Environmental Exposure Report

Depleted Uranium in the Gulf

The Office of the Special Assistant for Gulf War Illnesses is reporting on what we know today about specific events that took place during the Gulf War of 1990 and 1991. This particular report focuses on the use of, and exposures to, depleted uranium (DU). This is an interim report, not a final report. We hope that you will read this and contact us with any information that would help us better understand the events reported here. With your help, we will be able to report more accurately on the events surrounding DU use and exposures. Please contact my office to report any new information by calling:

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Many veterans of the Gulf War have been experiencing a variety of physical symptoms, collectively called Gulf War illnesses. In response to veterans' concerns, the Department of Defense (DoD) established a task force in June 1995 to investigate all possible causes. The Investigation and Analysis Directorate (IAD) of the Office of the Special Assistant for Gulf War Illnesses (OSAGWI) assumed responsibility for these investigations on November 12, 1996, and has continued to investigate depleted uranium. Its interim report is contained here.

As part of the effort to inform the public about the progress of this effort, DoD is publishing (on the Internet and elsewhere) accounts related to possible causes of illnesses among Gulf War veterans, along with whatever documentary evidence or personal testimony was used in compiling the accounts. The report that follows is such an account.

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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" with the addition of radioactive isotopes taken from other uranium. The leftover uranium, drained of 40% of its original radioactivity, is called "depleted uranium," or DU.

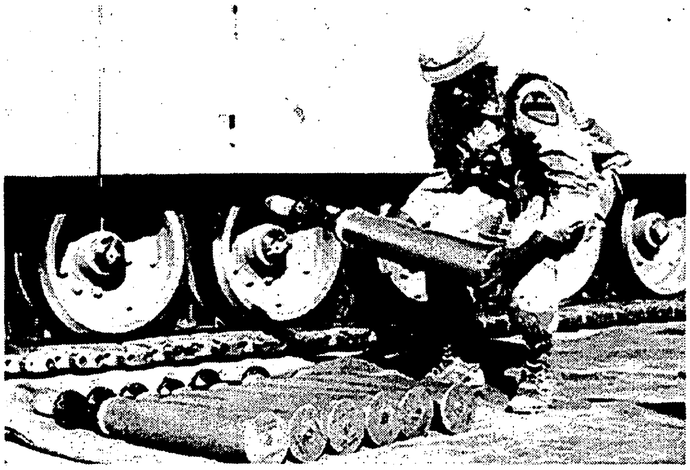

Figure 1 - Abrams tank and DU sabot rounds

Depleted uranium played a key role in the overwhelming success of US forces during the Gulf War. Machined into armor-piercing 120mm DU 'sabot' rounds (Figures 1 and 2), DU penetrators were called "silver bullets" by tankers, 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—upon striking armor, small particles break off and combust spontaneously in air, often touching off explosions of fuel and munitions.

Figure 2 - DU round discarding its sabot

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

During the Gulf War, DU helped US forces fight more effectively and defend themselves more confidently. American tankers and A-10 pilots destroyed thousands of Iraqi combat vehicles without the loss of a single US tank to enemy fire. Since the Gulf War, DU's battlefield effectiveness has encouraged its steady proliferation into the arsenals of allies and adversaries

[1] A Glossary and List of Acronyms is located at Tab A.

alike. There is little doubt, therefore, that DU will be used against our troops in some future conflict.


Figure 3 – M1A1 in the Gulf

While DU's combat debut showed the metal's clear superiority for both armor penetration and armor protection, its chemical toxicity—common to all forms of uranium and similar to other heavy metals—and its low-level radiological properties gave rise to concerns about possible combat and non-combat health risks associated with DU use. The issues to be addressed in this report are: did DU pose an unacceptable health risk to American troops; were personnel trained to recognize and communicate that risk; and were troops, once exposed to DU, adequately monitored and treated?

To many veterans and members of the public, the term "exposure," especially when associated with the word "radiation," signifies that adverse health effects will follow. In fact, exposure in the present case is used to describe events and situations where soldiers came into contact with depleted uranium fragments and particles formed when DU struck armor targets or "slow cooked" in fires. "Exposure" in the current context is better understood if equated with most people's daily "exposure" to automobile exhaust, second-hand smoke, or similar noxious or potentially toxic substances. In minute quantities, such exposures will not produce harmful effects; however, when certain thresholds are exceeded, adverse health effects might result.

This report examines a variety of exposures that occurred during and after the Gulf War. 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 DEPLETED URANIUM—A SHORT COURSE, page 11). The report then describes DU exposures that occurred during the Gulf War, and relates those exposures to possible health effects (see ASSESSMENT OF POTENTIAL HEALTH EFFECTS FROM DU USE IN THE GULF THEATER, 1990-1991, page 20). Next, the report addresses recent environmental studies of various DU munitions, environmental assessments of DU contamination on the battlefield, results of current medical studies, future monitoring efforts, and on-going and planned research (see FOLLOW-UP, page 29). After the Follow-up, the report presents some lessons learned since the Gulf War (see LESSONS LEARNED, page 37), addressing pre-Gulf War training shortfalls, and recommending steps DoD can take to better prepare troops to operate in environments where they might encounter DU contamination. The Conclusion (see CONCLUSION, page 42) summarizes the contents of the report, describes ongoing research and medical follow-up programs, and relates key findings and conclusions based on evidence analyzed to date.

This investigation, and medical and scientific research to date, have not established any relationship between DU exposures and the undiagnosed illnesses presented by some Gulf War veterans. These efforts are ongoing, and this office will continue to apply lessons learned from the investigation and research efforts to safeguard the health of our troops.

Investigators from the Office of the Special Assistant have interviewed hundreds of Gulf War combatants and eyewitnesses, reconstructed numerous operations, consulted with subject matter experts, and researched the most current body of knowledge regarding DU's medical effects and environmental impact. The investigation classifies possible DU exposures into three Levels, encompassing 13 separate activities, shown in Table 1 (see page 8). These Levels are based on initial estimates about the extent of the exposures. For each Level, Table 1 provides a description of the activity, a current estimate of the number of soldiers involved, the duration of the exposure, and the personal protective equipment used, if any.

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

A second, lower level of exposures to DU occurred after combat as explosive ordnance disposal (EOD) personnel entered DU-contaminated 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. Also classified with this group would be personnel involved in cleanup and recovery operations in the North Compound of Camp Doha, Kuwait, following the motor pool fire in which DU munitions detonated and burned. These personnel, and others who may have come into direct contact with the dust-like residue of expended DU rounds, are categorized under the Level II exposure category (see Tab G).

A third category of DU exposure, Level III, also discussed in Tab G, defines 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-contaminated vehicles on the battlefield or in salvage yards.

These three exposure categories are not exclusive. Given the complexity of combat operations during the Gulf War and the wide variety of post-combat assignments, there are other possible DU-exposure scenarios which could overlap categories. The purpose of this report is to relate the documented incidents during which exposure to DU was a distinct possibility, and to discuss what is currently known about the potential health effects resulting from those exposures.

