I. OVERVIEW[1]

The Gulf War was the arena for the first battlefield use of armor-piercing munitions and reinforced tank armor incorporating depleted uranium (DU). This very dense metal is a by-product of the process by which natural uranium is "enriched" to produce reactor fuel and nuclear weapons components. The leftover uranium, 40% less radioactive than natural uranium, is called "depleted uranium," or DU.

Figure 1. Abrams tank and DU sabot rounds

Depleted uranium played a key role in US forces' overwhelming success during the Gulf War. Machined into armor-piercing 120mm DU "sabot" rounds (Figures 1 and 2), DU penetrators were called "silver bullets" by armor forces, who quickly recognized the tremendous lethal advantage these rounds provided against enemy tanks. The extreme density of the metal and its self-sharpening properties make DU a formidable weapon; its projectiles slice through thicker, tougher armor at greater ranges than other high-velocity rounds. In addition, DU is pyrophoric -- on striking armor, small particles break off and burst into flames spontaneously in air, often touching off fuel and munitions explosions.

Figure 2. DU round discarding its sabot

US forces also used DU to enhance their tanks' armor protection. In one noteworthy incident, an M1A1 Abrams Main Battle Tank (Figure 3), its thick steel armor reinforced by a sandwiched layer of DU, rebuffed a close-in attack by three of Iraq's T-72 tanks. After deflecting three hits from Iraq's tanks, the Abrams' crew dispatched the T-72s with a single DU round to each. (Tab F contains an expanded version of the encounter.) Similarly, Air Force A-10 "tank-busters" and Marine Corps AV-8B Harrier aircraft fired 30mm and 25mm DU rounds, respectively, with deadly effect against Iraq's armor. (Tab F describes DU use in the Gulf.)

Figure 3. M1A1 tank in the Gulf

During the Gulf War, DU helped US forces fight more effectively and defend themselves more confidently. American tanks and A-10s destroyed thousands of Iraq's combat vehicles, which had no DU armor, without enemy fire penetrating the DU armor of a single US tank. Since the Gulf War, DU's

battlefield effectiveness has encouraged its steady proliferation into the arsenals of allies and adversaries alike. There is little doubt, therefore, DU will be used on the battlefield against US personnel in some future conflict.

While DU's combat debut showed the metal's clear superiority for both armor penetration and protection, its chemical toxicity -- common to all forms of uranium and similar to other heavy metals such as lead and tungsten -- and its low-level radioactivity raised concerns about possible combat and non-combat health risks from DU use.

To many veterans and members of the public, the term "exposure," especially when associated with the word "radiation," means health will be adversely affected. In the Gulf War, soldiers were exposed when they came in contact with depleted uranium fragments and particles formed when DU struck armor targets or when they were close to burning DU. This report uses "exposure" in much the same way as we commonly refer to people's daily "exposure" to automobile exhaust, second-hand smoke, or similar noxious or potentially toxic substances. Any effect from an exposure depends on the dose, which is a factor of the strength (how much) and the duration (how long) of the exposure. When doses are low, the exposures are very unlikely to produce any harmful effects, but when doses are high, health might be adversely affected.

The purposes of this report are to determine whether DU posed an unacceptable health risk to American forces and whether personnel had been adequately trained to deal with this risk. To accomplish these objectives, the report examines the documented incidents of DU exposure and discusses what is currently known about the potential health effects from them. This second interim report follows the same format as our initial August 1998 report with important updates on the latest findings of:

- the Baltimore Veterans Affairs (VA) Medical Center DU Follow-up Program for "friendly fire" victims, initiated in 1993;
- the expanded VA and DoD DU Medical Follow-up Program, initiated in 1998;
- the Agency for Toxic Substances and Disease Registry's "Toxicological Profile for Uranium;"
- RAND's "A Review of the Scientific Literature As It Pertains to Gulf War Illnesses," Volume 7, "Depleted Uranium;"
- the Armed Forces Radiobiology Research Institute's and Lovelace Respiratory Research Institute's animal research efforts on implanted DU;
- the US Army Center for Health Promotion and Preventive Medicine's exposure estimates; and
- the Institute of Medicine's Gulf War and Health, "Volume 1, Depleted Uranium, Sarin, Pyridostigmine Bromide, Vaccines."

Office of the Special Assistant investigators interviewed hundreds of Gulf War combatants and eyewitnesses, reconstructed numerous operations, consulted with subject matter experts, and researched the most current body of knowledge about DU's health effects and environmental impact. The investigation classifies possible DU exposures into three levels (I, II and III), encompassing 13 separate activities or incidents, shown in Table 1. We derived these levels from initial assessments of the exposures' potential relative risks, decreasing from Level I to Level III. For each level, Table 1 describes the activity or incident, current estimates of the number of personnel involved, and the personal protective equipment used, if any.

