EXECUTIVE SUMMARY

1.0 Purpose

The Department of Defense (DOD) Office of the Special Assistant for Gulf War Illnesses (OSAGWI), now known as the Office of the Special Assistant to the Secretary of Defense for Gulf War Illnesses, Medical Readiness and Military Deployments, directed the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) to conduct a human exposure assessment and health risk characterization for military personnel potentially exposed to depleted uranium (DU) during service in Southwest Asia (see Memorandum, OSAGWI, 30 January 1998, subject: *Request for Assistance with Depleted Uranium (DU) Risk Assessment*).

In response to this tasking, this report provides the following:

- A review and evaluation of the existing DU munition test data.
- Identification of data gaps.
- Assessments of human exposures and qualitative health risk characterizations for each of the three OSAGWI DU exposure levels.
- Recommendations to fill data gaps by conducting further testing that will allow better health risk estimates.

2.0 Scope

This report is an assessment of the potential exposures to personnel and the intake of DU in each of the three exposure levels established by OSAGWI and is a qualitative characterization of human health risk. A qualitative health risk characterization is one that compares the estimated exposures to established benchmarks. For the purposes of this report, a series of conservative assumptions were used to fill data gaps. The reasonable upper-bound dose resulting from this process was compared to accepted chemical and radiation dose benchmarks. This upper-bound exposure and intake of DU is based on a single DU munition perforation of an Abrams tank with a 2-minute exposure duration. (See Section 4.0 of the Executive Summary.) The scaling factor for 2 perforations would be 1.5 to 3 times greater. (See Section 5.0 of the Executive Summary.)

The radiation dose benchmarks chosen for this report are the doses for occupational exposures [established by the Nuclear Regulatory Commission (NRC) and the Occupational Safety and Health Administration (OSHA)] in peacetime environments. The chemical dose benchmarks chosen for this report are for occupational and for general public exposures [established by American Conference of Governmental Industrial Hygienists (ACGIH) and Department of Energy (DOE)].

This report does not provide a dose reconstruction for individuals nor is it a retrospective human health risk assessment. Data are not robust enough to allow these types of assessments. Data are sufficient to allow a characterization of the human health risk for groups of individuals with similar exposure scenarios.

This assessment focuses on inhalation and ingestion intakes of DU. This exposure and intake assessment excludes personnel with embedded fragments and wound contamination because methods for assessing intake from these routes of exposure are not available at this time. It should be noted that the National Council on Radiation Protection and Measurements (NCRP) is in the process of developing these methods. In addition, estimates of dose for personnel with embedded fragments can be found in McDiarmid et al., (1999), Hooper et al., (1999), Ejnik et al., (2000), and McDiarmid et al., (2000).

3.0 Background

The OSAGWI has prepared an interim Environmental Exposure Report that examines three levels of potential exposure to DU that occurred during and after the Gulf War; the report incorporates thirteen exposure scenarios (see OSAGWI, 1998).

- Level I soldiers were those in, on or near combat vehicles at the time such vehicles were perforated by DU munitions; they were also soldiers (First Responders) who entered U.S. vehicles immediately after fratricide incidents to rescue occupants. These individuals were potentially exposed to airborne and deposited DU and subsequently inhaled DU aerosols or ingested DU residue generated by the impact of the DU round perforating the target.
- Level II individuals were those who worked in and on potentially DU-contaminated vehicles (mostly after fratricide incidents). Level II also included personnel who took part in the cleanup operations of DU contamination from the motor pool pads of Camp Doha, Kuwait

(see Appendix C). This level also included personnel whose maintenance or salvage duties required them to frequently enter and exit, or spend extended periods of time working in or on potentially DU-contaminated vehicles.

- Level III comprised "all others." It included personnel who were downwind of burning DU-contaminated equipment, who were potentially exposed to smoke or resuspended particles from oxidized DU, and who entered DU-contaminated Iraqi equipment. It also included personnel who were present at Camp Doha during and after the motor pool fire but who did not take part in cleanup operations in the North Compound. Part I, Section 1.7 provides a more in depth explanation of OSAGWI's three scenario levels.

Beginning in the 1970s and through the 1990s, many DU-weapons performance tests were conducted by the U.S. Army Materiel Command and its contractors. Because of DU's high density, it has been used in armor to increase resistance to enemy projectiles and in munitions to increase penetrating power.

