DEPARTMENT OF THE ARMY
UNITED STATES ARMY GARRISON-ROCK ISLAND ARSENAL
1 ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61299-5000

REPLY TO
ATTENTION OF

01 NOV 2004

Office of the Garrison Manager

Dr. Tom McLaughlin, Decommissioning Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC-20555

Dear Dr. McLaughlin:

Reference letter from the Nuclear Regulatory Commission RC dated May 20 2004, subject: Request for Additional Information to Support NRC's Evaluation of the Proposed Changes to the Environmental Radiation Monitoring Program Plan for Jefferson Proving Ground (License No. SUB-1435). As requested in reference letter, the Army response to the specific questions is enclosed. The specific question regarding the modification to the action level for DU in groundwater is also addressed in the enclosure.

I am forwarding a copy of this letter to AMC Safety Office, Safety Office (AMCPE-SF), US Army Materiel Command, 9301 Chapek Road, Fort Belvoir, Virginia 22060-5527.

Ms. Joyce Kuykendall, JPG License Radiation Safety Officer, may be contacted for additional information at (410) 436-7118, facsimile (410) 612-5377 or by email at joyce.kuykendall@us.army.mil.

Sincerely,

Alan G. Wilson
Garrison Manager

Enclosure

RESPONSES TO THE NUCLEAR REGULATORY COMMISSION MAY 20, 2004, REQUEST FOR ADDITIONAL INFORMATION REGARDING THE ENVIRONMENTAL MONITORING PROGRAM PLAN

FINAL

Submitted to:

U.S. Department of Army
Installation Support Management Agency
Aberdeen Proving Ground, Maryland

Prepared by:

Science Applications International Corporation
Reston, Virginia

November 2004

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TABLES

FIGURES

ACRONYMS

AEPI	Army Environmental Policy Institute
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
cm	centimeter
CSM	conceptual site model
DU	depleted uranium
EPA	U.S. Environmental Protection Agency
ERM	environmental radiation monitoring
ft	feet
g	gram
gpm	gallons per minute
in.	inches
JPG	Jefferson Proving Ground
M	molar
mg/m^2d	milligram per meter squared per day
mm	millimeter
mol/kg	moles per kilogram
mrem/yr	millirem per year
MSL	mean sea level
MW	monitoring well
NI	not indicated
NMSS	Office of Nuclear Material Safety and Safeguards
NRC	Nuclear Regulatory Commission
pCi/L	picocurie per liter
RAI	Request for Additional Information
SAIC	Science Applications International Corporation
SOP	Standard Operating Procedure
TECOM	Test and Evaluation Command
UK	unknown
UO_2	uraninite
USACHPPM	Center for Health Promotion and Preventative Medicine
USGS	U.S. Geological Survey
WBZ	water bearing zone
µCi/mL	microcuries per milliliter
µm	micrometer

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INTRODUCTION

On May 20, 2004, the Nuclear Regulatory Commission (NRC) provided the U.S. Army with a Request for Additional Information (RAI) to support NRC's evaluation of the proposed changes to the Environmental Radiation Monitoring (ERM) Plan for Jefferson Proving Ground (JPG) dated September 2003. The RAIs address seven topics, as noted below:

- Question 1. Conceptual Site Model,
- Question 2. Groundwater Flow and Well Placement,
- Question 3. Well Construction Details,
- Question 4. Groundwater and Surface Water Relationships,
- Question 5. Penetrator Dissolution Rate and Depleted Uranium (DU) Solubility,
- Question 6. Groundwater Corrective Measures, and
- Question 7. Uranium Concentrations in Deer.

In addition to information requested on these topics, the NRC requested the Army's recommended changes to the action level for DU in groundwater documented in the ERM Program Plan. This document also addresses the Army's revised position on the subject action level.

Each RAI is organized as follows:

- ***Question*** – The NRC's question on the subject RAI is stated.
- ***Basis*** – This section describes NRC's basis for the question posed.
- ***References*** – The references cited in NRC's question and/or basis are provided.
- ***Response*** – This section provides the Army's response to the question posed.
- ***Response References*** – References cited in the Army's response are detailed.

REFERENCES

U.S. Army. 2003. *Environmental Radiation Monitoring Plan for License SUB-1435, Jefferson Proving Ground.* Prepared by SAIC for the U.S. Army Installation Support Management Agency. September 2003.

NRC. 2004. *Request for Additional Information (RAI) to Support NRC's Evaluation of the Proposed Changes to the Environmental Radiation Monitoring (ERM) Plan for Jefferson Proving Ground (JPG).* Letter from Thomas McLaughlin (NRC) to Colonel Michael Mullins (Department of the Army). May 20.

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QUESTION 1 – CONCEPTUAL SITE MODEL

The Army should provide additional information on the conceptualized site model that was originally used to locate the sampling points for groundwater, surface water and stream sediments. The conceptual model of the hydrologic system for the DU Impact Area should include all potential water-bearing units, surface water systems, caves, springs, and the unsaturated zone that may be impacted by the degradation and movement of the DU penetrators. The Army should provide information on the interrelationship between DU concentrations in the groundwater, surface water, caves, springs and stream sediments.

BASIS

The Army submitted references and other reports on Jefferson Proving Ground (JPG) as part of its submission of proposed changes to the Environmental Radiation Monitoring Program Plan (ERM). The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison Indiana, August 2003, prepared by the United States Army Center for Health Promotion and Preventative Medicine (USACHPPM), states: "The question posed is whether the conceptualized site model used to locate the monitoring wells in the first place is correct." The JPG Karst Study (R. Sheldon, 1997) describes the investigation of numerous caves and other Karst features at JPG. An understanding of the interrelationships between unsaturated flow, groundwater, surface water, caves and springs that impact the fate and transport of the DU from degrading penetrators is critical in design of the monitoring system.

REFERENCES

United States Army for Health Promotion and Preventative Medicine (USACHPPM). 2003. *The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana.* August 2003.

U.S. Department of Army Soldier and Biological Chemical Command. 2003. *Environmental Radiation Monitoring Program Plan for License SUB-1435, Jefferson Proving Ground*, Aberdeen Proving Ground, Maryland. September 2003.

R. Sheldon. 1997. *JPG Karst Study.*

RESPONSE

Original Conceptual Site Model (CSM)

The details of the CSM used to locate the monitoring well locations (groundwater sampling points), surface water, and stream sediments were discussed within the *Review of the Environmental Quality Aspects of the Test and Evaluation Command (TECOM) DU Program at Jefferson Proving Ground, Indiana*, prepared by the Monsanto Research Corporation (Abbott et al. 1984). This report was submitted following the installation of the initial eight (8) depleted uranium (DU) program monitoring wells (MW01-08 in **Figure 1-1**). Key features of this report related to the CSM are summarized below:

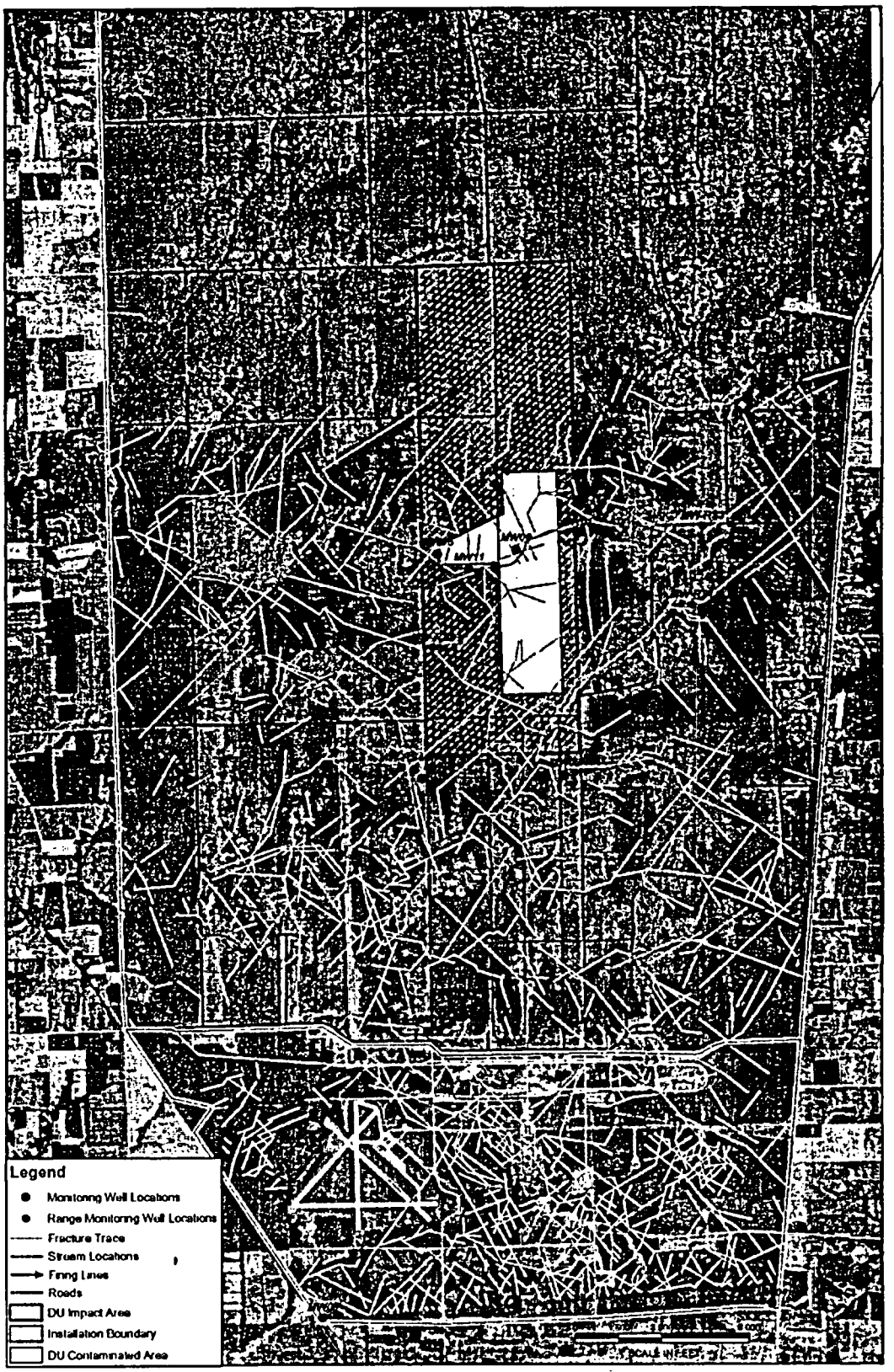

Figure 1-1. DU Wells Within and Surrounding the DU Impact Area

- Within the DU Impact Area were low-permeability soils that effectively prohibited the surface water infiltration into the underlying bedrock aquifer. The soils were described as glacial tills and loess with the development of low-permeability fragipans. Additionally, stratified layers of sand and gravel may be present that have resulted from the glacial outwash during the glacial melt.
- The level of the surface water (streams) was below the groundwater surface and that groundwater could, at times, discharge to the surface water through streams, but the surface water did not recharge groundwater.
- One avenue for surface water recharge to the bedrock aquifer could occur at a karst feature such as a sinkhole, where a direct connection from the surface to the bedrock aquifer had been established due to dissolution of limestone and collapse of the overlying layers and soil. Surface water recharge to the bedrock aquifer was noted as not occurring in this manner because no sinkholes were present within the DU Impact Area.
- The underlying bedrock aquifer, as described from observations during the boring and monitoring well installations, consisted of a light gray to gray limestone with a weathered zone of 1 ft or less that was not present at all locations. Generally, the limestone was very hard and fine-grained with occasional more heavily weathered thin shale or siltstone seams and occasional coarse-grained limestone and pitting as a result of dissolution.
- Groundwater was noted to exist under water table conditions, with topography having a major influence on the direction of flow. If permeable strata, consisting of coarse sand, gravel, fractured rock, etc., were present, this information would have been discovered during the initial drilling program. The presence of these types of permeable media would be important in evaluating the possibility of a hydraulic connection between the surface water and the groundwater.

