Annual calculated corrosion mass from a single penetrator less the mass dissolved into soil (27.3 grams)
RF	=	Removable fraction (10 percent)
SGTR	=	Surface-to-glove transfer rate (0.384 m^2/h)
HGF	=	Hand/glove factor (20 percent)
HMR	=	Hand-to-mouth ratio (10 percent)
AC	=	Area contacted (1 m^2)

$$Intake\ Mass(g/hr) = 27.3g * 0.1 * 0.384\, m^2/hr * 0.2 * \frac{0.1}{1m^2} = 0.021\, g/hr$$

Note: The area of a penetrator is 273 cm^2. For the purpose of this evaluation, it is assumed that the receptor handles the DU penetrator many times in the 1 hour period so that a total of a 1 m^2 (10,000 cm^2) area is handled. This equates to touching the entire surface area of the penetrator more than 35 times. This is an exceedingly conservative assumption in that as the surface of the penetrator is contacted, some of the removable source (i.e., corrosion products) will adhere to the hands, leaving a smaller source term each time the penetrator is handled. The calculation in the equation above assumes that the entire removable portion of the DU penetrator remains constant such that the amount of DU corrosion products available as a source of contamination remains constant rather than decreasing with time.

The final step is to determine the total activity intake for all 12 hours and calculate a dose. The total intake mass was 0.25 grams (0.021 g/h * 12 hours). This equates to total activity intake of 9.1×10^4 pCi using a conversion factor of 3.6×10^5 pCi/g. The ingestion dose conversion factor (DCF) for uranium-238 (U-238) (2.38×10^{-5} mrem/pCi), uranium-235 (U-235) (2.67×10^{-5} mrem/pCi), and uranium-234 (U-234) (2.61×10^{-5} mrem/pCi) are approximately the same. However, the DCF for U-235 is slightly higher than the others and was used in this evaluation. The selected DCF is based on an f_1 value of 0.002 as specified for tetravalent uranium compounds, as listed in Table D.1 of International Commission on Radiological Protection (ICRP) Publication 119 (ICRP 2012). The indirect ingestion dose to a receptor who handles a DU penetrator for 12 hours per year is 2.4 mrem/y.

U.S. ARMY DOSE ASSESSMENT COMPARISON – MECHANICAL DISTURBANCE

USACHPPM 2004 evaluated doses to individuals who entered tanks and other military vehicles that had been perforated by a DU penetrator. These personnel performed a variety of tasks inside these vehicles. Breathing zone air samplers and gloves were worn by workers while inside the vehicles. Air monitoring results provided real time data, which was used to determine dose. Gloves used inside the vehicles were collected and analyzed to determine the mass of DU that adhered to the gloves. Depending on the scenario, a dose rate was calculated for both inhalation and ingestion. The maximum dose for "individuals who received relatively fleeting DU exposures from climbing on or entering U.S. or enemy combat vehicles to assess damage, remove equipment, or collect souvenirs" was 40 mrem (entering a

burned tank) and 10 mrem (entering a DU-damaged vehicle). Dose was primarily due to inhalation resulting from 100 hours of exposure. These dose values are much less than the 100 mrem/y dose standard mandated in 10 CFR 20, Subpart E. The USACHPPM 2004 dose evaluation has higher doses than the scenario of an individual removing a DU penetrator from JPG and taking it home and is conservatively comparable to an individual who mechanically disturbs an intact penetrator. The higher doses in the USACHPPM evaluation are due to vehicles in the USACHPPM 2004 dose evaluation having much higher levels of DU activity available for intake because approximately 20 percent of the DU penetrator is aerosolized on impact and particles produced adhered to the vehicle's interior walls. In addition, DU that is aerosolized versus corroded generates a larger percentage of particles that are of respirable sizes. For the corroded JPG DU penetrators, approximately 1 percent of the activity is available for intake. Also, corroded JPG DU penetrators have less surface area for potential contact and the volume of the breathing atmosphere (shop/garage versus inside a vehicle) is larger. A larger breathing atmosphere volume will reduce the airborne concentration of respirable DU when it is resuspended.

SUMMARY

The dose to an individual who finds a DU penetrator on JPG, takes it home, stores it in the shop/garage, is in the shop/garage near the penetrator for 100 hours per year, and handles the penetrator for 12 of those hours is 5.1 mrem/y. This value is well below both the 25 mrem/y and 100 mrem/y dose criteria prescribed by 10 CFR 20, Subpart E. The dose to an individual who conducts mechanical disturbance of a DU penetrator is conservatively comparable to the dose received by personnel entering DU contaminated vehicles as evaluated by the Army (i.e., 40 mrem or less). This value is well below the 100 mrem/y dose criteria prescribed by 10 CFR 20, Subpart E. As shown herein, the calculated dose is exceedingly conservative given:

- It is unlikely that an individual will be in the same room as the DU penetrator for 100 hours per year.
- It is unlikely that an individual will handle a DU penetrator for 12 full hours per year.
- The largest piece of the penetrator expected to remain intact after impact was used to model dose even though smaller pieces with less DU for potential exposure are more abundant and portable.
- The amount of modeled DU available for inhalation and ingestion is more than what would actually be available because a rectangular volume verses a cylindrical volume was used.
- The amount of DU available for transfer to the hands would be less because the modeled surface-to-hands transfer rate was based on aerosolized DU versus corroded DU. Aerosolized DU is much finer than corroded DU and, therefore, is more likely to adhere to the gloves used in the USACHPPM 2004 evaluation.
- The DU penetrator handling calculation requires the receptor to handle 100% of the DU penetrator area 35 times per hour for 12 times per year. The calculation assumes the amount of DU available for transfer remains constant at the highest level. In reality, each time the DU penetrator is handled, the amount of activity would be reduced by the amount transferred to the hands.
- The receptor's breathing rate was increased to match that of an individual working outdoors versus in a shop/garage.
- The higher ingestion dose conversion factor for U-235 was used instead of that for U-238 and U-234.