The favorable characteristics of DU as a munition are its density, adiabatic shearing (self-sharpening) and pyrophoric nature. The density of DU is about 1.7 times the density of lead [18.95 grams per cubic centimeter (g/cm^3) compared to 11.35 g/cm^3]. Also, it has a self-sharpening or adiabatic shearing characteristic when used as a munition against hard targets, such as tank armor. This means that as the DU penetrator perforates a hard target, it self-sharpens, flaking off particles that may burn (oxidize) if sufficient oxygen is present. Softer targets include items such as the light armor on Bradley Fighting Vehicles. DU's pyrophoric nature, as well as the heat generated upon perforation of a target, may ignite fuel, ammunition or other combustible material in the vehicle.

Although testing during the development of these applications focused on military performance only, these tests could yield possible data to evaluate potential health hazards from the battlefield use of DU munitions and armor. The data from these tests were evaluated to estimate the DU intakes and the resultant chemical exposures and radiation doses that may have been received by personnel in, on or near potentially contaminated vehicles as a result of a DU perforation or fire.

These data came from tests performed primarily for evaluating the effectiveness of DU munitions under particular test conditions, not for estimating DU aerosol generation and environmental transport under probable battlefield conditions.

In the scenarios considered in this report, inhalation and ingestion are the major routes of entry into the body. For DU to be inhaled, the particles must be airborne and of an appropriate size. Secondary ingestion occurs primarily from the hand-to-mouth transfer of DU. Once DU particles are deposited either in the vehicle or in the environment, they may again become resuspended into the air and be inhaled and ingested. Resuspension may be caused by various mechanisms, both natural and man-made.

4.0 Methodology

The methodology used in this report was to review DU test data literature for information relating to the input parameters for human health characterizations. Information concerning soldier activities during the Gulf War was obtained from a review of the interviews conducted by OSAGWI with Gulf War veterans.

The test data reviews showed that data gaps existed. When this occurred, conservative assumptions were made to allow the process to continue. The reasonableness of the final result was determined by comparing estimated intakes to available measurements of DU in Gulf War veterans made by the Department of Veterans Affairs (VA), McDiarmid et al., (1999); Hooper et al., (1999); Ejnik et al., (2000); and McDiarmid et al., (2000).

Standard models established by the International Commission on Radiological Protection (ICRP), along with validated computer models, were used to estimate DU airborne concentrations, intakes, and doses. The inputs to these models included existing data or conservative assumptions based upon other data and professional judgment.

The differences in the nature of the exposures between Level I and Levels II and III and the quality of the data were significant. The primary difference between these levels is the source of the intake. Level I has two populations: the first is those personnel who were in, on, or near combat vehicles at the time of perforation, and the second being First Responders. The first group was exposed to the DU generated by the perforation and suspended DU. The First

Responders were exposed to the residual airborne concentration from the perforation(s) and resuspension of DU contamination. Levels II and III personnel were exposed to resuspended DU or DU entrained from smoke from fires containing DU munitions. All three groups were subjected to ingestion via the same mechanisms.

A review of the technical literature showed that Fliszar et al., (1989) was the best data to use in estimating the Levels I, II, and III exposures. The Fliszar data were robust enough to allow the development of best-estimates for Levels II and III. The test data had limitations that precluded the development of a single best-estimate of an exposure for Level I. In this case, a range of upper-bound values was developed using probabilistic analysis techniques.

Level I Methodology. The results of air sampler data in Test 5A from Fliszar et al., (1989) were used to estimate upper-bound intakes for Level I individuals. The U.S. General Accounting Office review of the August 1998 version of the USACHPPM interim report brought to the surface a controversy over the interpretation of the air-sampler run-time data (General Accounting Office, 2000). The air sampler run-time data was a key parameter in the intake estimation. (See Part IV and Appendix O for a detailed discussion of the air sample run-time controversy.)

The primary question was why, with the exception of the air-sampler located above the breech of the gun, did all of the air samplers shut off soon after perforation. This issue was not resolved at the time of Test 5A. Two explanations surfaced that resulted in two distinct air-sampler run-time estimates. The first assumed that the air sampler reported run-times were inaccurate and that all of the air samplers shut off within "moments" (1 to 2 seconds) after perforation. The second assumed that the air sampler reported run-times were accurate and that they ran for 1 to 2 minutes. Both assumptions could be supported by the data. The approach used to resolve these differences was to estimate intakes for each of the two estimated run-times. This would establish a range of upper-bound doses for Level I. The short run-time assumption (Assumption 1) would establish the upper limit of this range. The long run-time assumption (Assumption 2) would establish the lower limit of this range.

Since Assumption 1 assumed that the reported run-times were inaccurate, a method for estimating time was required. The surface contamination measurements in the vehicle were used to estimate sampler run-time. (See Part IV.)