Based on the information presented (Abbott et al. 1984), the CSM being used at the time appears to have:

— Assumed Darcian flow conditions. As a result, wells were placed accordingly, three in the up-gradient direction of the DU Impact Area (east side of impact area, MW-1, MW-2, and MW-3); three in the down-gradient direction (west side of impact area, MW-5, MW-6, and MW-7); and two in background locations (south of the firing line, MW-4, and MW-8).

— Located soil samples based on a grid pattern and included several background samples outside the impact area.

— Located surface water and sediment samples so that surface water entering (background) and exiting the impact area could be monitored. Two sample locations (one from each crossing stream) were located inside the impact area.

Present Conceptual Site Model

Subsequent to the Abbott et al. (1984) report, additional investigations were completed at JPG. The following descriptions of the surface water and groundwater are based on these reports, and other available information detailed in historical reports and the available project files.

Aquifer recharge through surficial materials

The soils present on the site and within the DU Impact Area are characterized generally as having low permeability; therefore, surface water infiltration is expected to be slow. Several other factors, such as sand and gravel lenses/layers, jointing or fracturing of the soils, and karst features (i.e. sinkholes), can increase the permeability and flow, or recharge, through the soil and to the shallow bedrock aquifer.

Higher permeability materials (sand and gravels) are often present in glacial deposits from glacial outwash. These higher permeability materials, if present at this site, would influence surface water infiltration and recharge to the bedrock aquifer. The boring and well completion logs from the initial eight DU program wells did not indicate the presence of these types of materials, although several wells drilled during the Training Range Site Characterization and Risk Screening Regional Range Study (MW-RS4 through MW-RS8, **Figure 1-1**) intersected intervals of fine sand or sand, which may be a result of glacial outwash deposition. These wells are all located approximately 1,600 to 3,300 ft to the southwest of the southwestern corner of the DU Impact Area with the exception of MW-RS8. MW-RS8 is located within the southwestern portion of the DU Impact Area approximately 300 ft east of the western boundary and 2,500 ft to the north of the southern DU Impact Area boundary. The description of sands observed during the installation of theses wells indicates that areas of higher permeability materials may occur in the southwest portion of the DU Impact Area and outside of the DU Impact Area to the southwest.

Within the report entitled *Final Phase II Remedial Investigation* (MWH 2002), which was completed for investigation areas south of the firing line, it was stated that studies of till that are similar to the glacial till at JPG show that the permeability of the soils may be higher in areas due to jointing in the soils or from the presence of sands and gravels resulting in the majority of the flow within the till materials occurring in the joints/fractures and in the sand/gravel lenses and layers. The soils present south of the firing line consist mainly of the Cobbsfork-Avonburg soil group with lesser amounts of the Cincinnati-Rossmoyne soil group. The soils north of the firing line consist of the same two soil groups present south of the firing line.

The DU Impact Area is bisected by two streams, Big Creek and Middle Fork Creek. These streams have several unnamed tributaries and ephemeral portions. The streams are incised and it is not known whether they are losing or gaining streams. If the streams are losing streams, recharge from surface waters could be occurring to the shallow bedrock aquifer. Based on these observations, it is probable that there is hydraulic communication (i.e. recharge) from the surface water to the shallow bedrock aquifer.

An evaluation of the groundwater elevations from the limited number of monitoring wells in the DU monitoring program and the Range Study (U.S. Army 2002) indicates that shallow groundwater flow directions seasonally and on a local scale are toward the local surface water drainages, indicating that groundwater within the unconsolidated aquifer flows toward, and may discharge to, the streams. Due to the presence of the streams and the indication of shallow groundwater potentially flowing to the surface water drainages, shallow groundwater flow directions within the DU area may be locally, and seasonally migrating toward the smaller streams.

Karst features present on site

Numerous karst features consisting of caves, sinkholes, springs, and a combination of the previous were observed and investigated as part of a karst study (Sheldon 1997). Several of the documented caves are present within the DU Impact Area and along downstream sections of Big Creek and Middle Fork Creeks. This karst study documents the presence of karst at JPG and within the DU Impact Area. The presence of these karst features suggests that a hydraulic connection between the surface water and the shallow bedrock aquifer exists, and recharge of the shallow bedrock aquifer from surface water may be occurring.

Shallow bedrock aquifer

The shallow bedrock aquifer consists of carbonate rocks (limestone and dolomite) with lesser amounts of shale. The primary porosity of the bedrock aquifer is believed to be low. There is evidence of significant secondary porosity within the bedrock aquifer that is derived from fractures/jointing and karst features. A

fracture trace analysis (Greeman 1981) documented numerous fractures and lineaments present within the DU Impact Area (see **Figure 1-1**).

Numerous types of karst features were observed to be present on JPG and within the DU Impact Area. Several caves along Big Creek within the DU Impact Area and along downstream sections of Big Creek were identified. All three of the caves identified within the DU Impact Area along Big Creek were noted as having springs discharging at their entrances. There are two caves that were identified along the Middle Fork Creek. Neither cave is located within the DU Impact Area, but one is located approximately 1,000 ft to the west of the westernmost 2000-meter (m) target location and is noted to have a stream discharging from the cave into Middle Fork Creek. Based on the location of this cave, some of the groundwater contribution of this stream could originate in the DU Impact Area.

Regionally, the bedrock groundwater flow direction is toward the west to southwest. The presence of the observed karst features and mapped fracture traces/lineaments indicates that solution-enlarged discontinuities are present in the bedrock. These features act as preferential flow pathways within the bedrock aquifer and will control and dramatically affect groundwater flow volume and direction and, therefore, contaminant transport. The shallow bedrock aquifer could receive recharge from the surface water and unconsolidated aquifer (sinkholes, caves, jointing within the till, and losing stream sections) in addition to potentially discharging to the surface water (springs, streams from caves, and gaining stream sections). Either or both of these conditions, recharge to or discharge from the shallow bedrock aquifer, could be occurring depending on the position within the individual groundwater basins and the local conditions.

Conceptual model of DU transport through the environment to potential receptors

The dose assessment (Appendix C) in support of the *Decommissioning Plan for License SUB-1435* (U.S. Army 2002) indicates that, "Doses to humans and ecosystem receptors can come from any number of exposure pathways beginning when the munitions are tested and lasting until the DU is removed from the system. Thus, the dose to humans from DU must be assessed for a variety of pathways, and for a relatively long time due to slow transport through the soils." **Figure 1-2** is graphic representation of the DU sources, transport mechanisms, potential exposure pathways, and potential receptors.

The DU has been deposited on, or immediately below, the ground surface and/or within the surface water (streams). Once the DU has been deposited within the soil or surface water, it could be transported through the environment by several different processes. DU in the soil or surface water can be subject to physical movement by erosion, flooding/high-water conditions, and dust movement by wind or fire and leaching. Processes of erosion could cause migration and transport of DU penetrators or fragments (during floods and high-runoff events) along the ground surface and along surface water drainage ways. Leached DU from the penetrators and/or fragments in the soil and in the surface water could be transported to groundwater and surface water. Soluble DU could be absorbed by plants and incorporated within the plant matter. The simplest and most direct exposure pathway to wildlife and humans would be from direct contact with the penetrators and/or fragments and incidental ingestion of DU or DU-impacted soils. Impacted surface water and groundwater could migrate to drinking water sources. The drinking water and surface water could be ingested by humans, livestock, and wildlife. Meat and/or animal products from animals ingesting DU-impacted water could be ingested by humans. Humans could have contacts with, and incidental ingestions of, impacted surface waters during recreational activities such as fishing and hunting.

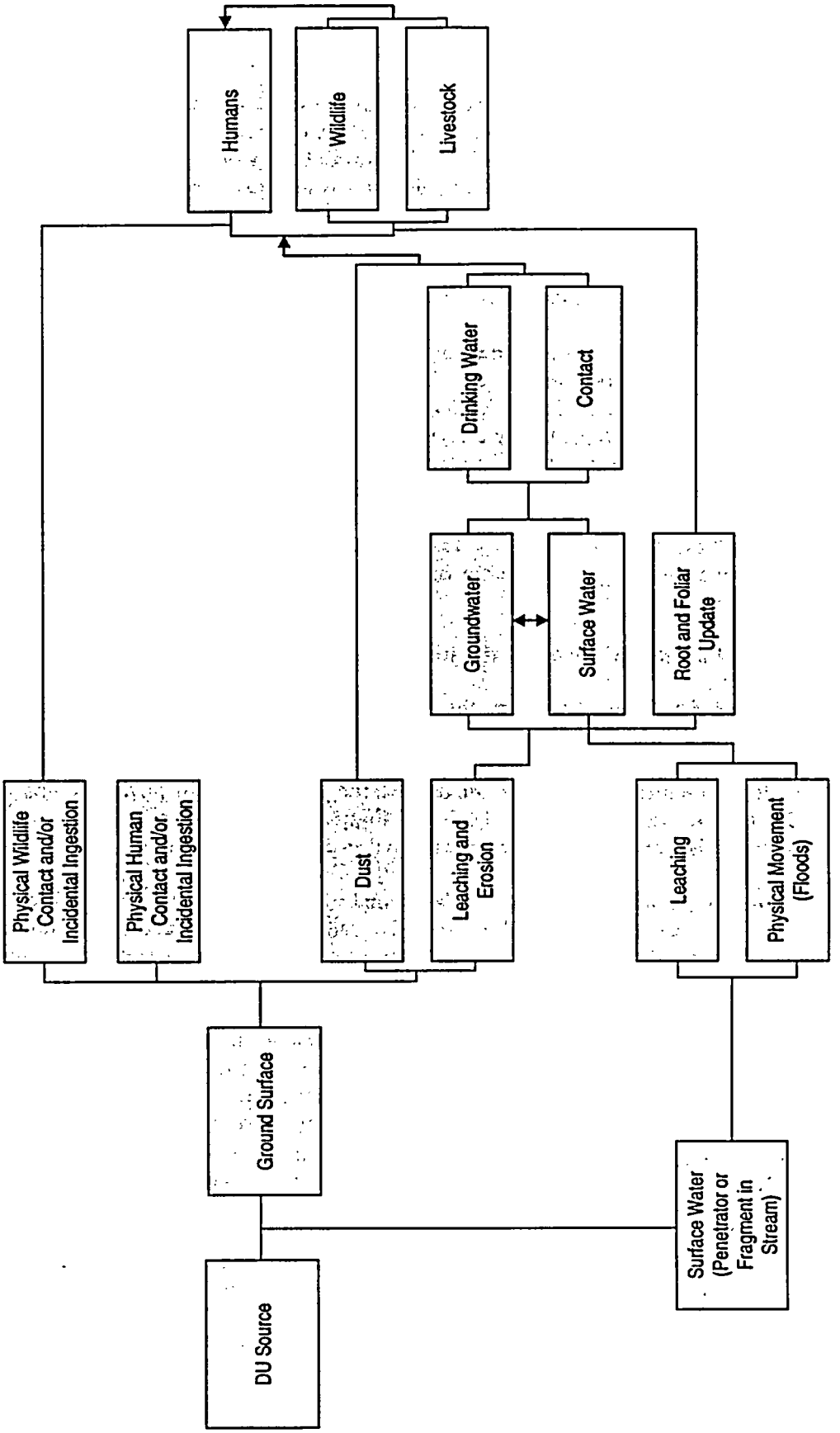

Figure 1-2. Conceptual Model of DU Transport Through the Environment

Interrelationships of DU concentrations in surface water, groundwater, and sediments