Table 1. Incident Summary

Exposure Classifications: Levels and Scenarios	Number of Persons	Personal Protection Worn

Level I		
Soldiers in or on a US vehicle when a DU munition penetrated it.	104	None
Soldiers who entered US vehicles to rescue occupants immediately after friendly-fire DU impacts.	» 30-60*	None
Level II		
Explosive Ordnance Disposal (EOD) and unit personnel who removed equipment and munitions from US vehicles struck by DU munitions.	» 10-20*	None
Unit personnel who performed maintenance on or recovered items from US vehicles struck by DU munitions.	» 60-80*	None
Logistics Assistance Representatives (LARs) who inspected US vehicles struck by DU munitions to determine reparability.	» 6-12*	Some Wore PPE**
Battle Damage Assessment Team (BDAT) members who examined US combat vehicles damaged and destroyed by DU munitions.	16	Most Wore PPE**
144th Service and Supply Co. personnel who processed damaged equipment, including some struck by DU munitions.	29	None
Radiation Control (RADCON) team members.	11	Most Wore PPE**
Personnel exposed to DU during cleanup operations at Camp Doha's North Compound.	» 600*	None
Level III		
Personnel exposed to smoke from burning DU rounds at Camp Doha.	Hundreds	None
Personnel exposed to smoke from burning Abrams tanks.	Unknown	None
Personnel who entered DU-contaminated equipment.	Unknown	None
Personnel exposed to smoke from Iraq's DU-struck equipment.	Unknown	None

* Number is not final; remains under investigation.

** Personal Protective Equipment (PPE) includes respirator, coveralls, boots and gloves. Reports of respiratory protection ranged from the military M25 and M17A2 respirators to industrial dust mask, surgical-type paper mask, etc.

Level I includes incidents in which US tanks mistakenly fired DU armor-piercing rounds into other US combat vehicles, exposing surviving crew in those vehicles to wounds from DU fragments and/or inhaled and ingested particles formed when DU munitions penetrate armor, especially tank armor. During these "friendly-fire" incidents, personnel rushing to evacuate and rescue fellow soldiers from stricken vehicles also may have been directly exposed to DU. Level I includes these immediate, direct exposures (see Tab G).

Level II exposures to DU occurred after combat, when explosive ordnance disposal (EOD) personnel entered DU-struck vehicles to remove unexploded munitions. In addition to EOD personnel, battle damage assessment teams (BDAT), radiation control (RADCON) teams, and salvage crews worked in and on the damaged or destroyed vehicles as they were processed for repair or disposal. This group also

includes personnel involved in cleanup and recovery operations in the North Compound of Camp Doha, Kuwait, after a July 1991 motor pool fire in which DU munitions, among others, detonated and burned. Level II includes these personnel and others who may have come into direct contact with expended DU rounds' dust-like residue (see Tab G).

Level III, also discussed in Tab G, includes personnel whose exposure to DU was short-term and generally very low. These exposures may have occurred as personnel passed through and inhaled smoke from burning DU, casually handled spent DU penetrators, or briefly entered DU-struck vehicles on the battlefield or in salvage yards.

The amount of DU present, route of entry, solubility, particle size, other physical and chemical factors, and toxicity determine potential health effects. The US Army Center for Health Promotion and Preventive Medicine (USACHPPM) completed its health risk characterization of DU in the Gulf War after we published our initial environmental exposure report on DU. They reassessed earlier Level I estimates the General Accounting Office (GAO) called into question,[2] and developed Level II and III estimates. Although more refined than their original estimates, USACHPPM's new Level I estimates rely on the same test data as used previously. USACHPPM employed statistical tools to develop upper and lower limits for these Level I exposure scenarios. To improve the reliability of these Level I estimates, OSAGWI has directed and funded the US Army to further evaluate DU aerosol concentrations inside combat vehicles penetrated by DU rounds.[3] In the meantime, the Baltimore Veterans Affairs (VA) Medical Center's comprehensive medical follow-up program provides the most important health assessment for Level I exposures. The VA's studies of these Level I veterans have shown no untoward medical effects to date from depleted uranium's radiological or chemical toxicity. USACHPPM's risk assessments for the Level II and III scenarios are based on much better Department of Defense (DoD) experimental data and indicate that the radiological and chemical risks for these events are well within current regulatory limits for industrial workers. These results for participants in all levels confirm our initial scenario classification.

Since 1993, the Baltimore VA Medical Center has monitored veterans seriously injured in friendly-fire incidents involving depleted uranium. While these veterans have medical afflictions resulting from their wartime injuries, the Baltimore medical evaluators report that the veterans are not sick from DU's chemical or radiological toxicity. About half the original group of 33 still have depleted uranium fragments in their bodies. The VA is following the group very carefully, administering a broad battery of medical tests to determine if the embedded depleted uranium fragments are causing any health problems. To date, the VA has seen no adverse effects in the kidney; only subtle perturbations[4] in the reproductive and central nervous systems; and elevated concentrations of urinary uranium of veterans with retained DU fragments. The study veterans without retained DU fragments generally have not shown higher than normal levels of uranium in their urine or any other medical effects from uranium.