The uncertainties associated with this overall approach were difficult to quantify. A Monte Carlo Simulation technique was used to quantify the impact of this uncertainty in Level I. (See Appendix O.) The reasonableness of the derived estimates of upper-bound doses for Level I was determined by comparing the obtained values to the results of the measurements of DU exposure in Gulf War veterans conducted by the VA.

Levels II and III Methodology. The Fliszar et al., (1989) data were robust enough to allow the development of best estimates of exposures and intakes for OSAGWI Levels II and III. Measurement data of DU airborne and soil concentrations and of residual surface contamination were of sufficient quality for estimating a range of best estimates of DU concentrations for the Levels II and III scenarios. Intake and dose estimates were made using these data as input for standard ICRP models. Additional factors such as the potential source term of DU available for internalization, routes of exposure, exposure durations, frequency of the different scenario exposures, and the individuals at risk were also applied. Results of these exposure assessments were used to characterize the chemical and radiological toxicity of DU.

Background information was obtained from the OSAGWI interviews of veterans who were present at Camp Doha during the fire and from DU fire test data. Using this information and standard atmospheric transport models, DU-intake estimates were obtained. The intakes were converted into radiation dose and chemical concentrations using standard ICRP models. (See Part V and Appendix C.)

5.0 Results

5.1 OSAGWI Level I Scenarios

The upper-bound exposure and intake of DU from inhalation and indirect ingestion for a single perforation is estimated to be 79 milligrams (mg) and the resultant radiation committed effective dose equivalent (CEDE) is 1.6 rem for a 2-minute exposure. This intake is the median value for Assumption 1.

For two perforations the intake of DU and the radiation dose (CEDE) could be 1.5 to 3 times greater as discussed in Part IV. Two perforations could result in an upper-bound intake of

118.5 mg (79 mg * 1.5) to 237 mg (79 mg * 3). The upper-bound dose for two perforations would be less than 5 rem (1.6 rem * 3), the current NRC and OSHA radiation safety standards.

The upper-bound intake of 79 mg would result in a concentration of DU in the kidney of 1.5 microgram (μg) DU/gram of kidney. This value is below the ICRP chemical toxicity guidelines of 3 μg DU/g of kidney. This guideline was established in 1959 and should be updated. Scaling for two perforations could result in an intake of 237 mg. The resulting concentration of DU in the kidney would be 4.4 μg DU/g of kidney. Although this concentration is above the guidelines of 3 μg DU/g of kidney, for the reasons outlined in Part IV, it cannot be concluded that adverse health effects will result.

The lower-bound exposure and intake estimated from inhalation and indirect ingestion for a single perforation is estimated to be 9 mg, and the resultant CEDE is 0.2 rem for a 2-minute exposure. This intake is the median value for Assumption 2.

The VA DU medical monitoring effort provides some support that our Level I estimates are upper-bound estimates of the inhalation intake for all Gulf War exposure scenarios including those with long exposure durations.

If any of the Gulf War veterans actually received an exposure equal to or greater than Assumption 1, the level of DU in the urine would be above natural levels and would be detectable using kinetic phosphorescence analysis and, more readily detectable, using inductively-coupled plasma-mass spectrometry out to almost 10 years post-exposure. The VA has been monitoring a group of Level I personnel since 1994. In McDiarmid, et al., (2000), it was reported that the results of a 1997 measurement found elevated levels of uranium only in personnel with embedded DU fragments. This work provides an indication that the estimates for inhalation exposure for all Level I personnel are in fact upper bound.

The upper-bound exposure and intake of DU from secondary ingestion (hand-to-mouth) for a single perforation is estimated to be 24 mg and the resultant radiation dose is 0.0006 rem. For two perforations the intake of DU and the radiation dose could be within a factor of 2 to 5 times greater. (See Part IV and Appendix F.) The lower-bound exposure and intake for a single perforation is estimated to be about 50 percent of the upper-bound value.

5.2 OSAGWI Level II and III Scenarios

Level II. The upper-bound exposure and intake of DU from inhalation and indirect ingestion for a single perforation is estimated to be 0.025 mg and the resultant radiation CEDE is 0.0004 rem for a 1-hour exposure in a vehicle.

For Level II personnel who may have entered vehicles perforated by two DU rounds, the secondary intake of DU and the radiation dose (CEDE) could be 2 to 5 times greater as discussed in Part V. Two perforations could result in an upper-bound intake of 0.05 mg (0.025 mg * 2) to 0.125 mg (0.025 mg * 5). The upper-bound dose for two perforations would be less than 0.1 rem (0.0004 rem * 5) which is well below the current NRC and OSHA radiation safety standards.