Sampling and analysis for DU concentrations of water discharges from springs and caves has not been completed to date at JPG; therefore, this evaluation cannot address this interrelationship. DU is defined as uranium in which the isotope uranium-235 is less than 0.711 weight percent of the total uranium present (10 *Code of Federal Regulations* 40). The presence of DU can be determined by completing isotopic analysis for U-238 and U-234 and calculating the U-238/U-234 ratio, which is compared with the accepted and published isotopic ratio of natural uranium. Analysis of the individual uranium isotopes was completed for groundwater from 1984–1996, for surface water from 1983–1996, and for stream sediments from 1984–1994. The most recent monitoring event, April 2004, includes isotopic analyses of groundwater. Without uranium isotope analyses, the presence of DU within the matrices cannot be determined after 1996 for groundwater and surface water and after 1994 for stream sediments (except for the 2004 sampling event for groundwater).

During the collection of the historical samples at the DU Impact Area, no flow data were collected in conjunction with sampling of surface water, sediment, and groundwater. No flow data have been collected from any of the springs or caves documented to be within the DU Impact Area. Without flow data, the interrelationship of groundwater, surface water, springs, caves, and sediment cannot be identified and evaluated. Flow data are needed to determine the inputs of groundwater and surface water and what conditions are present, such as a losing stream, gaining stream, discharge of groundwater from springs and streams to the surface water causing dilution or addition of DU, and conditions affecting sediment load in the stream and erosion/deposition rates. These data are essential to establishing the interrelationship of the groundwater, surface water, caves, springs, and sediments.

REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana.* Miamisburg, OH, Monsanto Research Corporation.

CFR (*Code of Federal Regulations*). 2004. 10 *CFR* Part 40.4. Energy. Nuclear Regulatory Commission. Domestic Licensing of Source Material. Definitions.

Greeman, T. 1981. *Lineaments and Fracture Traces, Jennings County and Jefferson Proving Ground, Indiana.* Open-File Report 81-1120. U.S. Geological Survey (USGS).

MWH (Montgomery Watson Harza). 2002. *Final Phase II Remedial Investigation, Jefferson Proving Ground, Madison Indiana.* Contract No. DACW27-97-D-0015, Task Order 4008. September.

Sheldon, R. 1997. *JPG Karst Study.*

USACHPPM (U.S. Army Center for Health Promotion and Preventative Medicine). 2003. *The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana.* August.

U.S. Army. 2002. *Decommissioning Plan for License SUB-1435.* Prepared by U.S. Army for NRC. June.

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QUESTION 2 – GROUNDWATER FLOW AND WELL PLACEMENT

There appears to be conflicting information on the direction of groundwater flow. The Army should provide additional information on the adequacy of the placement (and screened interval), number, and spacing of the current 11 monitoring wells to detect depleted uranium (DU) in groundwater.

BASIS

The Army submitted references and other reports on Jefferson Proving Ground (JPG) as part of its submission of proposed changes to the Environmental Radiation Monitoring Program Plan (ERM). The training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana, August 2003, prepared by the United States Army Center for Health Promotion and Preventative Medicine (USACHPPM), states: "The direction of ground-water flow in the glacial till is roughly the same as the surface water drainage, which is to the west-southwest over much of JPG." "Due to the size of JPG, the number of streams, the fact that some streams are incised, and because ground water in glacial till and shallow bedrock tend to discharge to surface drainages, there are probably multiple ground-water basins." "As shown on Figure 6-4, the estimated direction of ground-water flow is to the south." "As shown on Figure 6-6, the estimated direction of ground-water flow is to the southeast and the northwest." And "Monitoring wells near and within the Delta Impact Area south of Big Creek are too widely spaced to construct a meaningful ground-water elevation contour map."

In the ERM, the Army states: "To assess the groundwater conditions in and surrounding the DU Impact Area, a number of groundwater monitoring wells were installed and sampled over a substantial period at locations experts believed adequate for acquiring such information." "No one can ensure that groundwater monitoring systems in karst environments will not involve a contaminant 'end-running' a network." "It is well known that a complete deterministic description of the preferential pathways is not possible in karst/fractured environments." "The site is located in karst topography; therefore, the complex physics of flow and transport in fractured media apply. In these systems, the flow patterns may or may not match the directions typically inferred from the slopes indicated on groundwater table maps. Therefore, locating monitoring wells directly downgradient of a source area is complicated. In addition, migration of uranium in the subsurface is a complex biogeochemical reactive process."

REFERENCES

United States Army for Health Promotion and Preventative Medicine (USACHPPM). 2003. *The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana.* August 2003.

U.S. Department of Army Soldier and Biological Chemical Command. 2003. *Environmental Radiation Monitoring Program Plan for License SUB-1435, Jefferson Proving Ground.* Aberdeen Proving Ground, Maryland. September 2003.

RESPONSE

Generally, groundwater flow direction has been indicated to be in the west-to-southwest direction paralleling the overall direction of the surface water drainages across Jefferson Proving Ground (JPG). The groundwater elevation plots covering limited areas within JPG and around the Depleted Uranium

(DU) Impact Area appear to represent the localized flow directions within the shallow aquifer, which if they mimic the local surface water drainage, will have varying flow directions based on the location and proximity to established surface water drainage. Groundwater elevation contours for the entire DU Impact Area cannot be constructed because of the wide spacing of the wells included in the DU monitoring network and the complexity of the groundwater flow system due to the presence of multiple stream/surface water drainages, karst, and fractures/lineaments.

The usefulness of the DU program monitoring wells is detailed in **Table 2-1** for each well assessed based on existing documentation and a well inspection survey (Abbott et. al 1984, Greeman 1981, SAIC 2004a and b, SEC Donohue 1992, Sheldon 1997, and U.S. Army 2003a and b). The wells evaluated include the current 11 monitoring wells as well as the eight (8) wells installed as part of the 2002 Range Study (U.S. Army 2003b). The location, anticipated flow direction at the well location, depth, screened interval, proximity to mapped fractures/lineaments [see Figure 1-1], proximity to established surface water drainage, and well development and recharge during purging and sampling (hydraulic connectivity) were all evaluated while determining the usefulness of the these 19 wells. Seventeen of the 19 wells evaluated are useful for collection of ground water elevation data to aid in determining groundwater head potentials and flow directions. Monitoring wells MW-1 and MW-4 appear to be the least useful for determining groundwater head potentials and flow directions due to construction of multiple screened intervals. The DU monitoring program wells that appear to be useful for collection of groundwater elevation data, but less useful for monitoring the DU impact, and the reasons that they are less useful, are as follows:

- **MW-1:** This well has two separate screened intervals and one continuous filter pack that connects the two screened intervals. Due to the construction with the two screened intervals, the monitored interval cannot be determined. The well is located on the up-gradient side of the DU Impact Area and is not located on mapped fractures.

- **MW-4:** This well has two separate screened intervals and one continuous filter pack that connects the two screened intervals. The well is also screened in both the unconsolidated overburden and the underlying bedrock. Due to the construction with the two screened intervals and the location of the screened intervals, the monitored interval cannot be determined. The well location is approximately 3.75 miles toward the south–southeast from the southeastern corner of the DU Impact Area and is too far to monitor environmental impacts of DU within the impact area.

- **MW-7:** The screened interval is appropriate and the location is satisfactory only for monitoring water level elevations at a cross-gradient location. Even though the well location is close to mapped fracture traces, the recharge rate is low and the hydraulic connectivity and the effectiveness of the well in monitoring environmental impacts of DU to groundwater are questionable. The well does not appear to be connected with the preferential flow pathway network.

- **MW-8:** The well location is approximately 3.7 miles toward the south–southwest from the southwestern corner of the DU Impact Area and is too far to monitor the environmental impacts of DU within the impact area.

- **MW-9:** The screened interval is appropriate and the location is okay only for monitoring water level elevations at a potentially down-gradient location. Even though the well location is close to mapped fracture traces, the recharge rate is low and the hydraulic connectivity and the effectiveness of the well in monitoring environmental impacts of DU to groundwater are questionable. The well does not appear to be connected with the preferential flow pathway network.

Table 2-1. Well Usefulness for Detecting DU
Jefferson Proving Ground, Indiana

DU Program Wells	Description	Usefulness to Monitor DU Impact Area?
MW-1	This well has two screened intervals and the monitored interval cannot be determined. The well is at a location for an upgradient bedrock aquifer monitoring well. The well is not located on mapped fractures.	No
MW-2	Well location and screened interval are both satisfactory for monitoring at an upgradient bedrock aquifer location. Well location is not located on mapped fractures.	Yes
MW-3	Well location and screened interval are both satisfactory for monitoring at an up-gradient, cross-gradient, or background bedrock aquifer location. Well location is not located on mapped fractures.	Yes (background)
MW-4	This well has two screened intervals and the monitored interval cannot be determined. The well also is screened in both the unconsolidated and the bedrock aquifers. This well is located too far from the DU Impact Area to be used for anything but background information.	No.
MW-5	Well location and screened interval are both satisfactory for monitoring from a possible downgradient bedrock aquifer location. Well is located on, or close to, mapped fractures.	Yes
MW-6	Well location and screened interval are both satisfactory for monitoring from a possible downgradient unconsolidated aquifer location. Well screen could possibly have been installed 10 ft shallower.	Yes
MW-7	Screened interval is satisfactory. The well location is satisfactory for a cross-gradient or background location. The recharge rate is low and usability and hydraulic connectivity of the well are questionable. Well location is close to mapped fractures.	Yes (elevation only)
MW-8	This well is located too far from the DU Impact Area to be used for anything but background information. The screened interval is satisfactory, and the location is close to the end of a mapped fracture.	Yes (background only)
MW-9	Well location and screened interval are both satisfactory for monitoring from possible downgradient bedrock aquifer location. The recharge rate is low and usability and hydraulic connectivity of the well are questionable. Well location is located close to mapped fractures.	Yes (elevation only)
MW-10	Well location and screened interval are both satisfactory for monitoring bedrock aquifer location. Well location is not on mapped fractures.	Yes
MW-11	Location of well is satisfactory. Large screened interval, but the recharge rate is low and usability and hydraulic connectivity of the well are questionable. Well location is on mapped fractures.	Yes (elevation only)
MW-RS1	The well is not in a location to monitor the environmental impacts from the DU Impact Area. May possibly used as an up gradient monitoring location.	Partial
MW-RS2	The well is not in a location to monitor the environmental impacts from the DU Impact Area. May possibly used as an up gradient monitoring location.	Partial
MW-RS3	The well is not in a location to monitor the environmental impacts from the DU Impact Area. May possibly used as an up gradient monitoring location.	Partial
MW-RS4	The well location is good for aiding in defining groundwater flow potentials in the unconsolidated aquifer at the southwest corner of the DU Impact Area. Possibly suitable for DU impact monitoring if additional flow evaluation indicates the location to be downgradient.	Partial
MW-RS5	The well location is good for aiding in defining groundwater flow potentials in the unconsolidated aquifer at the southwest corner of the DU Impact Area. Possibly suitable for DU impact monitoring if additional flow evaluation indicates the location to be downgradient. The recharge rate is low and usability and hydraulic connectivity of the well are questionable.	Partial
MW-RS6	The well location is good for aiding in defining groundwater flow potentials in the unconsolidated aquifer at the southwest corner of the DU Impact Area. Possibly suitable for DU impact monitoring if additional flow evaluation indicates the location to be downgradient.	Partial