Table 1 - Incident Summary

Exposure Classifications: Levels and Scenarios	**Number of Personnel**	**Duration of Exposure**	**Personal Protection Worn**
Level I			
Soldiers in or on vehicle at the time it was penetrated by a DU munition.	≈113*	Minutes to Days**	None
Soldiers who entered US vehicles immediately after friendly fire DU impacts to rescue occupants.	≈30-60*	Minutes	None
Level II			
Explosive Ordnance Disposal (EOD) and unit personnel who downloaded equipment and munitions from DU-contaminated systems.	≈30-60*	~ 1 hour per vehicle	None
Unit maintenance personnel who performed maintenance on or in DU-contaminated systems.	≈30-60*	~ 1 hour per vehicle	None
Logistics Assistance Representatives (LARs) who inspected DU-contaminated Systems to determine reparability.	≈6-12	~ 1 hour per vehicle	Some Wore PPE***
Battle Damage Assessment Team (BDAT) members who examined US combat vehicles damaged and destroyed by DU.	12	3 hours per vehicle	Most Wore PPE
144th Service and Supply Co. personnel who processed damaged equipment, including some with DU contamination.	27	Various	None
Radiation Control (RADCON) team members.	10-12	Hours	PPE
Personnel exposed to DU contamination during cleanup operations at Camp Doha's North Compound.	≈600*	Hours	None
Level III			
Personnel exposed to smoke from burning DU rounds at Camp Doha.	hundreds	Minutes	None
Personnel exposed to smoke from burning Abrams tanks.	unknown	Minutes	None
Personnel who entered DU-contaminated equipment.	unknown	~5 to 10 minutes per vehicle	None
Personnel exposed to smoke from DU-impacted Iraqi equipment.	unknown	Minutes	None

* Number is not final, under investigation.

** Most soldiers were removed from friendly fire vehicles within minutes. However, we have received reports of soldiers driving around in minimally damaged Bradley Fighting Vehicles (BFVs) for several days.

***Personal Protective Equipment (PPE) includes surgical mask, coveralls, boots and gloves.

Dose and toxicity determine health effects. The US Army Center for Health Promotion and Preventive Medicine (CHPPM) is concentrating on determining possible DU intakes by Level I soldiers, who were most exposed. Initial estimates represent an upper bound to exposure, commonly called the "worst case," based on the limited available test data for DU sabot rounds which penetrated DU armor. In this report, "worst case" refers to conditions that are thought to produce a maximum exposure to DU. These estimates indicate that the radiological risk for these events is well within current regulatory limits for industrial workers. It should be cautioned that these dose estimates are very preliminary, requiring additional testing to fill data gaps, require further refinement of dose estimates, and will be influenced by current research about DU's medical effects.

Since 1993, the Department of Veterans Affairs has been monitoring 33 vets who were seriously injured in friendly fire incidents involving depleted uranium. These veterans are being monitored at the Baltimore VA Medical Center. While these veterans have very definite medical afflictions resulting from their wartime injuries, they are not sick from the heavy metal or radiological toxicity of DU. About half of this group still have depleted uranium metal fragments in their bodies. Those with higher than normal levels of uranium in their urine since monitoring began in 1993 have embedded DU fragments. These veterans are being followed very carefully and a number of different medical tests are being done to determine if the depleted uranium fragments are causing any health problems. The veterans being followed who were in friendly fire incidents but who do not have retained depleted uranium fragments, generally speaking, have not shown higher than normal levels of uranium in their urine. For the 33 veterans in the program, tests for kidney function have all been normal. In addition, the reproductive health of this group appears to be normal in that all babies fathered by these veterans between 1991 and 1997 had no birth defects.

The DoD and Department of Veterans Affairs recently instituted a new medical follow-up program to evaluate all individuals who were in or on vehicles that were struck by friendly fire, as well as those who worked around DU-contaminated vehicles. These individuals were less exposed than the 33 in the original program, but potentially more exposed than the general military population. While their DU exposures are unlikely to have exceeded the threshold levels at which health effects might be observed, prudence dictates that they be evaluated to establish any residual body burden of DU. Veterans whose known exposures caused them to be classified as Level I or Level II exposure participants who worked on DU-contaminated equipment (described further on page 8 and in Tab G) will be notified of their exposures and offered a medical evaluation. They will also receive the letter and DU information shown in Tab K, DU Notification and Medical Follow-up.

To illustrate specific examples of DU exposures that occurred during the war, this report draws upon several incidents during which US military personnel were exposed or potentially exposed to DU through inhalation, ingestion, wound or bare skin contact. Where the essential facts have been established, those incidents have been investigated and are reported here. Where the reports of DU exposure are incomplete or remain unsubstantiated, the investigation continues.

A. Health Effects From the Chemical Toxicity of Depleted Uranium

1. Chemical Properties of DU

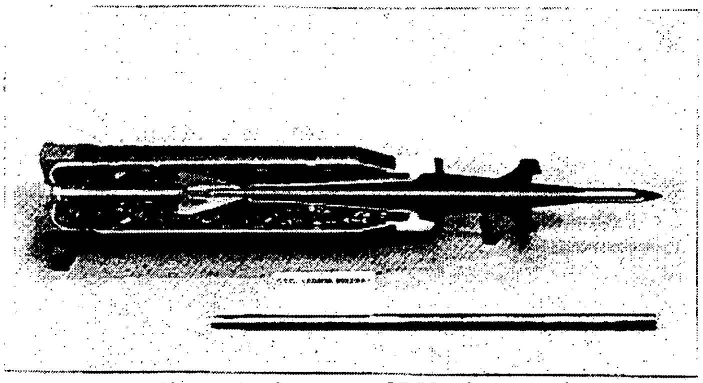
Figure 4 - Cutaway of DU sabot round

Uranium is all around us. It is a heavy metal similar to tungsten, lead, and cadmium, occurring in soils at an average concentration of 3 parts per million, equivalent to a tablespoon of uranium in a truckload of dirt.[2] All of us take in uranium every day from the air we breathe, the water we drink, and the foods we eat. On average, each of us takes in 1.9 micrograms (about two millionths of a gram) of uranium a day from food and water, and inhales a very small fraction (7×10^{-3} or 0.007) of a microgram every day.[3]

DU's ability to self-sharpen as it penetrates armor is the primary reason why DU is a more potent weapon than alternate tungsten munitions, which tend to mushroom upon impact. Fragments and uranium oxides are generated when DU rounds strike an armored target. The size of the particles varies greatly; larger fragments can be easily observed, while very fine particles are smaller than dust and can be inhaled and taken into the lungs. Whether large enough to see, or too small to be observed, DU particles and oxides contained in the body are all subject to various degrees of solubilization—they dissolve in bodily fluids, which act as a solvent.

The solubility of uranium varies greatly depending on the particular compound—or form of uranium—and the solvent. The human body's natural fluids, which are water-based, provide the solvent that acts on DU that has entered the body. In this report, references to "soluble" and "insoluble" forms of depleted uranium are relative generalizations about depleted uranium's overall solubility; over time, all uranium is soluble. The three uranium oxides of primary concern (UO_3, UO_2, and U_3O_8) all tend to dissolve slowly (days for UO_3 to years for UO_2 and U_3O_8) in bodily fluids.[4] Once dissolved, uranium may react with biological molecules and, in the form of the uranyl ion, may exert its toxic effects. Those toxic effects are: cellular necrosis (death of cells) in the kidney and atrophy in the tubular walls of the kidney resulting in a decreased ability to filter impurities from the blood.[5]

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[2] Toxicological Profile for Uranium, Draft for Public Comment. Atlanta, GA: US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, September 1997, p. 1.
[3] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 111.
[4] Bioassay Programs for Uranium, An American National Standard, HPS N13.22-1995, Health Physics Society; McLean, VA; October 1995, p. 13, 38.
[5] Toxicological Profile for Uranium, Draft for Public Comment. Atlanta, GA: US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, September 1997, p. 15.