The upper-bound intake of 0.025 mg would result in a concentration of DU in the kidney of 0.00067 μg DU/g of kidney. This value is below the ICRP chemical toxicity guidelines of 3 μg DU/g of kidney. Scaling for two perforations will result in an intake of 0.125 mg. The resulting concentration of DU in the kidney would be 0.0035 μg DU/g of kidney. This 0.0035 μg DU/g of kidney is below the guideline of 3 μg DU/g of kidney. (See Part V.)

Level III. The upper-

Camp Doha Exposure Scenarios. The Camp Doha scenarios in Level II and Level III are addressed in Appendix C. This Pacific Northwest National Laboratory study estimated the exposures to DU for residents and recovery workers at Camp Doha, Kuwait, following the July 1991 fire. People who were exposed to airborne concentrations from the fire (Level III) were estimated to have received negligible chemical doses. The upper-bound concentration in the kidney was estimated to be 1.8×10^{-8} μg DU/g of kidney for people assembled in the United Nations Compound at the base and about 2.8×10^{-7} μg DU/g of kidney for a person who was located in the area of highest air concentration. Estimated chemical doses for recovery workers (Level II) who spent extensive time in the contaminated areas of the North Compound after the fire range from 3.3×10^{-3} μg DU/g of kidney to 9.5×10^{-2} μg DU/g of kidney, depending on which type of activity they were involved in. People exposed to airborne concentrations from the fire were estimated to have received negligible radiation doses: about 0.000000062 rem for people assembled in the United Nations Compound at the base and about 0.000003 rem for a person who may have been located in the area of highest air concentration. Estimated doses for recovery workers who spent time in the contaminated areas of the North Compound after the fire range from 0.001 rem to 0.065 rem, depending on which type of activity they were involved. A summary of exposures, intakes, and radiation dose (CEDE) for Levels I, II, and III OSAGWI Exposure Scenarios is found in Executive Summary Tables 1 and 3. The range of DU exposures for chemical toxicity for Levels I, II, and III Exposure Scenarios is found in Executive Summary Tables 2 and 4.

The tables within this Executive Summary are meant to present a bounding of potential DU exposure for Gulf War veterans, who can then identify themselves as being included in a specific OSAGWI Gulf War scenario(s). By identifying with a particular scenario(s) (such as Explosive Ordnance Disposal (EOD) personnel), they can estimate the range in values of a potential DU intake and a characterization of health risk. This assessment may satisfy the veterans' interests or may encourage them to request further evaluation by the VA or the DOD Comprehensive Clinical Evaluation Program.

Executive Summary Table 1. Ranges of DU Intakes by Inhalation and Indirect Ingestion, Level I Scenarios

Exposure Scenario	Total Estimated DU Intake Range (mg)							Chemical Toxicity Risk

Executive Summary Table 2. Ranges of DU Exposures for Chemical Toxicity Consideration, Level I Scenarios

Exposure Scenario	Total Estimated DU Intake Range (mg) in a vehicle[1]	Calculated Kidney Concentration (mg DU/g of tissue)	Possibility Chemical Exposure Guideline Exceeded[2]	Estimated Air Concentration[3] (mg/m^3)	Possibility Chemical Exposure Guideline Exceeded[4]
Individual inside a tank at time of impact or perforation by a single DU round	9 (LB) to 79 (UB)[5]	0.2 (LB)	NO	270 to 2,400	YES
		1.5 (UB)	NO		

[1] No credit for PPE, such as respirators or military protective masks, was given for the calculations in this table.
[2] Toxicity Guideline: 3.0 µg uranium per gram (U/g) of kidney tissue is the derived guideline (Spoor and Hursh., 1973).
[3] Air concentration guidelines used for comparisons are Department of Energy (DOE) temporary emergency exposure limits (TEELs) (0.5 mg/m^3 – 10 mg/m^3) and American Conference of Governmental Industrial Hygienists short-term exposure limits (STELs) (0.60 mg/m^3) (Craig 1998 and ACGIH 2000).
[4] (UB) - Upper Bound of range is Assumption 1 median value for a single perforation; (LB) - Lower Bound of range is Assumption 2 median value for a single perforation. For two perforations, the intake and dose can be scaled to a factor of 1.5 to 3. The UB and LB are based on a 5 µm AMAD particle size distribution.
[5] Exceeding a guideline does not imply that adverse health effects will result (see Part IV).