Table 2-1. Well Suitability for Detecting DU
Jefferson Proving Ground, Indiana (continued)

DU Program Wells	Description	Suitable to Monitor DU Impact Area?
MW-RS7	The well location is good for aiding in defining groundwater flow potentials in the unconsolidated aquifer at the southwest corner of the DU Impact Area. Possibly suitable for DU impact monitoring if additional flow evaluation indicates the location to be downgradient. The recharge rate is low and usability and hydraulic connectivity of the well are questionable.	Partial
MW-RS8	Well location and screen depth are good for aiding in defining flow along the southwest side of the DU Impact Area. Possibly suitable for DU impact monitoring if additional flow evaluation indicates the location to be downgradient.	Partial

DU = depleted uranium.
MW = monitoring well.

- **MW-11:** The screened interval is slightly large and may be connecting several water-bearing zones. The location is okay only for monitoring water level elevations at a potentially down-gradient location. Even though the well location is close to mapped fracture traces, the recharge rate is low and the hydraulic connectivity and the effectiveness of the well in monitoring environmental impacts of DU to groundwater are questionable. The well does not appear to be connected with the preferential flow pathway network.

Nine of the DU program wells [MW-2, MW-3, MW-5, MW-6, MW-7 (elevation only), MW-8 (background, elevation only), MW-9 (elevation only), MW-10, and MW-11 (elevation only)] appear to be useful for inclusion in the monitoring program for evaluating groundwater at the DU Impact Area. Of the nine DU program wells, only three of the wells (MW-5, MW-6, and MW-10) appear to be situated in potentially down-gradient locations and have appropriate construction and hydraulic connectivity for monitoring the environmental impacts from DU within the DU Impact Area. Two of the DU program wells (MW-2 and MW-3) are located along the up-gradient side of the soft target area, between the DU Impact Area and the firing line, and will be useful for monitoring at up-gradient or cross-gradient locations from the DU Impact Area. The remaining three wells (MW-7, MW-8, MW-9, and MW-11) are only suitable for monitoring groundwater elevations and/or background locations.

Five of the Range Study wells (MW-RS4 to -8) are in locations that would aid in the determination of flow direction along the southwest side and southwest corner of the DU Impact Area. MW-RS8 is located within the DU Impact Area along the western edge. With additional groundwater flow direction evaluation, several of these wells may be determined to be down-gradient of DU-impacted areas and, therefore, useful in monitoring DU impacts to groundwater from the DU impact area. Three of the Range Study wells (MW-RS1 to -3) are located east of the DU impact area and may be useful for monitoring of groundwater head potentials and flow direction along the up gradient or eastern edge of the impact area. Even if the Range Study wells are determined to be appropriate for use within the monitoring program, the inclusion of these wells would not provide enough additional groundwater elevation data to construct groundwater elevation contours for the DU Impact Area and adequately evaluate groundwater flow through and from the DU Impact Area.

The present wells that appear to be useful are all located in the southern two-thirds of the DU Impact Area and south of the DU Impact Area. The scoping survey results discussed in the 2003 *Environmental Radiation Monitoring Program Plan* (U.S. Army 2003) indicate that the most heavily DU-impacted area generally is located in the eastern portion of the southern two-thirds of the DU Impact Area. There are no

wells located in positions to monitor potential DU impacts in the northernmost portion of the DU Impact Area.

REFERENCES

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QUESTION 3 – WELL CONSTRUCTION DETAILS

The Army should provide additional information on the construction, development, and maintenance of the current 11 monitoring wells.

BASIS

Recent submittals by the Army have cast doubt on the viability of the existing monitoring wells to adequately measure DU in groundwater. The Range Study Report (USACHPPM, 2003) states: "The seven existing wells incorporated into this range study were installed during the 1980's. Wells MW-1, MW-2, MW-5 and MW6 were installed in 1983. These wells were constructed from PVC riser pipes and screens and were fitted with steel protective covers. Well caps and locks were missing from each well. The protective casing lids were also partially or completely open at each well allowing the introduction of vegetation and precipitation into the well pipes. Wells MW-9, MW-10 and MW-11 were installed in 1988. These wells were all flush mounted and only MW-10 was fitted with a well cap and lock. Wells MW-9 and MW-10 were not capped, making the introduction of vegetation, debris, precipitation, and surface runoff into the wells possible."

The SEC Donahue Characterization Study (SEC, 1992) states: "An evaluation of the available well logs for the DU area wells was performed. The logs were lacking in many aspects, thus a comprehensive evaluation of the data obtained from the wells was not possible. For instance, most of the well logs did not specify the depth of the first saturated zone, and those that did were not screened at the first water producing interval. Two of the wells, DU-1 (sic) and DU-4 (sic), were screened at two separate intervals in the bedrock so determination of which interval was actually sampled is not possible. It is generally deemed of utmost importance for site investigations to obtain groundwater from the water producing zone most likely to be contaminated, which is almost always the top one. The well construction diagrams and written descriptions of the well construction were often contradictory, making it difficult to tell if the wells were constructed properly or if the appropriate water producing zone was sampled. The wells are two widely spaced across the area to interpret the potentiometric surface or identify the preferred flow paths." In addition there are numerous citations of poor recharge rates for MW-6, MW-9 and MW-11, leading to no samples being taken for some studies. Because of the age and potential lack of maintenance on these wells, each monitoring well should be redeveloped or replaced before any new monitoring is performed.

REFERENCES

United States Army for Health Promotion and Preventative Medicine (USACHPPM). 2003. *The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana.* August 2003.

U.S. Department of Army Soldier and Biological Chemical Command. 2003 *Environmental Radiation Monitoring Program Plan for License SUB-1435, Jefferson Proving Ground.* Aberdeen Proving Ground, Maryland. September 2003.

SEC Donahue. 1992. *Characterization Study.*

RESPONSE

All available information on the construction and development of the current 11 monitoring wells within the depleted uranium (DU) monitoring program is included on the available monitoring well logs (MW-1 through MW-8, attached) [Abbott et al. 1984, SAIC 2004a and b, and U.S. Army 2003]. Well construction details for DU monitoring program wells MW-9 through MW-11 were included in the 2003 Range Well Study (U.S. Army 2003). Available construction and development details for the DU program monitoring wells and Range Study wells were compiled and assessed. The results of this assessment are presented in **Table 3-1**. Information that is not presently available for most of the wells consists of encountered water-bearing zones, well yields, and adequacy of development.

An inventory and maintenance check of the wells included in the DU monitoring program is completed during the biannual sampling events conducted under the Environmental Monitoring (ERM) Program. The condition and security of the well is assessed prior to the initiation of sampling at each of the well locations. Information acquired during the most recent sampling event in April 2004 and a well inventory on July 20, 2004, indicate that all of the DU program wells had lids/caps in place and were secured with locks. DU program wells MW-1 through MW-8 all had surface completions consisting of a protective casing stickup with a locking outer cap that visually appeared to have been constructed in accordance with industry standards of well completions. MW-9, MW-10, and MW-11 all have well pipe risers that are at grade with locking compression plug caps. They have not been completed with industry standard, permanent flush-mount covers that protect the end of the well riser pipe and locking compression plug as well as assisting in exclusion of surface water and debris from entering the well. MW-RS1 and MW-RS7 Range Study wells could not be located during the July well inspections but were later located and inspected by Jefferson Proving Ground (JPG) staff. The Range Study wells all had locking protective casing stickup lids in place that were secured with locks and had protective casing surface completions in good condition that visually appeared to have been constructed in accordance with industry standards of well completions.

The reported well completion depths were compared with the measured total depths of the wells to determine if silt has accumulated within the wells. DU program wells that appear to have silt accumulations and may need to be redeveloped include MW-2 through MW-8. The inspection of MW-RS1 and MW-RS7 JPG staff did not include gauging of the wells. The gauged Range Study wells did not appear to have as much silt accumulation as the DU program wells with the exception of MW-RS8. If sampling were to occur at wells MW-2 through MW-8, MW-RS2, MW-RS3, MW-RS6, and MW-RS8, all would benefit from redevelopment prior to the initiation of sampling.

REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana.* Miamisburg, OH, Monsanto Research Corporation.

SAIC (Science Applications International Corporation). 2004a. Well Inspection Survey. July 20.

SAIC. 2004b. *Well Purging and Recharge Observations from Semi-annual Sampling Events.* William Wilkinson (SAIC) and Phil Mann (U.S. Army). April.

U.S. Army. 2003. *The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana.* U.S. Army for Health Promotion and Preventative Medicine (USACHPPM). August 2003.