2. Chemical Effects

Once dissolved in the blood, about 90% of the uranium present will be excreted by the kidney in urine within 24-48 hours.[6] The 10% of DU in blood that is not excreted is retained by the body, and can deposit in bones, lungs, liver, kidney, fat and muscle. Insoluble uranium oxides, if inhaled, can remain in the lungs for years, where they are slowly taken into the blood and then excreted in urine.

Although heavy metals are not attracted to single biological compounds, they are known to have toxic effects on specific organs in the body. Previous research has demonstrated that the organ that is most susceptible to damage from high doses of uranium is the kidney. The uranyl-carbonate complexes decompose in the acidic urine in the kidney. This reaction forms the basis for the primary health effects of concern from uranium. The effects on the kidney from uranium resemble the toxic effects caused by other heavy metals, such as lead or cadmium.

So far, very few Gulf War veterans have been diagnosed with types of kidney damage in which DU would be on the list of possible causative agents. Diabetes and lupus would be the most likely causes on the list, however. Among the first 20,000 veterans who were evaluated in the CCEP, there were only 25 individuals (0.1%) who were diagnosed with these types of kidney damage. These included 13 individuals with glomerulonephritis and 12 individuals with renal insufficiency.[7] None of these 25 individuals were among the group of 33 veterans with the highest DU exposures who have been followed in the Baltimore VA program. The rates of these diagnoses in this self-selected population are consistent with the rates of similar kidney problems in the general US population.

3. Chemical Toxicity Standards

For uranium, the Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have established protection standards for workers based on the chemical toxicity to the kidney. The standards are based on the assumption that they will provide adequate protection for workers over a normal working (40 hours per week) lifetime. Additionally, levels for short-term exposures are also defined to limit acute exposure effects. The Permissible Exposure Limits (PELs) listed in Table 2 are from the Code of Federal Regulations dealing with occupational exposures to toxic and hazardous substances. Table 2 is intended only for a general comparison of the relative toxicity of the

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[6] Naomi Harley, Earnest Foulkes, Lee Hilborne, Arlene Hudson, C. Ross Anthony, "A Review of the Scientific Literature as it Pertains to Gulf War Illnesses, Volume V: Depleted Uranium, Draft," RAND, National Defense Research Institute, Washington DC, June 29, 1998, p. 13.

[7] Stephen P. Joseph and the Comprehensive Clinical Evaluation Team, A Comprehensive Clinical Evaluation of 20,000 Persian Gulf War Veterans, Military Medicine, Vol. 162, March 1997, p. 149-155.

various metals. Although the PEL was derived for natural uranium, the chemical effects of the various isotopes of uranium are expected to be identical.

Table 2 - Comparison of OSHA PELs for Metals from Inhalation Exposures.[8]

Element	Soluble Compounds (mg/m^3)	Insoluble Compounds (mg/m^3)
Lead*	0.05	0.05
Cobalt - metal, dust and fume (as Co)*	0.1	0.1
Uranium	0.05	0.25
Nickel	1	1
Tungsten	1	5
Mercury	0.01	
Titanium Dioxide		
Total dust*		15

* No distinction is made between soluble and insoluble compounds.

In addition to OSHA's limits, ACGIH has established a Threshold Limit Value (TLV®) of 0.2 mg/m^3 (for both soluble and insoluble compounds). For brief periods of exposure, ACGIH has set a short-term exposure limit (STEL)(an average concentration over a 15 minute period that allows for brief excursion above the TLV) of 0.6 mg/m^3.[9] PELs and TLVs® are based on the principle that there is a threshold below which no adverse health effects occur. As the exposure increases above the threshold, the adverse health effect becomes more severe. PELs and TLVs® are called time-weighted-average values because they are averaged over an 8-hour workday, for a 40-hour workweek over a working lifetime.

The OSHA PELs and ACGIH TLVs® were intended to apply to the common workplace, not to the battlefields of Desert Storm. Nevertheless, these limits provide a set of guidelines for use as a starting point in evaluating hazards. However, since only limited environmental data are available from the operational environment, the guidelines serve as reference points for comparison with experimental data.

4. Implications for the Military

DU exposures for the Level II and Level III exposure categories are believed to be well below levels expected to produce either temporary or permanent kidney damage. The friendly fire victims (Level I exposures) are believed to have had the highest exposures during the Gulf War (Reference Section III.B.1.c.). It is impossible to assess temporary DU-related kidney

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[8] 29 CFR 1910.1000 Table Z-1 Limits for Air Contaminants; 29 CFR 1915.1000 Table Z; and 29 CFR 1910.1025 Lead.

[9] 1998 TLVs and BEIs, Threshold Limit Values for Chemical Substances and Physical Agents, Biological Exposure Indices, American Conference of Governmental Industrial Hygienists.

dysfunction in these soldiers immediately following their accidents, because traumatic injuries and major surgeries may also cause temporary renal abnormalities. In addition, routine urinalysis tests do not detect subtle, early renal damage that might be associated with DU heavy metal toxicity. However, no kidney abnormalities have been documented in any of the 33 veterans studied in the Baltimore VA program, including their most recent examinations in 1997.

B. Health Effects From the Radiological Toxicity of Depleted Uranium

1. Radiological Properties of DU

Depleted uranium—described above as a metallic remnant of one of several processes that begin with uranium ore—is composed of three isotopes of uranium (^{234}U, ^{235}U, and ^{238}U). Depleted uranium, like all uranium and other elements, is composed of atoms; the basic building block of nature. Atoms consist of atomic particles called neutrons (neutral particles), protons (positively charged particles), and electrons (negatively charged and relatively massless). For any element, like uranium, the number of protons and electrons determine the chemical properties. Atoms of the same element can have different numbers of neutrons. These different atoms of the same element are called isotopes. Isotopes of an element have the same chemical properties, but may have different nuclear or radiological properties. In nature, uranium consists of the isotopes ^{234}U, ^{235}U, and ^{238}U in a certain ratio. Depleted uranium has a lower content of ^{234}U and ^{235}U, which have been removed in the enrichment process.

The number of heavy particles (protons and neutrons) in the nucleus of an atom determines the stability of the element. Unstable elements 'decay' through a nuclear transformation process into new elements called progeny or daughter products. Each daughter product has a lower atomic weight than the unstable parent isotope. This process of decay—radioactivity—emits one or more forms of ionizing radiation (among them, alpha particles, beta particles, neutrons, X-rays, or gamma rays) during each nuclear transformation. This decay process continues until a stable (non-radioactive) element is produced. For example, after completing several stages of the radioactive decay process, ^{238}U becomes lead. A more thorough description of the origins of depleted uranium can be found at Tab C.

2. Radiological Effects

As it decays, DU emits alpha, beta, and gamma radiation. An understanding of how DU's emissions may cause health effects can be drawn from existing knowledge of how radiation, in general, causes health effects.

Radiation is everywhere. People live their lives being bombarded by gamma rays, neutrons, and charged particles produced by materials in nature and even in their own bodies. This ever-present background radiation has persisted for as long as the earth has existed. Humans have evolved and developed in this ionizing radiation environment.