In the summer of 1998, the Departments of Defense and Veterans Affairs (VA) extended the medical follow-up program to evaluate all individuals who were in or on vehicles struck by friendly fire, as well as those who worked around DU-struck vehicles or burned vehicles containing DU. While their DU exposures were not expected to cause health effects, these veterans are being evaluated to measure any residual DU. The follow-up program guidelines called for OSAGWI to notify these veterans of their exposures and offer a medical evaluation. Thus far, we have notified more than 200 veterans of this follow-up program. Since 1998, the Baltimore VA Program has evaluated more than 30 additional veterans involved in friendly-fire incidents, including 4 with known or suspected embedded DU fragments. In addition, as part of the Gulf War Registry program DoD and the VA agreed to perform a physical examination, collect a questionnaire for DU exposure, and collect a 24-hour urine sample to

measure urinary uranium for any concerned Gulf War veteran. To date, 398 veterans have requested and received this examination and are at various stages of completion.[5]

Since we published our initial DU environmental exposure report in August 1998, three major scientific reviews of the toxicology of uranium and depleted uranium have been published. The first was the RAND Corporation's comprehensive medical literature review on depleted uranium's health effects. The study is one of eight the Special Assistant to the Deputy Secretary of Defense for Gulf War Illnesses commissioned from RAND's National Defense Research Institute. The second review, dated September 1999, is the Toxicological Profile for Uranium published by the Department of Health and Human Services' Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR toxicological profiles are recognized internationally as an authoritative source of information about hazardous substances' human and environmental effects. The third review was "Gulf War and Health, Volume 1 Depleted Uranium, Pyridostigmine Bromide, Sarin, Vaccines" recently completed by the Institute of Medicine (IOM) at the request of congress. The National Academy of Sciences established the IOM to perform independent studies. These three reports assess the chemical and radiological effects of uranium on health.

RAND concluded that medical literature contains no evidence of radiological health effects resulting from exposure to uranium or depleted uranium.[6] RAND also concluded that while uranium in large doses can cause changes in kidney function and at very high levels result in kidney failure, no increased kidney disease has been observed in a relatively large occupational population chronically exposed to natural uranium. The RAND study also cited the absence of kidney effects in friendly fire victims with embedded DU fragments in the Baltimore VA follow-up program despite the presence of elevated urine uranium levels.[7] The ATSDR profile concluded that because of scientific evidence and the low radioactivity of natural and depleted uranium, it expects no radiological health hazard from inhalation, dermal, or oral exposure to natural or depleted uranium.[8]

In September 2000 the Institute of Medicine (IOM) released its report on depleted uranium, chemical warfare agents (sarin and cyclosarin), pyridostigmine bromide, and vaccines (anthrax and botulinum toxoid). In assessing the two primary concerns commonly associated with uranium exposures (renal dysfunction and lung cancer) the IOM concluded that there was "limited/suggestive evidence of no association" between uranium exposure and renal dysfunction nor to lung cancer at cumulative exposures less than 20 rem (a unit of radiation dose). Twenty rem is at least four times higher than the highest radiological doses estimated for Gulf War veterans. The finding of "limit/suggestive evidence of no association" is one of five categories used by IOM to classify the evidence of association between exposure and a health outcome. It is the most definitive category available, indicating that no cause-effect relationship has been established between exposure to uranium and the suspected adverse health outcomes; i.e., renal dysfunction and lung cancer at cumulative exposures less than 20 rem. The IOM report also stated the data were inadequate or insufficient to determine whether exposure to uranium is associated with a variety of other health conditions including bone cancer, lung cancer (at cumulative exposures greater than 20 rem), lymphatic cancer, nervous system disease, nonmalignant respiratory disease, and other various health outcomes.[9]

Based on data developed to date, we believe that while DU could pose a chemical hazard at high intakes, Gulf War veterans did not experience intakes high enough to affect their health. Furthermore, the available evidence indicates that due to DU's low-level radioactivity, adverse radiological health effects are not expected. The available scientific and medical evidence to date does not support claims that DU

caused or is causing Gulf War veterans' illnesses. Nevertheless, medical research to date has suggested several areas of concern for soldiers with embedded DU fragments that warrant further medical follow-up which DoD and the VA are committed to perform.[10]

This investigation identified significant shortcomings in how the military trained US personnel to operate in DU-contaminated environments. Pre-war training was given only to select military occupation specialties, leaving most servicemembers unaware of DU's use and simple measures that could have mitigated DU exposures. This paper outlines the steps the services have taken to correct this shortfall.

The report begins with a short, but important lesson on DU -- what it is and the potential health risks of its chemical and radiological properties (see Section III, "Depleted Uranium -- A Short Course"). The report then describes DU exposures that occurred during the Gulf War and relates those exposures to possible health effects (see Section IV, "Potential Health Effects from DU Use in the Gulf Theater, 1990-1991"). Next, we address environmental studies of various DU munitions, environmental assessments of DU contamination on the battlefield, results of current medical studies, future monitoring efforts, and ongoing and planned research (see Section V, "Follow-Up"). The report then presents some lessons learned since the Gulf War (see Section VI, "Lessons Learned and Recommendations"), addressing pre-Gulf War training shortfalls and reporting on the status of corrective action. The Conclusion summarizes the report's contents and relates key findings and conclusions based on evidence analyzed to date.

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