Table 3-1. Monitoring Well Details
Jefferson Proving Ground, Indiana

DU Program Wells	Date Installed	Ground Surface Elevation (ft MSL)	TOC Elevation (ft MSL)	Total Depth (feet bgs)	Surface Completion Type	Lock Present and Operable	Screen Length (ft)	Screen and Riser Diameter (in.)	Screen Slot Size (in.)	Screen Interval (ft MSL)	Sand Pack Interval (ft MSL)	Seal Interval (ft MSL)	Formation Exposed In Open Interval	Reported Water-Bearing Zone (Interpreted WBZ from Well Log) [ft bgs]	Well Yield	Development	Location on Mapped Fracture or Lineament Trace
MW-1	12/6/1983	851.7	853.49	33.2	Stick-up	Yes	4.8	2	0.006	818.5–823.3	818.5–848.49	848.49–847.7	Limestone	NI, UK	UK	Pumped at least 3 well volumes	No
					Stick-up	Yes	4.8	2	0.006	838.6–843.42	818.5–848.49	848.49–847.7	Limestone	NI, UK	UK	Pumped at least 3 well volumes	No
MW-2	12/13/1983	848	850.18	23.7	Stick-up	Yes	10	2	0.006	824.3–834.3	824.3–835.5	835.5–836.5	Limestone	NI (> 14.5)	UK	Pumped at least 3 well volumes	No
MW-3	12/13/1983	852.21	854.71	42.8	Stick-up	Yes	10	2	0.006	809.41–819.41	809.41–821.21	821.21–822.21	Limestone	NI, (> 33)	~10 gpm	Pumped at least 3 well volumes	No
MW-4	12/14/1983	900.47	902.97	28	Stick-up	Yes	5	2	0.006	872.47–877.47	871.97–893.47	893.47–894.47	Siltstone/ Limestone	NI, UK	Low (Handbail Dry)[a]	Pumped at least 3 well volumes	UK
					Stick-up	Yes	5	2	0.006	886.97–891.97	871.97–893.47	893.47–894.47	Silty Clay, Clayey Silt, Weathered Limestone	NI, UK	Low (Handbail Dry)[a]	Pumped at least 3 well volumes	UK
MW-5	12/7/1983	801.6	804.05	33.4	Stick-up	Yes	10	2	0.006	768.2–778.2	768.2–779.6	779.6–780.6	Limestone	NI (> 24)	UK	Pumped at least 3 well volumes	Yes/Close
MW-6	12/17/1983	858.4	861.12	40	Stick-up	Yes	10	2	0.006	818.4–828.4	814.4–830.4	830.4–831.9	Silty Clay	NI, UK	Slow Recharge[a]/ Handbail Dry[b]	Pumped at least 3 well volumes	No
MW-7	12/8/1983	848.71	850.71	53.7	Stick-up	Yes	10	2	0.006	795.01–805.01	795.01–806.71	806.71–807.71	Limestone	NI (> 44)	Low (Handbail Dry)[a]	Pumped at least 3 well volumes	Close
MW-8	12/9/1983	843.86	846.11	28.2	Stick-up	Yes	10	2	0.006	815.66–825.66	815.66–826.86	826.86–827.86	Limestone	NI (Poss. 20 ft)	~ 35 gpm	Pumped at least 3 well volumes	Close/End
MW-9	9/9/1988	819.6	819.58	38.2	Flush	Yes	20	2	UK	781.4–801.6	781.6–804.6	801.6–804.6	Limestone & Shale	UK	Slow Recharge[a,b]	UK	Close
MW-10	9/18/1988	860.8	865.75	41.3	Flush	Yes	20	2	UK	819.5–839.5	819.5–839.8	839.8–843.3	Sandy to Clayey Silt	UK	UK	UK	No
MW-11	9/19/1988	809.4	809.56	41.9	Flush	Yes	30	2	UK	767.5–797.5	767.5–797.4	797.4–806.9	Limestone & Shale	UK	Slow Recharge[c]	UK	Yes
Range Study Program Wells																	
MW-RS1	8/20/2002	865.1	867.43	13.5	Stick-up	UK	8	2	0.010	851.6–860.8	851.6–860.8	860.8–862.2	Limestone & Clayey Silt	NI, UK	UK	Manual bailing, 5 gal removed	No
MW-RS2	8/16/2002	872.8	875.43	25.7	Stick-up	Yes	10	2	0.010	847.1–857.6	847.6–859.9	859.9–868.7	Limestone	NI (18)	UK	Manual bailing, 20 gal removed	No
MW-RS3	8/17/2002	878.7	881.25	12.5	Stick-up	Yes	5	2	0.010	866.2–871.2	866.2–872.7	872.7–874	Silty Clay	NI, UK	Slow Recharge[b]	Manual bailing, 2.5 gal removed (dry)	No

Table 3-1. Monitoring Well Details
Jefferson Proving Ground, Indiana

DU Program Wells	Date Installed	Ground Surface Elevation (ft MSL)	TOC Elevation (ft MSL)	Total Depth (feet bgs)	Surface Completion Type	Lock Present and Operable	Screen Length (ft)	Screen and Riser Diameter (in.)	Screen Slot Size (in.)	Screen Interval (ft MSL)	Sand Pack Interval (ft MSL)	Seal Interval (ft MSL)	Formation Exposed in Open Interval	Reported Water-Bearing Zone (Interpreted WBZ from Well Log) [ft bgs]	Well Yield	Development	Location on Mapped Fracture or Lineament Trace
MW-RS4	8/19/2002	858.1	860.72	14.8	Stick-up	Yes	9	2	0.010	843.3–853.3	843.3–853.3	854.6–853.9	Silty Clay & Fine Sand	NI (~ 11)	UK	Manual bailing, 5 gal removed	Close
MW-RS5	8/18/2002	851.2	853.72	13.1	Stick-up	Yes	8	2	0.010	838.1–846.2	838.1–847.4	847.4–848.7	Silty Clay & Fine Sand	NI, UK	Slow Recharge[d]	Manual bailing, 3 gal removed (dry)	No
MW-RS6	8/18/2002	857.9	860.17	14.8	Stick-up	Yes	9	2	0.010	843.1–853.9	843.1–853.9	853.9–855.4	Silty Clay & Sand	NI (> 11)	UK	Manual bailing, 10 gal removed	Close
MW-RS7	8/19/2002	859.2	861.72	12.5	Stick-up	UK	5	2	0.010	846.7–854.2	846.7–854.2	854.2–855.7	Silty Clay & Sand	NI (> 10)	Slow Recharge[d]	Manual bailing, 4 gal removed (dry)	No
MW-RS8	8/21/2002	864	866.93	15.7	Stick-up	Yes	10	2	0.010	848.3–858.3	848.3–860.1	860.1–861.1	Silty Clay & Sand	> 9	UK	Manual bailing, 12 gal removed	No

Notes:
UK = Unknown.
NI = Not Indicated.
[a] As indicated by site Army personnel (responsible for purging wells).
[b] USACHPPM 2003.
[c] SEC Donohue (1992).
[d] Well development logs (USACHPPM 2003).
bgs = below ground surface.
DU = depleted uranium.
MSL = mean sea level.
MW = monitoring well.
WBZ = water-bearing zone.

QUESTION 4 – GROUNDWATER AND SURFACE WATER RELATIONSHIPS

The Army should provide additional information on the relationship between stream flow in Big and Middle Fork Creeks, and DU concentrations in surface water and stream sediments. The Army should describe how DU concentration in the surface water and stream sediments vary during high, average and low stream flow conditions. The Army should also state if its corrective measures first proposed in 1984, to be taken if the surface water action level is exceeded, are still current.

BASIS

The DU concentration in the surface water and sediments may vary depending on the flow rate in Big and Middle Fork Creeks. Without flow rate data for the streams, the current surface water and sediment data is of limited use. Relating the DU concentrations in surface water and sediments to stream flow will help in the construction of the site conceptual model (see QUESTION 1). Corrective measures if the action level is exceeded in groundwater were first proposed in 1984 (Abbott et al., 1984): "If DU migration is detected within the primary environmental impact area, specific control measures will be taken for isolation and removal with decontamination of the primary area with monitoring and additional protective measures taken for the secondary environmental impact area." For surface water, the control measures listed are silt traps and settling basins.

REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana*. Miamisburg, OH, Monsanto Research Corporation.

RESPONSE

Monitoring of flow conditions at Big Creek and Middle Fork Creek has not been completed as part of the depleted uranium (DU) monitoring program or other monitoring programs (U.S. Army 2000 and USGS 2004). There are no known, established stream-flow monitoring locations present on either Big Creek or the Middle Fork Creek (USGS 2004). A discussion of surface water hydrology at Jefferson Proving Ground (JPG) presented in the *Final Phase II Remedial Investigation* (MWH 2002) focuses mainly on the area south of the firing line. The report does indicate that Middle Fork Creek has an approximate average flow of 50 cubic feet per second (cfs). Big Creek is much larger than Middle Fork Creek and includes a much larger surface water drainage basin. Harberts Creek, south of the firing line, is identified as having a gauging station approximately 3 miles downstream of JPG and is the only stream with an established flow monitoring location. Middle Fork is noted as being incised, and the incision is deep enough that groundwater intercepts the creek at some locations. Middle Fork Creek is anticipated to be both a losing and a gaining stream, depending on the depth of incision and the elevation of groundwater and season. Three spring locations were identified in the Range Study (U.S. Army 2003) and during the sampling conducted as part of the study; two of the spring locations were dry due to drought conditions. The third spring had very low flow and was gauged at approximately 1/10th of a gallon per minute (gpm).

No flow data have been collected from the streams during sediment sampling. Furthermore, flows during the sampling are unknown. There has been no coordination of past sediment sampling activities with high, average, and low stream flow conditions. Without flow data from the streams and possibly from

each sediment sampling location, an analysis of the relationship and variability of the DU concentrations in the surface water and stream sediments cannot be completed.

Stream, cave, and spring flows have not been measured within the monitored DU Impact Area. Groundwater elevation measurements have been collected routinely from the DU monitoring program wells as part of the ongoing monitoring program (U.S. Army 2000). The relationships between groundwater elevations and flows from streams, caves, and springs cannot be evaluated without comprehensive flow data from the streams, springs, and caves in conjunction with groundwater elevations.

The question of whether the corrective measures first proposed in Abbott et al. (1984) are still current is answered in the response to Question 6. Specifically, with respect to surface water and this question, the control measures cited in the recommendations (Section 5.6.1) [i.e., silt traps in affected creeks and settling basins] are not explicitly called out in the Army's current program (U.S. Army 2000), although such measures are among the suite of alternatives that would be evaluated in the event DU action levels are exceeded.

REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana.* Miamisburg, OH, Monsanto Research Corporation.

MWH (Montgomery Watson Harza). 2002. *Final Phase II Remedial Investigation, Jefferson Proving Ground, Madison Indiana.* Contract No. DACW27-97-D-0015, Task Order 4008. September.

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U.S. Army. 2000. *Standard Operating Procedure – Depleted Uranium Sampling Program, Environmental Radiation Monitoring Program, Jefferson Proving Ground, Madison, Indiana,* Soldier Biological Chemical Command, OHP 40-2, March 10.

USGS (U.S. Geological Survey). 2004. Streamflow Information. Email correspondence between Paul Buska (USGS) and Paul Cloud (U.S. Army). June 8.

QUESTION 5 – PENETRATOR DISSOLUTION RATE AND DU SOLUBILITY

The Army should provide additional information on the rate of dissolution of the penetrators. The Army should also provide data on the solubility of DU.

BASIS

The Decommissioning Plan submitted by the Army in 2002 stated that the rate of dissolution of the penetrators was unknown. However, in a report by the Royal Society in 2002, the authors state: 'Much of our knowledge of the environmental behavior of DU introduced into the environment comes from studies at sites where DU munitions were tested. For example, a series of experiments and geochemical modeling were used to determine the corrosion rates, solubility, and sorption of DU in soil at the Aberdeen Proving Ground in Maryland and the Yuma Proving Ground In Arizona. Results from these studies, and from studies performed in the UK at Kirkcudbright, indicate that corrosion rates are highly variable and that under conditions that favour corrosion a 1 cm diameter by 15 cm long penetrator would release approximately 90g of DU per year. For a larger projectile, such as 120 mm round (3 cm by 32 cm penetrator), this equates to a release of approximately 500 g of DU per year. Based on this corrosion rates, the Penetrators will only remain as metallic DU for between five and ten years."