In discussing health effects relating to ionizing radiation, the term "dose" is used. "Dose" comes from the early medical use of x-rays, much as a dose of medicine is measured in grains or ounces. It refers to the amount of radiation energy absorbed by an organ, tissue, or cell, measured in rems.[10] Today, the average American receives a dose of 0.3 rem every year from natural sources—radioactive materials in rocks and soil, cosmic radiation, radon, and radioactivity in our bodies. Over a 70-year lifetime, the average dose is 21 rems. In some areas of the world, people receive much higher doses from background radiation. For example, in areas of India and Brazil the ground is covered with monazite sand, a radioactive ore. Radiation exposure rates there are many times the average background levels elsewhere. People who live in these areas receive doses of up to about 0.7 rem each year from the gamma radiation alone.[11] These levels combined with the other sources of background radiation (cosmic rays, radon, etc.), cause average doses that are about three times more than the US average. Yet these people show no unusual rates of cancer or other diseases linked to radiation.[12]

The effects of ionizing radiation can be categorized as either prompt or delayed, based on the time frame in which the effects are observed. Prompt effects, like rapid death, occur when high doses are received in a short period of hours to weeks. Delayed effects, such as cancer, can occur when the combination of dose and dose rate is too small to cause prompt effects. Both animal experiments and human exposures to high levels of radiation show that ionizing radiation can cause some cancers.[13] All of the observed effects of ionizing radiation in humans occur at relatively high doses. At the low doses that are of interest to radiation workers and the general public (that is, below a few rems), studies to date are inconclusive.[14] Although adverse health effects have not been observed at low doses, the carcinogenic nature of ionizing radiation makes it wise to limit the dose.

For low-doses, there is no reliable data relating dose to health effects or showing a threshold, or minimum, level for cancer. Because of this, experts who study radiation effects have decided that the results from high-dose, high-dose-rate studies must be used to control the low-dose, low-dose-rates experienced by workers and the public. The easiest way to do this is to assume that no effects occur at zero dose. Also, since the rate at which effects occur is extrapolated from higher doses, it is also assumed that the effect increases linearly with dose. These two assumptions are known as the "linear-dose-response, non-threshold" (LNT) hypothesis. This implies that the same number of additional cancers would occur from exposing 100 persons to 100 rems, or 10 thousand persons to 1 rem, or 10 million persons to 0.001 rem. No threshold

[10] A rem (roentgen equivalent in man or mammal) is a measurement of the relative effectiveness of a radiation dose. See Glossary at Tab A for a more detailed definition.
[11] BEIR V, Health Effects of Exposure to Low Levels of Ionizing Radiation, National Academy Press, Washington, D.C., 1990, p. 384.
[12] BEIR V, Health Effects of Exposure to Low Levels of Ionizing Radiation, National Academy Press, Washington, D.C., 1990, p. 385.
[13] BEIR V, Health Effects of Exposure to Low Levels of Ionizing Radiation, National Academy Press, Washington, D.C., 1990, p. 385.
[14] BEIR V, Health Effects of Exposure to Low Levels of Ionizing Radiation, National Academy Press, Washington, D.C., 1990, p. 385.

effects have ever been reliably observed in humans below about 10 rems[15], but reports from the Japanese atomic bomb survivor studies conclude that the location and reality of such a threshold, if one does exist, are difficult to assess.[16]

3. Radiological Protection Standards and Guidelines

Ionizing radiation offers many benefits to society in medical diagnosis and treatment, greenhouse-gas-free power, food safety, etc. At the same time, it carries risks to safety and health as discussed above.

Within the first 30 years after the discovery of x-rays, standards were developed for the measurement of radiation. At about the same time, acceptable levels of dose were set. The first level, known as the 'tolerance dose', or that amount of radiation that could be tolerated, was set at one-tenth of a unit (about 0.1 rem in today's units) per day for 300 days a year.

From World War II to the early 1980s, radiation dose limits were adjusted downward in response to increased concern about radiation effects, the increased uses of radiation, and because improved radiation protection technologies appeared. The National Council on Radiation Protection and Measurements (NCRP, established in the 1930s) developed the recommended changes for the United States. During that time, the dose limit was reduced from three-tenths of a rem in a six-day period in 1946 to 5 rems per year in the mid-1950s. Also, a limit for the public was set at one-tenth of the worker limit to provide an additional margin of safety.

Research does not show a clear threshold dose for cancers from radiation, so the small risk per person at low doses had to be considered in relation to the large number of workers who were receiving those doses.[17]

The NCRP adopted three radiation protection principles: (a) no practice shall be carried out unless it produces a positive net benefit (sometimes called justification); (b) all exposures shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account (called optimization); and (c) the dose equivalent to individuals shall not exceed the recommended limits (called limitation). These principles work together to protect against both prompt and delayed effects in large groups of workers and the public.

In 1993, the NCRP released a new set of national recommendations based on International Council on Radiation Protection's (ICRP) 1990 recommendations. Those limits for non-threshold effects differ slightly from the earlier recommendations: 50 rems per year to any tissue

[15] Adverse Reproductive Outcomes in Families of Atomic Veterans: The Feasibility of Epidemiologic Studies, Institute of Medicine, 1995, p. 23-24.

[16] Otake, M. et. al., Radiation Effects Research Foundation Technical Report RERF TR 16-87, Severe Mental Retardation Among the Prenatally Exposed Survivors of the Atomic Bombing of Hiroshima and Nagasaki: a Comparison of the T65DR and DS86 Dosimetry Systems, 1987.

[17] Limitation of Exposure to Ionizing Radiation, Report No. 116, National Council of Radiation Protection and Measurements, Bethesda, MD, 1993, p. 33.

or organ and 15 rems to the lens of the eye to avoid cataract formation. The recommended occupational limits on whole-body doses (total effective dose equivalent), first set at 5 rems per year in 1958, are now set at no more than 5 rems in any one year and a lifetime average of no more than 1 rem per year.[18]

Occupational radiation exposure limits for federal agencies are currently established in "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," 52FR 1717, signed by President Reagan on January 20, 1987. The Nuclear Regulatory Commission implemented that guidance in its regulations on radiation protection (Title 10, Code of Federal Regulations, Part 20). These limits apply to all licensed uses of radioactive material under NRC's jurisdiction. Similarly, other Federal agencies as a matter of policy and directive, including the DoD in DODI 6055.8, Occupational Radiation Protection Program, also observe this guidance.[19]

The current established protection standards are:[20]

- 5 rems in a year for workers (to protect against cancer).
- 50 rems in a year for workers to any organ (to protect against threshold effects, such as radiation burns, etc.).
- 50 rems in a year to the skin or to any extremity.
- 15 rems in a year to the lens of the eye (to protect against cataracts).
- 0.1 rem in a year (70-year lifetime) for members of the public.

These limits are in addition to the radiation doses a person normally receives from natural background, medical testing and treatment, and other sources.

Because any amount of radiation dose is assumed to lead to some health effects (regardless of how small), guidance also requires that doses be kept "as low as reasonably achievable" (ALARA). This means that one should try to reduce doses to as far below the limits as reasonably possible.

For DU, the annual occupational limit of 5 rems was selected as the benchmark for evaluating the consequences of exposure in the Gulf War. This benchmark has been shown to be well below the levels at which any effects from ionizing radiation have ever been observed in people. Furthermore, the limit is consistent with the safe practices in the radiation industry.

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[18] Limitation of Exposure to Ionizing Radiation, Report No. 116, National Council of Radiation Protection and Measurements, Bethesda, MD, 1993, p. 34.

[19] "Occupational Radiation Protection Program, Department of Defense Instruction 6055.8, revised May 6, 1996.