Executive Summary Table 3. Ranges of DU Intakes by Inhalation and Indirect Ingestion, Levels II and III Scenarios

Exposure Classification: Levels and Scenarios	Total DU Intake Range (mg/hr) in a vehicle [See Note 1]	Insoluble DU Intake Range (mg/hr) in a vehicle	Radiation Dose Range (rem/hr) in a vehicle (See Note 2)	Possibility Radiation Exposure Limit Exceeded [See Note 3]	Radiation Risk	Soluble DU Intake Range (mg/hr) in a vehicle	Possibility Chemical Exposure Limit Exceeded [See Note 4]	Chemical Risk	Discussion In Sections of Part V	**Scenario Example:** Estimated Total DU Intake (mg) [See Notes 5 & 6]
Level II										
Explosive Ordnance Disposal (EOD) and other unit personnel who downloaded equipment and munitions from DU contaminated vehicles/systems	0.00078 (LB) to 0.025 (UB)	0.00065 to 0.023	0.00001 to 0.0005	No	Acceptable	0.00013 to 0.002	No	Acceptable	5.2 and 5.2.1	Appendix S
Radiation Control (RADCON) team members	0.00078 (LB) to 0.025 (UB)	0.00065 to 0.023	0.00001 to 0.0005	No	Acceptable	0.00013 to 0.002	No	Acceptable	5.2 and 5.2.2	Appendix S
Battle Damage Assessment Team (BDAT) members who examined U.S. combat vehicles damaged and destroyed by DU	0.00078 (LB) to 0.025 (UB)	0.00065 to 0.023	0.00001 to 0.0005	No	Acceptable	0.00013 to 0.002	No	Acceptable	5.2 and 5.2.3	Appendix S
Logistics Assistance Representatives (LARs) who inspected DU-contaminated vehicles/systems to determine reparability	0.00078 (LB) to 0.025 (UB)	0.00065 to 0.023	0.00001 to 0.0005	No	Acceptable	0.00013 to 0.002	No	Acceptable	5.2 and 5.2.4	Appendix S

Executive Summary Table 3. Ranges of DU Intakes by Inhalation and Indirect Ingestion, Levels II and III Scénarios (con"t)

Exposure Classification: Levels and Scenarios	Total DU Intake Range (mg/hr) in a vehicle [See Note 1]	Insoluble DU Intake Range (mg/hr) in a vehicle	Radiation Dose Range (rem/hr) in a vehicle (See Note 2)	Possibility Radiation Exposure Limit Exceeded [See Note 3]	Radiation Risk	Soluble DU Intake Range (mg/hr) in a vehicle	Possibility Chemical Exposure Limit Exceeded [See Note 4]	Chemical Risk	Discussion In Sections of Part V	**Scenario Example:** Estimated Total DU Intake (mg) [See Notes 5 & 6]
Unit maintenance personnel who performed maintenance on or in DU-contaminated vehicles/systems	0.00078 (LB) to 0.025 (UB)	0.00065 to 0.023	0.00001 to 0.0005	No	Acceptable	0.00013 to 0.002	No	Acceptable	5.2 and 5.2.5	Appendix S
144th Service and Supply Co. personnel who processed damaged equipment, including some with DU contamination	0.00078 (LB) to 0.025 (UB)	0.00065 to 0.023	0.00001 to 0.0005	No	Acceptable	0.00013 to 0.002	No	Acceptable	5.2 and 5.2.6	Appendix S
Personnel exposed to DU contamination during cleanup operations at Camp Doha's North Compound	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	5.2, 5.2.7, and App S	---
Level III										
Personnel exposed to smoke from burning DU rounds at Camp Doha	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	[See Note 7]	5.2.7 and App S	---
Personnel exposed to smoke from burning Abrams tanks	0.0000039 (LB) to 0.0028 (UB)	0.0000036 to 0.0026	0.0000001 to 0.00007	No	Acceptable	0.0000003 to 0.0002	No	Acceptable	5.2 and 5.3.1	5.2 and 5.3.1

Executive Summary Table 3. Ranges of DU Intakes by Inhalation and Indirect Ingestion, Levels II and III Scénarios (con"t)

Exposure Classification: Levels and Scenarios	Total DU Intake Range (mg/hr) in a vehicle [See Note 1]	Insoluble DU Intake Range (mg/hr) in a vehicle	Radiation Dose Range (rem/hr) in a vehicle (See Note 2)	Possibility Radiation Exposure Limit Exceeded [See Note 3]	Radiation Risk	Soluble DU Intake Range (mg/hr) in a vehicle	Possibility Chemical Exposure Limit Exceeded [See Note 4]	Chemical Risk	Discussion In Sections of Part V	**Scenario Example:** Estimated Total DU Intake (mg) [See Notes 5 & 6]
Personnel who entered DU-contaminated Iraqi vehicles/ equipment	0.00078 (LB) to 0.0057 (UB)	0.00065 to 0.0047	0.00001 to 0.0001	No	Acceptable	0.00013 to 0.001	No	Acceptable	5.2 and 5.3.2	5.2 and 5.3.2
Personnel exposed to smoke from DU-perforated Iraqi vehicles/ equipment	0.000063 (LB) to 0.0044 (UB)	0.000052 to 0.0037	0.000001 to 0.00007	No	Acceptable	0.000011 to 0.00075	No	Acceptable	5.2 and 5.3.3	5.2 and 5.3.3