The concern is that since it has been roughly ten years since the last penetrator was fired into the DU Area, a "slug" of DU has or will enter the environment and be transported into surface waters or groundwaters. The Royal Society report goes on to state: "Projections of exposure over the next 1000 years at these sites (Jefferson Proving Ground) (Ebinger et al, 1996; Ebinger and Oxenburg 1997) indicated a gradual decline of the importance of contaminated dust, and a gradual increase in groundwater contamination over the next 1000 years, before reach a steady state concentration between 100 and 1000 years. Obviously such rates are extremely dependent on the exact mineralogy, local soil type, and water conditions. The calculated level of risk was extremely sensitive to the solubility of the uranium and it was recommended by the authors that these parameters must not be overlooked when assessing potential risks associated with exposures to uranium or DU from the environment."

REFERENCES

The Royal Society, 2002. The Health Hazards of Depleted Uranium Munitions Part II.

RESPONSE

A large body of literature exists addressing the dissolution and corrosion of depleted uranium (DU) munitions, but it is important to clarify that actual dissolution rates are site-specific. Therefore, the actual dissolution rates for penetrators at Jefferson Proving Ground (JPG) are unknown. This literature, over the past few decades, has studied related phenomena through laboratory studies, field programs, and modeling approaches (e.g., AEPI 1995; Ebinger et al. 1990; ENREZA 1995; Ministry of Defense 2002; PNL 1990; The Royal Society 2002; Trzaskoma 1981 and 1982; United Nations 2003; QinetiQ 2002; Weirick and Douglas 1976). Information from these studies, combined with site-specific information, could be used to predict dissolution rates for penetrators at JPG with some level of confidence.

The responses provided herein are directed at providing direct responses to the Nuclear Regulatory Commission's (NRC's) questions and are based on a limited review of the open literature that was readily accessible. A more rigorous review would require detailed examination of the basis and assumptions of the field, analytical, or modeling exercise. For instance, in a field situation, the composition of the munitions, use conditions (e.g., soft or hard targets, etc.), impact phenomena, location of the penetrator (surface versus subsurface), site-specific geologic and hydrogeologic conditions, and weather, among other factors, would need to be assessed to determine the relevance of stated results to JPG with a high degree of confidence. The values provided for DU dissolution and solubility in **Tables 5-1 and 5-2**, respectively, are based on a review of the tabular references only.

Introduction

Dissolution rate is a key concept to understanding the potential impacts of DU penetrators on human health and the environment at JPG. DU is in the metallic form, which does not dissolve in water. However, corrosion products from DU penetrators produced through natural weathering processes can create different uranium species that can dissolve in water. The compounds that are soluble in water can transport through the environment and, thus, are a potential concern. Therefore, this response addresses corrosion of metallic DU and dissolution of the corrosion by-products.

Corrosion is an electro-chemical process that destroys the structures of materials. Typically corrosion occurs in metals, but other materials will also corrode. Electrochemical reactions occur in solutions such as those used to rust-proof nails (often referred to as "anodized" or "galvanized" nails for this reason). Since a thin film of condensed moisture often covers surfaces of materials exposed to weather, corrosion also is thought to occur in the atmosphere or in water-containing soils. The simplest example of atmospheric corrosion is the rusting of iron in air during which iron is spontaneously oxidized by the oxygen in air to iron oxides.

In electro-chemical processes occurring on DU penetrators, metallic or DU in solution acts as a short-circuited galvanic cell in which different areas of the metallic surface act as the anode and other areas act as the cathode. At anodic areas metallic uranium is oxidized to an oxide (typically uraninite [UO_2], Erikson 1990), while at cathodic areas the dissolved oxygen is reduced. Although corrosion products are typically oxides, other products (e.g., sulfides) can also form depending on the other metals and nutrients present in the environment.

The rate of corrosion and the factors that alter that rate include time, particle size, pH, Eh, temperature, and the nature of other metals and nutrients present in solution. The DU in DU penetrators is alloyed with small amounts of titanium, which significantly reduces corrosion and oxidation, thereby slowing the release and transport of soluble DU into and through the environment.

The solubilities of corrosion products vary depending on environmental conditions such as temperature, pH, Eh, and the presence of complexing ligands such as OH^-, Cl^-, CO_3^{2-}, PO_4^{3-}, F^-, $H_4SiO_4^0$, SO_4^{2-}, and soil organic acids (Erikson 1990). The following is required as a minimum for DU transport to occur in natural air-soil-water systems:

1. oxidation of the metal;
2. transfer of the oxidation products to adjacent soils, pore water, surface water, etc.;
3. dissolution of the oxidation products;
4. complexation of the oxidation products; and
5. transport of the dissolved or complexed oxidation products.

The following sections describe information about corrosion of DU penetrators and solubility/dissolution rates of corrosion products.

Rate of Penetrator Dissolution Through Corrosion

Overview. Metallic uranium in DU penetrators does not dissolve in natural air-soil-water systems under typical environmental conditions. Instead, DU penetrators are subject to corrosion processes that create uranium oxides and other uranium complexes that can dissolve in water. This section focuses on the first of a two-part dissolution process due to corrosion.

Corrosion of DU has been studied by various authors (Erikson 1990, QinetiQ Ltd., 2002, Trzaskoma 1981, Trzaskoma 1982, Epresa Nacional de Residuos Radiactivas, S.A. 1995). These authors conclude that corrosion and dissolution of the corrosion by-products depends primarily on the environmental conditions to which they are subject (groundwater chemistry, soil matrix composition, etc.), physical form of the alloy, and the available surface area of the particles. The authors of these various studies also concluded that predominant corrosion product is produced by oxidation to the hexavalent uranium species, U(VI), which commonly exists as UO_2^{+2}. While other species are produced, such as tetravalent, pentavalent, and trivalent uranium, they are less common and can be found only under particular chemical conditions. For example, tetravalent uranium is found in wet, reducing soils (Chen and Yiacoumi 2002).

The authors recognized the differences in solubility depending on the surrounding environmental conditions. Most studies were conducted under conditions of submersion in water or salt water; immersion in foggy air, salt-water foggy air, and dry air; and immersion in soil. These authors used various techniques for determining corrosion rates ranging from simple measurements of changes in mass to more detailed studies that involved advanced metallurgic techniques such as optical microscopy, scanning electron microscopy, energy dispersive X-ray analysis, and X-ray diffraction.

The surface area of the DU fragment and the oxidizing conditions will affect the rate of corrosion. The surface area to volume ratio increases as the size of the fragment decreases. For instance, the DU round that released 90 g of DU/year at Kircudbright referenced in the Royal Society report (1 cm by 15 cm) had a surface area to volume ratio of approximately 4.13/cm and a mass loss of 40% (Royal Society 2002).[1] The second DU round referenced in the report (3 cm by 32 cm) was estimated to lose 500 g/year. Although 500 g is much larger than 90 g, this value is only 14% of the original mass of the larger round, which has a surface area to volume ratio of 1.39/cm.[2] A 105-mm DU round that breaks up into several smaller fragments will oxidize (corrode) faster under oxidizing conditions than an intact round because the round now has a larger surface area that is available for exposure to corrosion. For example, if a 4-cm round is broken into two or four sections, the volume remains the same, but the surface area increases because there are more surfaces as depicted by Figure 5-1. It is important to note that the majority of the rounds fired at JPG were intact on impact; therefore, the corrosion rates would be much slower based on the surface area of the penetrator.

Published Data. **Table 5-1** presents the results of a literature search of various studies, which identify conditions similar to those at the JPG.

[1] The surface area and volume were calculated by using the dimensions of the DU rounds provided in the report and the density of DU, 18.90 g/cm^3.
[2] Same as note #1.

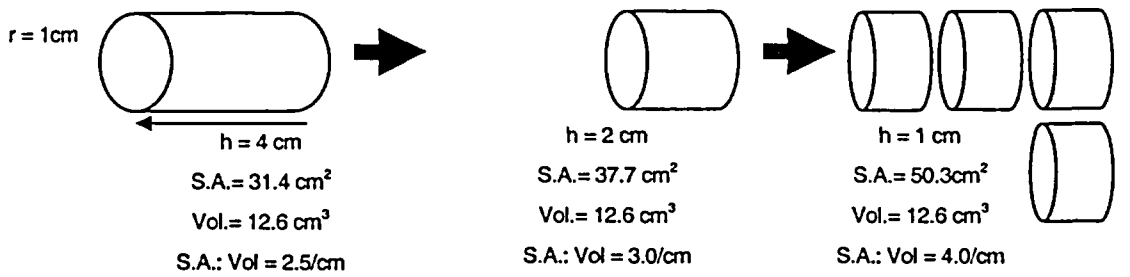


Figure 5-1. Surface Area-to-Volume Relationship as a Function of DO Penetrator/Fragment Size

Table 5-1. Corrosion Rates of Penetrators

Conditions	Rate	Author/Reference	Comment/Rationale
DU-Ti-H_2O	0.0011 mg/m^{2}d	Trzaskmo (1982)	This value was included as potential baseline for alloy exposed to water.
DU-Ti-3.5% NaCl	0.0063 mg/m^{2}d	Trzaskmo (1982)	
DU-Ti-5% NaCl, 5 days	0.023 mg/m^{2}d	McIntyre et al. 1988	
DU-Ti	0.0069 mg/m^{2}d	Winkel and Childs (1983)	
DU-Ti-soil	0.015–0.030 mg/m^{2}d	AEPI (1995)	This value was included because the soils had elevated presence of carbonate minerals and this is the most similar to the site conditions (presence of carbonates in limestones and dolomites).
DU-Ti-50 mg/L NaCl	0.00060 mg/m^{2}d	Weirick and Douglas (1976)	
DU-Ti-moist air (110% humidity)	0.0001 mg/m^{2}d	Weirick and Douglas (1976)	This value was included because of the potential similarities with site conditions (humidity and potential exposure to air in some cases).
DU-Ti-Kirkcudbright soil, up to 18-month exposure	0.0751 mg/m^{2}d	Catherine Toque, DSTL, Personal Communication	Sixty percent (60%) weight loss for a 275-g billet. Difficult to estimate rate given severe weight loss.
DU-Ti-Eskmeals soil, up to 18-month exposure	0.0039 mg/m^{2}d	Catherine Toque, DSTL, Personal Communication	Three percent (3%) weight loss for a 275-g billet. Difficult to estimate rate given severe weight loss.
UO_2 (100–300 μm)	0.60–0.0043 mg/m^{2}d (initial rate–final rate)	ENREZA 1995	This value was included as the study conditions may represent the site conditions: pH = 8, pO_2 = 5% and 0.01M $NaClO_4$. These values are results of batch tests.
UO_2 (900–1,100 μm)	0.64–0.0028 mg/m^{2}d (initial rate–final rate)	ENREZA 1995	This value was included as the study conditions may represent the site conditions: pH = 8, pO_2 = 5% and 0.01M $NaClO_4$. These values are results of batch tests.
UO_2 (pellet)	0.45–0.0048 mg/m^{2}d (initial rate–final rate)	ENREZA 1995	This value was included as the study conditions may represent the site conditions: pH = 8, pO_2 = 5% and 0.01M $NaClO_4$. These values are results of batch tests.