[20] Title 10, Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, Subpart C, 20.1201: Occupational Dose Limits for Adults; and Subpart D, 20.1301, Dose Limits for Individual Members of the Public.

4. Implications for the Military

External radiation exposures may occur when personnel are close to DU due to its beta and gamma radiation. Studies of external radiation measurements inside tanks show that the tank commander, gunner, and loader receive a radiation dose rate of 0.00001-0.00002 rem/hour, an amount which is somewhat less than the average natural background rate of about 0.00003 rem/hour.[21] The tank driver may receive slightly higher dose rates of 0.00003 (gun pointed forward) to 0.00013 rem/hour (bustle fully loaded with DU ammunition pointed forward), when the driver's hatch is open.[22] This means the driver inside a fully loaded "heavy armor" tank (a model using DU armor panels) continuously, 24 hours a day, 365 days a year, would still receive a dose of less than 25% of the current, annual occupational limit of 5 rems. Studies have also shown that the maximum dose rate outside the tank approaches 0.0003 rem/hr at the front of a HA turret or over a fully loaded bustle. Continuous exposure at that level would produce an annual dose of about 2.6 rems or slightly more than one-half the occupational limit. Fortunately, these exposure scenarios represent very unlikely situations. Actual exposures based on realistic times spent in the tanks are likely to be less than 0.1 rems in a year.

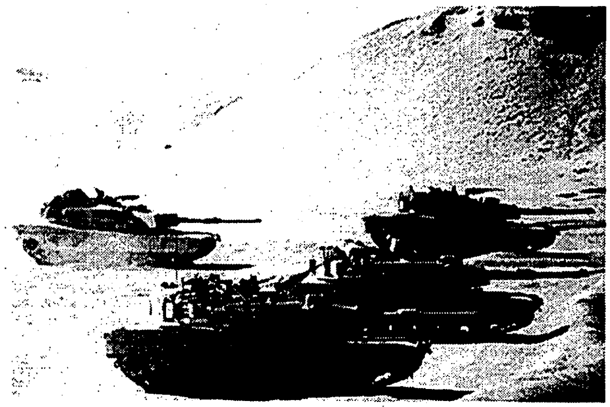

Figure 5 - M1A1s in the Gulf

Another external radiation hazard from DU is from contact with the bare skin. DU produces a dose rate of 0.2 rem/hour when it is located in contact with bare skin. The current dose limit for skin (50 rems in a year) would only be exceeded if unshielded DU remains in direct contact with the skin for more than 250 hours. Some reports have mistakenly applied the total effective dose equivalent (whole body dose) criteria of 0.1 rem/year for individual members of the public to this exposure. This leads to the erroneous conclusion that the exposure from one exposed DU penetrator could subject an individual to a dose of radiation thousands of times higher than the recommended maximum permissible dose. The correct criteria is the NRC's occupational dose limit of a shallow-dose equivalent of 50 rems/year to the skin or to each of the extremities.

In fires and during impact, DU forms both soluble and insoluble oxides. The inhalation of the insoluble oxides presents an internal hazard from radiation if they are retained in the lungs. Sustained exposure to the alpha and beta radiation from the material could damage lung tissue. As indicated in the following assessment section, the worst exposures in the Gulf were less than

[21] The figure of 0.00003 rem/hr is obtained when the average annual background dose (.3 rem) is divided by 8,760 hours in a year.

[22] Memo for Record (98-3), Subject: Radiation Measurements on M1A2 With Depleted Uranium, Aberdeen Test Center, 11 December 1997.

one-fifth the annual occupational limit and well below the level known to cause health effects in people.

III. ASSESSMENT OF POTENTIAL HEALTH EFFECTS FROM DU IN THE GULF THEATER, 1990-1991

For DU which enters the body, initial estimates of the radiation dose were derived from "worst case," computer-modeled scenarios in which an Abrams "Heavy Armor" model was struck and its DU armor panels penetrated by a 120mm DU round. The results of one round were doubled to represent the number of penetrations that posed a "worst case" exposure in the Gulf (several M1A1s were hit twice by DU rounds, but no penetrations of their DU armor occurred). Such a "DU-on-DU" penetration would produce levels of DU aerosolization and spalling (spattering of liquified metal) exceeding those that actually occurred during the Gulf War, and therefore result in higher estimates of crew intakes of DU than occurred.

Soldiers involved in such a hypothetical scenario, and who did not retain any DU fragments, would receive an effective dose equivalent of approximately 0.96 rem (See Section III.B.1.c). This radiation dose is less than one-fifth the annual occupational limit, and is well below the level known to cause adverse health effects in people.

Health effects assessments for 13 identified exposure events (shown in Table 1) are being prepared that describe the activities of the participants, specify the sources of potential DU exposure, and estimate the dose from inhalation, ingestion and wound contamination, as appropriate for each exposure category. These assessments also review the current understanding of health effects associated with DU, and provide descriptions of the health risks in plain language. Most of those studies are currently in progress and will be published in about one year. In the meantime, the circumstances of some of the more significant exposure incidents are described (Tab G) so veterans involved in these activities will be able to recognize and understand events that may have exposed them to DU. The veterans can then obtain information about possible health effects, and be advised as to what medical services are available to them.

A. Overview of Participants in Exposure Scenarios

As Table 1 shows, Gulf War personnel were exposed to DU in a number of ways. Some US combat vehicles were mistakenly destroyed or damaged by US tanks using DU sabot rounds. Personnel worked inside US vehicles contaminated with DU fragments and particles. Several accidental tank fires and an ammunition explosion and fire at Camp Doha, Kuwait in July 1991, resulted in DU rounds being burned, oxidized, or fragmented, which created potential exposure hazards to troops operating in the vicinity. Other troops entered Iraqi armor disabled by DU. Determining the medical consequences of these exposures, if any, requires a systematic, scientifically sound evaluation.

The first step in assessing the health risks from DU was to identify the potential exposures that took place, and then determine the essential facts of each event. This required an aggressive, thorough, and focused investigation that relied on hundreds of eyewitness interviews and thousands of pages of official and unofficial documents, records, reports, memos, and personal diaries and photographs. Information developed during this process was analyzed and synthesized to produce a detailed picture of events of concern.

The exposure scenarios observed during ODS/DS and in months following, were categorized into three levels based on the activities of the soldiers involved, and the resulting potential for direct contact with DU. These three exposure levels provided a prioritized approach to describing and evaluating the potential exposures that occurred:

<u>Level I</u> - Soldiers in or near combat vehicles at the time these vehicles were struck by DU penetrators, or who entered vehicles immediately after they were struck by DU munitions. These soldiers could have been struck by DU fragments, inhaled DU aerosols, ingested DU residues, or had DU particles land on open wounds, burns, or other breaks in their skin.

<u>Level II</u> - Soldiers and a small number of DoD civilian employees who worked in and around vehicles containing DU fragments and particles (mostly friendly fire wrecks). These soldiers may have inhaled DU residues stirred up (resuspended) during their activities on or inside the vehicles, transferred DU from hand to mouth, thus ingesting it, or spread contamination on their clothing. Soldiers who were involved in cleaning up DU residues remaining on Camp Doha's North Compound after the July 11, 1991, explosion and fires are also included in this group.