Note 1. No credit for PPE, such as respirators or military protective masks, was given for the calculations in this report. UB) - Upper Bound of range; (LB) - Lower Bound of range. The UB and LB are based on a 5 µm AMAD particle size distribution.

Note 2: CEDE dose for each hour spent in the vehicle.

Note 3. Internal radiation dose is expressed in terms of CEDE which is based on a 5 µm AMAD particle size distribution. Radiation Standard: 5 rem per year (10 CFR).

Note 4. Chemical Toxicity Standard: 40 mg of soluble uranium as threshold for permanent renal damage; 8 mg of soluble uranium as threshold for transient renal injury (National Defense Research Institute, 1999, and ANSI, 1995).

Note 5. Examples developed from OSAGWI interview data (see Appendix S for dose assessments).

Note 6. Assessment of secondary ingestion (hand-to-mouth) intakes has been considered and is included in Part V.

Note 7. Analysis of Camp Doha scenarios (Level II and Level III) is provided in Appendix C.

Executive Summary Table 4. Ranges of DU Intakes by Inhalation and Indirect Ingestion and Chemical Guidelines, Levels II and III Scenarios

Exposure Classification: Levels and Scenarios	Total DU Intake Range (mg/hr) in a vehicle[1]	Calculated Kidney Concentration (µg DU/g of tissue)	Possibility Kidney Concentration Guideline Exceeded[2]	**Air Concentration** (mg/m^3)	Possibility Air Concentration Guideline Exceeded[3]	Discussion in Sections of Part V	**Scenario Example:** Estimated Total DU Intake (mg) [See Notes 5 & 6]
Explosive Ordnance Disposal (EOD) and other unit personnel who downloaded equipment and munitions from DU-contaminated vehicles/systems	0.00078 (LB)[4] to 0.025 (UB)	0.000032 to 0.00067	No	2.6 x 10^{-4} to 8.4 x 10^{-3}	No	5.2 and 5.2.1	Appendix S
Radiation Control (RADCON) Team members	0.00078 (LB) to 0.025 (UB)	0.000032 to 0.00067	No	2.6 x 10^{-4} to 8.4 x 10^{-3}	No	5.2 and 5.2.2	Appendix S
Battle Damage Assessment Team (BDAT) members who examined U.S. combat vehicles damaged and destroyed by DU	0.00078 (LB) to 0.025 (UB)	0.000032 to 0.00067	No	2.6 x 10^{-4} to 8.4 x 10^{-3}	No	5.2 and 5.2.3	Appendix S
Logistics Assistance Representatives (LARs) who inspected DU-contaminated vehicles/systems to determine reparability	0.00078 (LB) to 0.025 (UB)	0.000032 to 0.00067	No	2.6 x 10^{-4} to 8.4 x 10^{-3}	No	5.2 and 5.2.4	Appendix S
Unit maintenance personnel who performed maintenance on or in DU-contaminated vehicles/systems	0.00078 (LB) to 0.025 (UB)	0.000032 to 0.00067	No	2.6 x 10^{-4} to 8.4 x 10^{-3}	No	5.2 and 5.2.5	Appendix S

Executive Summary Table 4. Ranges of DU Intakes by Inhalation and Indirect Ingestion and Chemical Guidelines, Levels II and III Scenarios (con't.)

Exposure Classification: Levels and Scenarios	Total DU Intake Range (mg/hr) in a vehicle[1]	Calculated Kidney Concentration (µg DU/g of tissue)

Executive Summary Table 4. Ranges of DU Intakes by Inhalation and Indirect Ingestion and Chemical Guidelines, Levels II and III Scenarios (con't.)

Exposure Classification: Levels and Scenarios	Total DU Intake Range (mg/hr) in a vehicle[1]	Calculated Kidney Concentration (µg DU/g tissue)	Possibility Kidney Concentration Guideline Exceeded[2]	**Air Concentration** (mg/m^3)	Possibility Air Concentration Guideline Exceeded[3]	Discussion in Sections of Part V

6.0 Recommendations

The critical review and evaluation of published DOD DU munitions test data reports have identified a number of data gaps and areas where data exist but still need improvement. These data reports were reviewed to determine relevant health and safety data for use in performing human health risk characterizations. The sections below highlight the data gaps, areas where data are incomplete or extremely variable, and on-going research efforts. A more complete discussion of data gaps and areas for data improvement can be found in Appendix P. Additional research and testing, which will be more scientifically defensible, are planned to fill in the data gaps and to produce more accurate data for a more definitive health risk characterization.