The corrosion rates presented in ENREZA (1995) vary substantially because they include initial corrosion rates as well as final ones. These data indicate that the rate of corrosion varies by two orders of magnitude between initial and final corrosion. Therefore, corrosion rates also vary with respect to time (i.e., in addition to environmental conditions, physical form of the alloy, and available surface area).

Recommendations. Ideally, the recommended corrosion rate would consider all the factors that influence it: environmental conditions, physical form of the alloy, available surface area, and time. However, because none of the studies include corrosion rates with respect to all variables over time, a range of corrosion rates based on the limited site-specific data and literature search suggests that the 0.0150–0.03 milligram per meter squared per day (mg/m^2d) dissolution rates of penetrators should be recommended for use at JPG. Because the characteristics of this experiment most closely represent the site conditions and the experiment included the heterogeneity of munitions that include those used at JPG: pH = 8, pO_2 = 5% and 0.01 molar (M) $NaClO_4$ [Royal Society 2002. *The Health Hazards of Depleted Uranium*, Part II, Appendix G; Study Number 5-AEPI (1995)]. The Army will continue to review and assess the relevance of these rates to JPG and will update its recommendations as new information and research becomes available.

Solubility of DU

Overview. Solubility is the maximum mass of uranium (solute) that can be dissolved in a particular volume of water (solvent). Solubility is a major concern because dissolved uranium is more readily transportable through the environment and through the human body via the bloodstream. When the rate that a solute dissolves into a solvent equals the rate that solids precipitate from the solvent, the solution is at equilibrium. According to the Le Chatelier's Principle, a system in equilibrium responds to any stress by restoring the equilibrium. In the case of uranium at JPG, the "stress" on solubility could be temperature, pressure, or the presence of other ions, and changes to these stresses could enhance solubility or facilitate precipitation of solids from solution.

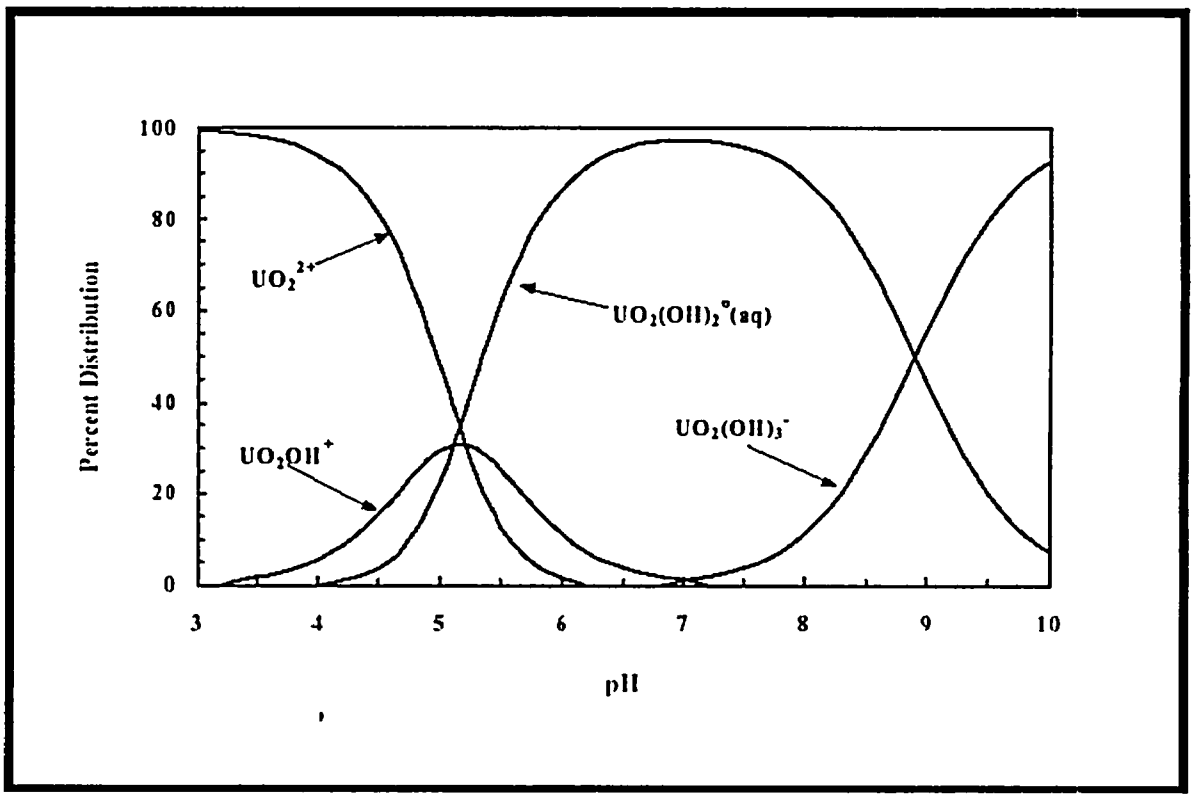
In addition to solubility, other geochemical factors control the transport of uranium in natural air-soil-water systems, including aqueous speciation, reduction-oxidation (redox), complexation, ion-exchange, and sorption reactions. DU can form complexes with the commonly existing ions in groundwater, which retard the transport through the unsaturated soil column and through groundwater. Complexes can be formed during the adsorbed with organic matter (e.g., humic and fulvic acids) [Chopping and Shanbhag 1981].

Published Data. The solubilities of minerals depend primarily on complexing ions present, pH, redox potential (Eh), and temperature. **Table 5-2** presents the results of a literature search for the solubility of uranium under various conditions. The solubility of uranium was calculated for three conditions: (1) distilled water, (2) granitic water, and (3) brine water. The solubility using the distilled water will primarily be affected only by the pH and Eh since it does not contain any complexing ions. The granitic water was evaluated due to its low ionic strength. "The main difference is thought to be the presence of carbonate in these waters, which may influence the solubility of the elements forming aqueous complexes with this anion" (ENREZA 1995). The results of the solubility studies were included for comparison purposes although the brine conditions may not reflect the site conditions based on the known data. The brine conditions represent the influence of a medium with very high ionic strength.

Table 5-2. Solubility of Uranium Under Various Conditions

Media	Parameter	Reducing Conditions	Oxidizing Condition
Deionized Water	Solid Phase	U_4O_9	$UO_2(OH)_2$
	Complexes	$U(OH)_4$ (aq)	$(UO_2)_3(OH)^{7-}$ $(UO_2)_4(OH)^{7+}$
	Solubility (mol/kg)	6.6×10^{-10}	1.6×10^{-7}
Granitic Water	Solid Phase	UO_2	$UO_2(OH)_2$
	Complexes	$U(OH)_4$ (aq)	$UO_2(CO_3)_2^{2-}$ $UO_2(CO_3)_3^{4-}$
	Solubility (mol/kg)	1.9×10^{-7}	1.8×10^{-4}
Brine	Solid Phase	UO_2	$UO_2(OH)_2$
	Complexes	$U(OH)_4$ (aq)	$UO_2(OH)_3$
	Solubility (mol/kg)	3.5×10^{-7}	1.8×10^{-7}

The best way to ascertain the nature of precipitated (i.e., undissolved) uranium is through the use of solubility constants. Figure 5-2 (EPA 1999 from Wanner and Forest 1992) illustrates the calculated distribution of U(VI) hydrolytic species as a function of pH at 0.1 µg/L total dissolved U(VI). The species distribution is based on U(VI) dissolved in pure water (i.e., complexing ligands other than OH^- are not present) and thermodynamic data.



Source: EPA 1999.

Figure 5-2. Distributionj of U (VI) Hydrolytic Species as a Function of pH at 0.1 µg/L Total Dissolved U (V)

Recommendations. Based on limited site-specific data and literature search, the solubility product that resulted for granitic water under oxidizing conditions is recommended for use at JPG. Carbonates are available in the subsurface due to the presence of dolomites and limestones at the site. The oxidizing environment was considered due to the worse case for uranium mobilization, proximity to surface, and positive oxidation-reduction potential site-specific data (ERM, Sample Event Report 6/04, pg. 3-1). Hence, the solubility product of 43.6 mg/L is recommended for DU in the groundwater. The Army will continue to review and assess the relevance of these rates to JPG and will update its recommendations as new information and research becomes available.

Summary

The Army recognizes, as discussed in this response, that the oxidation, dissolution, and transfer of DU through the environment is a complex process, most readily understood through a systematic examination of the theoretical and experimental information in the context of actual site conditions where DU penetrators are present. The Army has concluded that the Royal Society data cited in the Request for Additional Information (RAI) are not relevant to JPG and presents its current best judgment as to the dissolution rate and solubility factors most appropriate for consideration at JPG in current and future studies. Since the penetrators at JPG were not fired at hard targets and most appear to be intact, the corrosion rate based on smaller fragment sizes in the Royal Society research (i.e., 500 g/year) does not appear to apply to the majority of penetrators at JPG. Furthermore, most visible penetrators show little evidence of the substantial corrosion suggested above, thus contradicting the statement that "penetrators will only remain as metallic DU for between five and ten years." The Army reserves the right to provide updated information on these factors as new information and research become available.

The dissolution rate of penetrators and solubility of uranium are essential to understanding the potential impacts of DU penetrators on human health and the environment at JPG. Since DU is in metallic form and it does not dissolve in water, corrosion processes must be considered when assessing risks to human health and predicting the transport of uranium the environment. The Army recommends using 0.0150–0.03 mg/m^2d dissolution rates for use at JPG. Several corrosion-related compounds are soluble in water and can transport through the environment and, thus, are a potential concern. Therefore, the Army recommends using 43.6 mg/L because it represents solubility in a similar groundwater system.

REFERENCES

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QUESTION 6 – GROUNDWATER CORRECTIVE MEASURES

The Army should state if its corrective measures first proposed in 1984, to be taken if the groundwater action level is exceeded, are still current.

BASIS

Corrective measures if the action level is exceeded in groundwater were first proposed in 1984 (Abbott et al., 1984): "If DU migration is detected within the primary environmental impact area, specific control measures will be taken for isolation and removal with decontamination of the primary environmental impact area with monitoring and additional protective measures taken for the secondary environmental impact area." For groundwater, the control measures listed are a drawdown collection program, and a in-situ containment/treatment program.

REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana.* Miamisburg, OH, Monsanto Research Corporation.

RESPONSE

The Army's Environmental Monitoring (ERM) Program for groundwater in 1984 required sampling of eight monitoring wells bi-annually. The plan established an action plan, documented in Section 1.2.2.5, if action levels for depleted uranium (DU) concentrations were exceeded. These action levels for water are restated below:

- $< 4 \times 10^{-5}$ microcuries per milliliter (μCi/mL) – No corrective action.
- $\geq 4 \times 10^{-5} - 1 \times 10^{-3}$ μCi/mL – Corrective action based on limited usage.
- $> 1 \times 10^{-3}$ μCi/mL – Decontaminate to acceptable levels.