<u>Level III</u> - An "all others" group whose exposures were largely incidental and very brief. This group includes individuals who entered DU-contaminated Iraqi equipment, troops downwind from burning Iraqi or US equipment struck by DU rounds, or personnel downwind from burning DU ammunition, such as occurred at Doha during the July 11 fire. While these individuals could have inhaled airborne DU particles, the possibility of receiving an intake high enough to cause health effects is extremely remote.

To date, 13 categories of possible DU exposure have been identified and classified within the three levels as shown in Table 1 on page 8.

Substantial research has been conducted to determine the detailed exposure scenarios for participants in the 13 categories; and to perform assessments of the dose and health risk using a quantitative risk assessment process. The activities of many of the Level I, II, and III participants have been reviewed to develop the exposure scenarios. The US Army's Center for Health Promotion and Preventive Medicine (CHPPM) has reviewed existing test data on DU exposures and releases, and is developing dose estimates (chemical and radiological) for Level I exposures. Level I exposures are being addressed first, because these veterans probably received the highest exposures. Results of preliminary dose and risk assessments are reported below.

B. Level I Exposures (Friendly Fire)

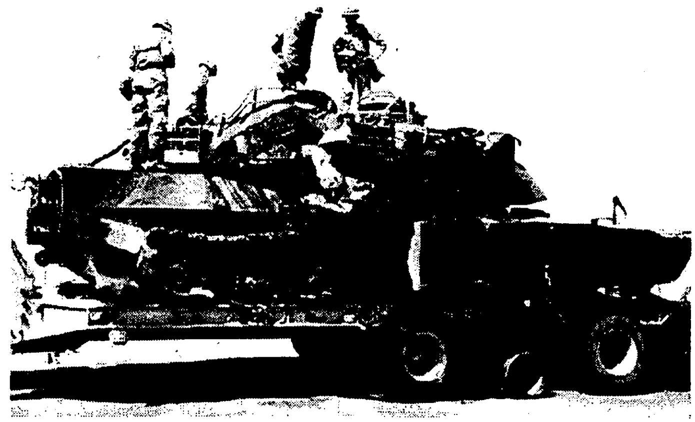

Figure 6 - M1A1 lost to friendly fire

Eight friendly fire incidents involving US M1A1s destroying or damaging occupied US-crewed vehicles with DU munitions occurred during the Gulf War. These incidents (distinct from non-DU friendly fire incidents or cases where friendly vehicles were evacuated and then deliberately destroyed to prevent their capture) resulted in the contamination of six M1/M1A1 tanks and 15 Bradley Fighting Vehicles. Another M1A1 was hit by a large shaped-charge round, believed to be a Hellfire missile fired from an Apache helicopter, that ignited an on-board fire. This incident is described in the "Tank Fires" Section (Tab J). Darkness and low visibility caused by heavy rains, sandstorms, etc., were major contributing factors in all of these incidents.[23]

In most cases, owing to battlefield confusion, soldiers manning the targeted vehicles initially believed that the Iraqis had fired the shots that penetrated their armor. The distinctive radioactive trace that DU leaves on the entrance and exit holes allowed a team of battle damage assessment experts to determine (after the fact) which vehicles had been hit by DU sabot rounds fired from Abrams tanks. After-action investigations and word-of-mouth reporting among the units involved generally resulted in the affected soldiers learning that they had been victims of friendly fire. Not all of these soldiers, however, were aware of the potential health effects associated with DU. Therefore, the investigation into the exposures resulting from friendly fire incidents is being accompanied by an effort to identify, locate, and contact all surviving soldiers who were in or on vehicles at the time they were penetrated by DU rounds.

As the spear-point of the ground campaign, US armored crews were often forced to make very rapid "friend or foe" decisions, where failure to engage could allow enemy gunners to take a first, fatal shot. Inevitably, given the swirling meeting engagements and close-in fights that erupted between friendly and enemy units, tragic misidentifications occurred.[24] A total of 21 US combat vehicles (6 Abrams tanks and 15 Bradley Fighting Vehicles) were struck by 120mm DU sabot rounds fired from US M1A1 tanks. Some of these vehicles were struck once, others several times. Based on typical manning configurations for the Abrams tanks (four crew members) and Bradleys (five to nine crew members depending on configuration), as well as

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[23] "Military Probes Friendly Fire Incidents" Washington, DC: Office of the Assistant Secretary of Defense, Public Affairs: News Release, August 13, 1991.

[24] For an in depth discussion of how fratricide can occur in ground combat, see: *Applying the National Training Center Experience—Incidence of Ground-to-Ground Fratricide, N-2438-A*, by Martin Goldsmith, The RAND Corporation, February 1986

information gathered from veterans, an estimated 113 soldiers were on board these combat vehicles at the time they were struck by DU penetrators. Table 3 lists the individual systems struck by DU and their estimated manning (see Tab H for a description of each friendly fire incident). Reports have suggested that at least one vehicle was struck initially by enemy fire, evacuated, and subsequently struck by a DU round. If these reports are verified, the numbers reported in Table 3 may decrease.

Table 3 - Summary of US vehicles hit by DU tank rounds

Army Unit	Vehicle Type	Bumper Numbers	Estimated Soldiers Onboard
4-7 Cavalry	Bradley	A-24, A-31, & A-22	15
1-37 Armor	Abrams	C-12	4
1-41 Infantry	Bradley	B-21, B-26, B-33, D-21 & D-26	30
3-66 Armor	Abrams	B-66, B-22, A-14, A-31 & A-33	20
3-15 Infantry	Bradley	C-11, C-22 & C-23	25
4-66 Armor	Bradley	HQ-55 & HQ-54	9
1-34 Infantry	Bradley	HQ-232	5
2-2 Cavalry	Bradley	G-14	5
		Total	113

Level I soldiers, injured or not, were in or around combat vehicles at the time they were struck by DU sabots, or immediately afterward. Besides the embedded fragments from wounds, these individuals may have inhaled DU aerosols generated by fires or by the impact of the DU projectile penetrating the target. The friendly fire incident summaries in Tab H describe the circumstances under which Level I soldiers were mistakenly targeted by US tank crews.

1. Soldiers in Vehicle On Impact

a) Summary of Activities

Armor crewmen and the "dismount" infantry transported in M2/M3 Bradley Armored Fighting Vehicles supplied the offensive striking power for Operation Desert Storm. US armored and mechanized infantry units counted on the speed, mobility, and firepower of their Abrams and Bradleys to maintain a rapid rate of advance while engaging and neutralizing enemy formations standing between Coalition troops and their objectives.

b) Hazard Identification

Table 4 shows possible combinations of personnel location, form of contamination, and route of exposure for Level I vehicle occupants. Additional details of the scenarios and assessments will be contained in the CHPPM exposure and health risk assessment report when published. Occupants of the vehicles were subjected to wounds from flying fragments, inhalation of airborne soluble and insoluble DU, ingestion of soluble and insoluble DU residues by hand-to-mouth transfer, and contamination of wounds by contact with contaminated clothing and vehicle interiors.

Table 4 - Potential Hazards to Occupants of Struck Vehicles.