6.1 Data Gaps

Many data gaps were identified during the review of published DOD DU munitions test data reports. An overview of these data gaps is provided below.

The largest data gap appears to be associated with DU aerosol production over sequentially integrated time periods inside different types of vehicles (such as Bradley Fighting Vehicles and Abrams tanks), beginning at the time of Crew Compartment perforation by a DU munition or with fires involving DU munitions. The major data gaps related to DU aerosol generation include—

- Reduction in the DU particle size and airborne concentration (inside the target) over time.
- DU particle shape, variation of size distribution, and morphology over time.
- DU particle chemical forms and isotopic uranium composition.
- Radioactive and non-radioactive elemental composition of DU particle residue.
- Lung fluid dissolution rates for aerosolized DU and particle size distributions.

Another major data gap is the extreme variability of the data concerning DU particle resuspension both inside and outside of a vehicle. Additional data collection both inside and outside the vehicle, under varying site conditions, needs to be planned to reduce the uncertainty in all resuspension data.

Other data gaps include:

- Potential loss of fine particle fraction during sample collection.
- Effect of fire suppression or environmental control or nuclear, biological, and chemical systems on DU aerosol concentration in a vehicle following perforation by a DU munition.
- Effects of perforating a light armor package by a non-DU munition or DU munitions and the associated contributions to the total DU aerosol production.
- DU aerosol production in a Bradley Fighting Vehicle when perforated by a large and/or small caliber DU munition.
- Incorporation of particle settling and resuspension models for occupants and recovery teams of armored vehicles or other enclosed spaces.

- Weathering and corrosion of DU munitions on the battlefield.
- Secondary and direct ingestion factors and gastrointestinal transfer coefficient for battlefield DU.

6.2 Areas for Data Improvement

Many areas for data improvement were identified during the review of published DOD DU munitions test data reports. An overview of these areas for data improvement is provided below.

A major area for data improvement is with information about the formation of DU oxides and the resultant lung fluid dissolution rates and aerodynamic particle sizes. DU oxide lung fluid dissolution rate data are limited and in some instances conflicting.

Oxidation in field studies has been used as a basis for estimating source terms from fires involving DU. However, a DU mass balance during the field studies was never successfully accomplished. Performing a mass balance on these types of studies would validate the data generated.

Other areas for data improvement include:

- Obtaining field data to verify and validate modeling assumptions, especially for accidental circumstances modeled.
- Reducing uncertainties in all measurements.

- Evaluating the environmental fate and effect of DU on U.S. test ranges.
- Ensuring all environmental and health-related data obtained to date is scientifically defensible.
- Developing environmental transport and fate models to evaluate the relative risk as a function of DU concentration and migration.

In addition to the above data needs, there is a critical requirement for the development of guidelines applicable to deployed soldiers. Appendix P contains a more complete discussion of the need for better guidelines and other areas for data improvement.

6.3 On-going Research Efforts

The OSAGWI has been instrumental in initiating the planning and design of a series of tests dedicated to obtaining scientifically defensible data for human exposure and health risk characterizations. The undertaking is a concerted effort between the U.S. Army materiel research, development and testing community, the U.S. Army Medical Department, OSAGWI, and a peer review panel that is independent from DOD.

To date, data quality objectives for tests have been developed by the Army community and have been reviewed by the DOD-independent peer review panel. The data quality objectives have been developed to address the data gaps and the areas for data improvement identified in this report. Draft test plans have been developed and a peer review is in progress. Once the final test plan has been approved, the testing phase of the effort will begin. The data generated during the test will also be peer reviewed and then published. This effort is anticipated to be completed during fiscal year 2002.

6.4 Conclusions

Based on this assessment of the potential exposures and qualitative characterization of health risk to military personnel potentially exposed to DU during service in Southwest Asia, USACHPPM makes the following conclusions concerning the three exposure levels established by OSAGWI:

6.4.1 Level I

These personnel internalized DU through various potential routes of exposure: inhalation, ingestion, and wound contamination and embedded fragments. Some of these personnel may have internalized DU through multiple routes. The potential exists that they may have internalized DU in excess of the annual occupational radiation and chemical exposure standards. Based upon medical evidence to date, the amounts internalized by these personnel were not sufficient to adversely affect their present health. However, the amounts estimated are high enough that continued medical follow-up of these individuals is warranted. The DOD originally partnered with the VA in establishing a voluntary, medical follow-up program for Gulf War veterans at the Baltimore VA Medical Center in 1993. This medical follow-up program continues to this day.