This section further states that if any action levels are exceeded, the findings would be assessed and recommendations provided on corrective actions.

Abbott et al. (1984) further states in Section 1.2.4, as noted above, "If DU migration is detected within the primary environmental impact area, specific control measures will be taken for isolation and removal with decontamination of the primary environmental impact area with monitoring and additional protective measures taken for the secondary environmental impact area." This discussion was intended to provide additional clarification on possible actions that might be taken if action levels were exceeded, or in this instance, if DU contamination was determined to be migrating. Therefore, this presentation was for illustrative purposes only and was not intended to be used as a prescribed protocol for responding if an action level were exceeded.

Since the ERM Program was first defined in 1984, the Army has modified its monitoring plan through license amendments to accommodate changes in the action levels; response procedures and rationale; and the number, type, and location of samples. Throughout this process, the Army has maintained its goal of ensuring protection of human health and the environment through its monitoring program. Consequently, the Army has retained, throughout its 20-year monitoring program, the basic philosophy of monitoring

the environment and providing general protocol to respond to events where DU contamination might be present. This program has included bi-annual multimedia sampling, predefined action levels and associated rationale, and follow-on actions (e.g., confirmatory sampling, assessments, consultations and notifications, and implementation of appropriate controls and/or remedial actions) to address situations where action levels are exceeded.

Consistent with the criteria and procedures outlined in the current program, *Standard Operating Procedure, Depleted Uranium Sampling Program, JPG, Indiana* (USACHPPM 2000), the Army would, in the event an action level were exceeded, make appropriate notifications and complete confirmatory sampling. Further actions, such as conduct of additional investigations, implementation of control measures, or decontamination, would be defined based on the results of the additional sampling and assessment of the magnitude and extent of potential impacts from the event. The control measures cited in the recommendations (Section 5.6.1) [i.e., drawdown collection program and in situ containment/treatment program] are not explicitly called out in the Army's current program, although such measures are among the suite of alternatives that would be evaluated in the event DU action levels are exceeded.

RESPONSE REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana.* Miamisburg, OH, Monsanto Research Corporation.

U.S. Army. 2000. Standard Operating Procedure (SOP). *Depleted Uranium Sampling Program, JPG, Indiana.* SOP No. OHP 40-2. U.S. Army Center for Health Promotion and Preventative Medicine (CHPPM). March 10.

QUESTION 7 – URANIUM CONCENTRATIONS IN DEER

The Army should provide additional information on the apparent trend of increasing uranium concentration in deer kidneys and bone, and how this relates to the potential for DU in deer meat that is consumed by humans.

BASIS

A detailed characterization survey was conducted for the Army in 1996 (Scientific Ecology Group, Inc., 1996). Deer showed a modest increase from background uranium concentrations in kidneys (from 0.05 to 0.151 pCi/g) and a larger increase from background in bone (from 0.0003 to 0.416 pCi/g). From the perspective of human health protection, the levels of uranium in deer remain low. However, it is not clear if the concentration of uranium in deer kidneys and bone will continue to increase and potentially be of concern to human health from the consumption of contaminated deer meat.

REFERENCES

Scientific Ecology Group, Inc. 1996. *Jefferson Proving Ground Depleted Uranium Impact Area: Characterization Survey Report.* Volume 1, Revision 0. Oak Ridge, TN.

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground*, Indiana. Miamisburg, OH, Monsanto Research Corporation.

RESPONSE

Based on available deer sampling data, there is no apparent increasing or decreasing trend in uranium activities in various deer tissue samples collected at Jefferson Proving Ground (JPG) and, because sampling is limited to tissues that accumulate uranium (i.e., bone, kidney, and liver), it is not possible to predict concentrations in deer tissue that is most often consumed by people in largest quantities (i.e., muscle). As listed in **Table 7-1** below, organ and tissue samples were collected and analyzed for activities of different uranium isotopes from 38 deer sampled at JPG between 1984 and 1996:

Table 7-1. Deer Sampling by Year at JPG

Year	Numbers of Deer	Samples
1984	9	Liver, kidney, and bone
1984	4	Unspecified location or body part
1987	16	Bone, kidney, and liver
1992	3	Kidney, liver
1993	5	Kidney[a]
1996	1	Liver, kidney, and bone
Total	**38**	

[a]Organ is assumed to be kidney in Ebinger and Hansen 1996.
JPG = Jefferson Proving Ground.

Generally, the activities for individual isotopes and organ samples ranged from nondetect to 0.221 picocuries per gram (pCi/g) [U-234 in bone collected in 1996]. Unfortunately, most reports do not indicate where deer were harvested. Also, it does not appear that any control samples were collected from deer nearby that are not exposed to the depleted uranium (DU) at JPG to infer the contribution of uranium body burdens that are attributable to the DU rounds at JPG versus contributions from background. In addition, the uranium activities could not always be attributed unambiguously to DU or natural uranium because U-235 activities were often below detection limits (Ebinger and Hansen 1996).

Furthermore, the sampling data referenced by the reviewer (Scientific Ecology Group, Inc., 1996) actually represent samples of liver, kidney, and bone harvested from a single 4- to 5-year-old female deer killed in the impact area. Although the samples collected from this single deer specimen appear higher than other samples collected from deer prior to that time, total uranium activities are low and do not indicate an impact from DU (U.S. Army 2002).

Even if there is an increasing trend of uranium concentrations in kidneys and bone, a similar trend may not be exhibited in muscle as uranium tends to preferentially concentrate in kidney and bone, rather than muscle tissues. However, there are no JPG sampling data of deer muscle tissue to support conclusions regarding activities of uranium in the primary meat that is consumed by humans. Abbott et al. (1984) explain why samples from livers, kidneys, and bones were collected, as follows: "Although these tissues are not ordinarily consumed by man, and thus would not be in a direct pathway to man, they were chosen for analysis because they tend to concentrate uranium and are easier to procure from hunters than muscle tissue (meat)."

Although muscle tissue samples were not collected, data from liver, kidney, and bone tissue samples may be used to support inferences about levels expected in deer muscle. **Table 7-2** was developed based on results presented in Ebinger and Hansen (1996). It presents sampling and modeling data for different organs and tissues collected from deer harvested from Aberdeen Proving Ground.

Table 7-2. On-site and Off-site Deer Sampling Data for Aberdeen Proving Ground, Maryland

Tissue	Average Activity (pCi/g)	Median Activity (pCi/g)	Percent of Total (Average)	Percent of Total (Median)
Impact Area				
Kidney	4.3E-04	2.6E-04	12%	10%
Liver	2.1E-04	1.3E-04	6%	5%
Muscle	2.6E-04	2.0E-04	7%	8%
Bone	2.7E-03	2.0E-03	75%	77%
Total	3.6E-03	2.6E-03		
Off-Site				
Kidney	1.3E-04	1.8E-04	13%	20%
Liver	4.0E-04	4.0E-04	41%	43%
Muscle	1.0E-04	ND	10%	ND
Bone	3.4E-04	3.4E-04	35%	37%
Total	**9.7E-04**	**9.2E-04**		

ND = Nondetect.
pCi/g = picocuries per gram.

From the table above, uranium activities in muscle generally represent a lower proportion of activities than those measured in other tissues (particularly bone, which is presumably not typically ingested by humans). In addition to the lower activities expected in muscle tissue, humans are more likely to consume larger quantities of muscle tissue because the relative mass is much greater than the masses of kidney and liver tissues. Therefore, overall risks to humans consuming muscle tissue are believed to be less than risks associated with consuming kidneys and livers.

REFERENCES

Abbott, D., T. Gates, and A. Hale. 1984. *Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground*, Indiana. Miamisburg, OH, Monsanto Research Corporation.

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COVER LETTER COMMENT ON GROUNDWATER ACTION LEVEL

The staff has discussed the groundwater action level proposed in Section 3.3.1.2 of the ERM with the Army and the Army has indicated that the action level for depleted uranium (DU) in groundwater in the impact area should be changed. Please include this modification to the action level with your response to the requests for additional information.

RESPONSE

The Environmental Radiation Monitoring (ERM) Program Plan (U.S. Army 2003) proposed an action level for depleted uranium (DU) at 50% [15 picocuries per liter (pCi/L)] of the U.S. Environmental Protection Agency's (EPA's) National Primary Drinking Water Standard limit of 30 pCi/L. Upon reevaluation of the potential applicable regulatory standards, the Army has determined that the standards and action levels presented in the Standard Operating Procedure (SOP) [U.S. Army 2000] are relevant and appropriate. Therefore, the Army proposes use of the latter standards in lieu of the action level based on the EPA Drinking Water Standard.

The Nuclear Regulatory Commission (NRC) is the lead regulatory agency for the conditions at Jefferson Proving Ground (JPG) under NRC Radioactive Materials License SUB-1435. Therefore, NRC's standards were reviewed to determine whether or not they were applicable, relevant or appropriate for the conditions present at JPG.

The NRC limit for effluent concentrations of uranium (natural) in water is 3.0×10^{-7} microcuries per milliliter (μCi/mL) or 300 pCi/L [*Code of Federal Regulations* (*CFR*) 2004]. This limit considers the potential dose to members of the general public located off-site, and is equivalent to 50 millirem per year (mrem/yr) using conservative assumptions. This NRC limit is for active licenses and is not intended to be used for the purposes of facility decommissioning.

For facility decommissioning, the NRC (NRC 1983) may apply EPA's National Primary Drinking Water Standards (EPA 2004) for public drinking water, on a case-by-case basis, to the cleanup and decommissioning of contaminated sites to ensure adequate protection of groundwater.

For JPG, the EPA standards are not relevant or appropriate for groundwater under current circumstances given that:

1. site cleanup and decommissioning are not planned presently for the DU Impact Area, and
2. the groundwater is not a current or potential source of drinking water.[1]

The SOP (U.S. Army 2000) for DU sampling at JPG specifies an action level of 1.5×10^{-1} pCi/mL (150 pCi/L) for total uranium in water. This value is one-half of the NRC's limit for effluent concentrations in water of 3.0×10^{-7} μCi/mL (*CFR* 2004). Use of an action level of 150 pCi/L for groundwater, therefore, has a sound regulatory basis under the current JPG license conditions and should be used in the ERM Program Plan when it is revised.

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[1] There are no sole source aquifers on, or in the vicinity of, JPG based on a review of EPA Region 5's sole source aquifer designations. 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 miles (8 km) from JPG.

REFERENCES

CFR (Code of Federal Regulation). 2004. *10 CFR Part 20, Appendix B, Table 2, Column 2. Effluent Concentrations for Water.* U.S. Nuclear Regulatory Commission, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 2001. *Use of Uranium Drinking Water Standards -Under 40 CFR 141 and 40 CFR 192 and Remediation Goals for Groundwater at CERCLA Sites.* Directive No. 9283.1-14, U.S. Environmental Protection Agency, Washington, D.C., November 6.

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