Location	DU Form	Route of Exposure
Inside or Outside the Vehicle	Metal Fragment oxides	Wound Inhalation Ingestion Wound Contamination

Depleted uranium strikes on the exterior of an Abrams differ from those on Bradleys. The Abrams's thicker armor—reinforced at the turret and flanks by DU panels inserted between regular steel armor—offers much greater resistance to the impacting DU round than does the thinner, lighter weight aluminum-alloy skin of the Bradley. This results in a commensurate increase in DU aerosolization and fragmentation created at the point of penetration (and exit) and in the interior of the tank. The Bradley, in contrast, is less vulnerable to interior contamination because DU penetrators typically performed a "through-and-through" penetration of the Bradley's relatively thin armor, forming little aerosolization. During one incident, two DU rounds penetrated and flew through one Bradley and struck a second BFV standing twenty feet away. The range of likely exposures from a DU strike, therefore, can span a broad spectrum. Each incident needs to be carefully analyzed to draw any inferences about an individual's potential exposure. To develop data for an upper bound (worst-case) exposure which could result in the highest levels of contamination, the US Army Center for Health Promotion and Preventive Medicine (CHPPM) calculated the results from a DU sabot round penetrating the DU-protected portion of an Abrams. It should be noted that no such "DU on DU" penetrations occurred during the Gulf War. In several cases, however, Abrams tanks were hit more than once by DU rounds that penetrated non-DU portions of their armor. For this reason, the results from CHPPM's assessment of a single DU round penetrating an Abram's DU armor were doubled.

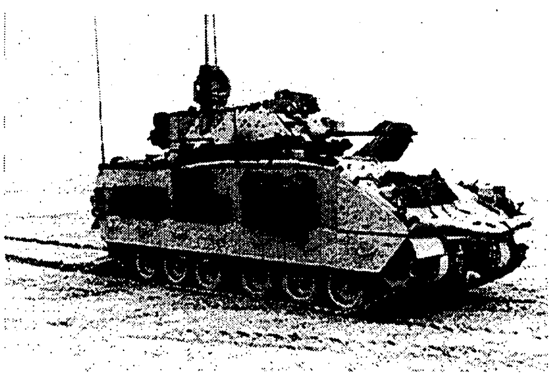

Figure 7 - Bradley Fighting Vehicle

c) Assessment of Health Effects

Soldiers in or on vehicles struck by DU munitions were possibly exposed through four routes: direct wounding, inhalation, ingestion, and contamination of wounds. Wounded soldiers who retained fragments of DU are among the 33 veterans currently being evaluated in the DU Follow-up Program (described in Section IV.C). Additional details of this assessment are discussed in Tab N.

To estimate the intake, the amount of DU taken into the body by inhalation, ingestion, and wound contamination must be established. CHPPM considered available test data from fires and DU impacts with tanks and other combat vehicles. In addition, computer-modeling results were used to show the effects of a DU round penetrating DU armor. Since several M1A1s were struck by more than one DU round during the Gulf war, the results for a single DU round striking DU armor were established, then doubled to provide a high bound or "worst case" estimate. As noted, this "worst case" estimate exceeds known exposures in the Gulf, since no penetrations of DU armor by DU rounds occurred during the Gulf War. In addition, most of the combat vehicles struck by friendly fire DU rounds were Bradleys. DU penetrations of Bradleys produce much less aerosol, since the Bradley's relatively thin aluminum alloy armor offers significantly less resistance to a DU sabot than the Abram's thicker steel and DU armor. Therefore, the data for single and multiple penetrations of an Abrams Heavy Armor tank considerably overstates the likely exposures for occupants of lightly armored vehicles, i.e. Bradleys.

The preliminary results of the computer-modeling analysis of these inhalation scenarios show a total inhalation intake of DU oxide from two DU penetrations of the tank's crew compartment to be 52 milligrams (mg) maximum and 24 mg average. These intakes were converted to radiation doses of 0.96 rem maximum, and 0.46 rem average using the Lung Dose Evaluation Program (LUDEP), a lung dosimetry modeling program accepted by the ICRP.

The maximum radiation dose for Level I individuals is estimated to be 0.96 rem from two DU penetrators. For comparison, the average radiation dose to a member of the US population from background radiation is 0.3 rem per year.[25] In other words, this maximum estimated exposure of 0.96 rem, that clearly overestimates the likely doses in Gulf War participants, is about the same as living in the United States for about three years[26] and is less that one-fifth the annual dose limit for workers of 5 rems.

The chemical-exposure based on the same dose scenario described above also assumes a 52 mg intake of DU particles for a 15 minute exposure. The 52 mg intake contains about 9 mg of soluble DU based on test data, indicating that up to about 17% of the airborne DU produced from impacts is soluble (ICRP Class D). For individuals who were in the vehicle when the DU penetrator did not enter the crew compartment, intakes of soluble DU are calculated to be much less, in the microgram range (14 μg).[27]

The estimates of DU intake and resulting radiation dose were used because test data (although limited) on DU concentrations in the air and on surfaces inside an Abrams tank were available to

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[25] Exposure of the Population of the United States and Canada from Natural Background Radiation, Report No. 94, NCRP (National Council on Radiation Protection and Measurements), Bethesda, MD, 1987.

[26] The earlier estimate (one year) reported in the Special Assistant's March 23, 1998 speech to the American Legion was revised upward to represent exposure from two rounds penetrating the turret and to reflect a much lower solubility than was previously used.

[27] Memorandum for the Office of the Special Assistant Secretary for Gulf War Illnesses, Subject: Program Summary, USACHPPM Assistance with OSAGWI's Depleted Uranium (DU) Environmental Investigation Report, August 3, 1998.

support the analysis. Although considerable data gaps prevent a better analysis now, studies to fill those gaps are expected to be available to support analyses in the final version of this report. In addition, this modeling is undergoing scientific peer review before the report is finalized. Nonetheless, the radiation dose estimated here is less than one-fifth the annual limit for workers. A comparison of the estimated health risks from radiation with the possible chemical toxicity effects of soluble uranium oxides demonstrates that DU's heavy metal toxicity effects may be the primary concern.

2. Soldiers Entering Vehicles Immediately After Impact

a) Summary of Activities:

Friendly fire incidents were usually witnessed by other US soldiers who in most cases served in the same platoon or company as the personnel in the struck combat vehicle. Typically these troops would rush to the aid of the stricken vehicle's occupants to perform emergency first aid and rescue operations. The responding troops often entered damaged or destroyed vehicles moments after they had been hit, raising concerns that they may have been exposed to DU residues or oxides still airborne from impacts, or stirred up by the activities of survivors and rescuers inside and outside the vehicles.

b) Hazard Identification

The activities outlined above for people who entered immediately after impact indicate that members of this group were potentially exposed in three ways. Personnel outside the tank could be subject to DU through ingestion of DU by hand-to-mouth transfer of contamination from the outer surfaces of the vehicle. Troops who enter the struck vehicles could inhale DU aerosols from the initial impact or resuspended (stirred up) DU residues. They could also ingest DU through hand-to-mouth transfer, or have DU settle in breaks in their skin (burns, wounds, or scratches).

c) Assessment of Health Effects

The full assessment of exposure details, dose, and risk for this group requires additional work to fill data gaps on resuspension of DU, transfer from hand to mouth, and wound contamination. CHPPM is continuing to research these cases, and has identified needs for additional information from the affected veterans. Initial assessments indicate that these individuals are very likely to have received smaller exposures than those who were in the vehicles when struck.

C. Level II Exposures

Once the crews and other injured personnel had been evacuated from the scene, Explosive Ordnance Disposal (EOD) teams, Battle Damage Assessment Teams (BDAT), Radiation Control (RADCON) teams and salvage and/or maintenance personnel converged on the damaged equipment. They removed munitions, personal weapons, and sensitive or salvageable equipment, surveyed the damage and surrounding area, and prepared the damaged vehicles for transport to a salvage depot in Saudi Arabia. At the salvage depot, troops from the 144th Service and Supply Company, unaware of the potential DU hazard, often worked inside the wrecked vehicles to salvage them or prepare them for destruction and/or burial.