6.4.2 Levels II and III

Exposure estimates to Levels II and III personnel are at least an order of magnitude below the annual occupational radiation and chemical exposure standards. These personnel internalized DU primarily through inhalation and ingestion. Based upon medical evidence to date, the amounts internalized by these personnel were not sufficient to affect either their present or future health.

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Glossary:

Activity Median Aerodynamic Diameter (AMAD) - The diameter in an aerodynamic particle size distribution for which the total activity above and below this size are equal. A lognormal distribution of particle sizes is assumed. The AMAD refers to the entire distribution. The AMAD is the aerodynamic diameter for which one-half of the radioactivity in a distribution has an AED smaller than the AMAD and one-half of the radioactivity in a distribution has an AED larger than the AMAD. The AMAD (along with the associated geometric standard deviation) is the most useful diameter for characterizing the behavior of the aerosol in air, in sampling instruments, and the respiratory tract.

Committed Effective Dose Equivalent (CEDE) ($H_{E,50}$) – The sum of the products of the tissue weighting factor and the radiation weighting factor or quality factor applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues. [$H_{E,50} = \Sigma w_t (H_{t,50})$].

Depleted Uranium (DU) – Uranium, which is depleted in the isotope U-235 (less than 0.711 weight percent of uranium present); primary 99.8 weight percent U-238.

Ingestion - The act or process of taking material into the body with absorption taking place in the digestive system.

- Ingestion, Direct - The act or process of taking foodstuffs, water, soil, or other substance via mouth and swallowed to GI tract.

- Ingestion, Indirect - The act or process of having material cleared from the respiratory tract via the mucociliary ladder and swallowed to GI tract.

- Ingestion, Secondary - The act or process of transferring material that is on the hands-to-mouth and swallowed to GI tract.

Intake – The total amount of material that enters the body through the principal exposure routes of inhalation, ingestion (direct, indirect and secondary), or skin wounds.

- For inhalation, it includes material that is immediately exhaled as well as the material retained and absorbed into the body. For small (< 1 µm AMAD) particles of Class D and Class W (or Types F and M, respectively), uranium or DU, about one-half of the intake will be absorbed by the body.

- For inhalation of DU oxides that enter the GI tract, the fraction of the material that passes from the GI tract to blood is termed the GI transfer coefficient. This depends on the solubility of the oxide. For Class D and W (or Types F and M, respectively, uranium or DU compounds, the value is 0.02. For Class Y (or Type S) uranium compounds, the value is 0.002. The GI transfer coefficients are applied to ingestion (direct, indirect and secondary) intakes of radioactive material.

Micrometer (mm) – A unit of length. One micrometer (1 µm) is one millionth of a meter (1×10^{-6} m).

Office of the Special Assistant to the Secretary of Defense for Gulf War Illnesses, Medical Readiness and Military Deployments (OSAGWI) – This office was created November 12, 1996, by the Deputy Secretary of Defense to investigate the possible causes of Gulf War Illnesses and care for those who fought in the Gulf War.

Perforation – Any rupture or penetration of the armored envelope caused by an impacting projectile, which results in behind-the-plate effect caused by the projectile or spall fragments. A perforation can occur only when the armor is defeated.

Rem - The special unit of any of the radiation quantities expressed as dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor or radiation weighting factor. One rem equals 0.01 sievert (Sv); (1 millirem (mrem) is 1/1000 of a rem.)

Risk Assessment - A systematic process for describing and quantifying the risk associated with a hazardous substances, processes action, or events. It may also be defined as a systematic process for calculating a probability distribution or similar quantification that describes uncertainty about the magnitudes, timing, or nature of the possible health or environmental consequences associated with possible exposure to specified substances, processes, actions, or events. Risk assessments consist of five interrelated but distinct steps: hazard identification, release assessment, exposure assessment, consequence/dose response assessment, and risk estimation/characterization.

Risk Characterization - The final phase of the risk-assessment process that involves evaluation and integration of the data and analysis involved in hazard identification, estimation of the source term, estimation of exposure and intake of a contaminant (upper and lower boundary). The upper-bound value is used to estimate the nature and likelihood of adverse human health effects as a result of exposure and intake of the contaminant.

Scenario – A combination of exposure pathways used to model conceptually the possible or potential conditions, events, and processes that result in exposure to individuals or groups of people.