In addition to six Abrams and 15 Bradleys knocked out in friendly fire incidents, several other tanks were damaged or destroyed by accidental non-combat fires (see Tab J for an accounting of vehicles sustaining accidental fires). These vehicles were contaminated by "cook-offs" of their on-board DU ammunition (typically 37 rounds per tank). As such, they required essentially the same decontamination as vehicles lost to friendly fire.

EOD and RADCON personnel also played key roles in responding to the post-war (July 11, 1991) Camp Doha motor pool fire in which three M1A1 tanks uploaded with M829 DU sabot rounds were destroyed, as well as several hundred DU rounds stored nearby. Cleanup efforts in Camp Doha's motor pool area (the North Compound) also exposed several hundred troops to residual DU contamination in the vicinity of the burned tanks and ammunition conexes (see Tab I for a description of the Doha fire and cleanup). EOD personnel also entered DU-contaminated enemy combat vehicles with greater frequency and duration than other troops. These activities exposed the troops involved to contact with "resuspended" (stirred-up) DU particles, oxides, and residues, albeit at a much lower level than the Level I cases. These exposures could take the form of inhalation and/or ingestion of DU (especially during hand-to-mouth transfer). A more complete discussion of Level II activities and practices can be found at Tab G.

Figure 8 – RADCON personnel atop M1A1 hulk.

D. Level III Exposures

This category includes individuals who incurred relatively fleeting exposures from climbing on or entering DU-exposed US or Iraqi combat vehicles to remove equipment or "trophy hunt" for souvenirs. It also includes personnel exposed to the smoke from burning tanks containing DU rounds. Several such incidents occurred during and after the War; the most notable being the Camp Doha, Kuwait, motor pool fire. In addition to personnel who are included in the Level II category—involved in cleaning up the North Compound—hundreds of additional troops may have received short-term exposure to the smoke from burning DU munitions stored in tanks or conexes. It is probable that some DU particles were entrained in the smoke that drifted over the soldiers who had evacuated to the southern tip of the base. A more complete discussion of Level III activities and practices can be found at Tab G.

E. Other Activities Under Investigation But Not Yet Categorized

The Office of the Special Assistant is often contacted by veterans who wish to report incidents that they believe could have exposed them to DU contamination. The incidents they describe are often isolated or unique events for which the available information is largely anecdotal. Each of these reports is investigated; in the following cases, however the Office of the Special Assistant cannot conclusively state, based on the available evidence, that DU exposures did or did not take place. Hence, they remain under investigation and have not been categorized. A more detailed description of these accounts is contained in Tab G after Level III Exposures.

1. Welders

Several veterans have reported welding DU armor panels onto the frontal turret armor of M1A1 tanks during refit operations to bring the tanks up to a higher survivability standard. Program managers, a senior metallurgist, and other personnel involved in the M1 refit program have disputed these claims, saying the panels in question were regular steel armor. Although this allegation remains under investigation, the initial assessment is that DU was not involved.

2. Reported Ammo Truck Explosion

A veteran reported seeing a US ammunition truck explode in the area of the 1st Infantry Division on the third or fourth day of the ground war. According to the veteran, a mixed load of high explosive and DU rounds exploded. Other soldiers and officers recalled an incident where a truckload of 155mm rounds or charges exploded after the truck's brakes caught fire and its driver (who apparently escaped injury), drove the truck into the desert to reduce the hazard to other soldiers. Although the available evidence suggests that DU rounds were not involved, information regarding this incident is still being sought.

3. Airmen Responding to A-10 Crash

An A-10 aircraft crashed and burned while trying to recover at King Khalid Military City (KKMC) in northern Saudi Arabia. The crash could have exposed emergency response personnel (firefighters, security policemen, rescue personnel) to smoke and DU oxides from burning 30mm DU rounds uploaded on the A-10. In addition, cleanup crews might have been exposed to DU fragments, residues, and oxides. This case is under investigation.

4. "Hot gun" response for A-10 Aircraft

30mm DU rounds sometimes misfired in the A-10's GAU-8 cannon. These "hangfires" would have to be cleared and removed from the gun barrel, potentially exposing ground crews to airborne DU. These incidents are still being identified and investigated by this office.

IV. FOLLOW-UP

Although DoD had conducted extensive research into environmental and medical concerns associated with the various DU munitions, several data gaps were identified during the Gulf War that necessitated further investigation. This section addresses environmental assessments of DU contamination on the battlefield, recent environmental studies of various DU munitions, results of current medical studies, future monitoring efforts, and on-going and planned research.

A. Environmental Assessments

Since Desert Shield/Desert Storm, the US Army Center for Health Promotion and Preventive Medicine (CHPPM) has conducted limited environmental sampling in the Gulf Region. Using radiation levels as a marker for the presence of DU or its compounds, i.e. DU oxides, a 16-member medical team deployed to Saudi Arabia, Kuwait, and Bahrain from October 19, 1994 to December 3, 1994, in part to evaluate potential occupational and environmental hazards to personnel deployed to the region. Potential exposures to DU were only one of the environmental concerns evaluated.

Figure 9 – Dr. Rostker (Special Assistant for Gulf War Illnesses) at Kuwait's "Valley of Death" Boneyard.

The team performed a screening survey for DU exposures at the "Valley of Death Boneyard" at the Udairi Range. This is the area used to store many of the vehicles destroyed by DU munitions during the Gulf War. The team collected a series of samples to evaluate the radiological hazard associated with the boneyard. The team selected vehicles, which had been hit by DU rounds, as confirmed by radioactivity levels at the penetration holes. Wipe samples were taken near the penetration holes to determine if the contamination was "fixed," as in molten spatters that had reformed and hardened around entrance or exit holes, or removable, i.e. oxides or residues that could be swept away. The report concluded that the remaining contamination was fixed. The team collected soil samples in drainage pathways on the site, and used lapel-mounted "personal breathing zone" samplers to assess personnel exposures at the site. The report concluded that:

> (N)o measurements significantly exceeded any applicable regulatory or consensus radiation protection exposure limit values used for assessing radiological health risk. In addition, these results indicate no DU exposure hazard to military personnel

working outside the boneyard but still within its immediate vicinity as long as there are no ongoing operations within the boneyard.[28]

CHPPM also conducted radiological analysis of 215 air samples collected during the 1991 Kuwaiti Oil Well Fires study at various military facilities throughout Kuwait and Saudi Arabia.[29] The report stated that "(A)ny dose assessments calculated using the measured radionuclide concentrations from air filter samples are well below US regulatory limits for the general public."[30]

In an effort to further evaluate environmental conditions encountered by US troops in Kuwait and Saudi Arabia, the US Army Central Command deployed the 520th Theater Army Medical Laboratory to Camp Doha in early March 1998, to supplement the already deployed Theater Medical Surveillance Team. These personnel conducted environmental surveillance during the Spring and early Summer. If available, the results of any DU investigations that they undertake will be incorporated in the next update of this DU Environmental Exposure Report.

In addition, there has been independent research concerning environmental testing for ambient exposures to uranium in the Gulf War Region. A study by Firyal Bou-Rabee, a professor in the Department of Geology at Kuwait University, reported on sampling performed on air, tap water, and soil samples at various locations in Kuwait. The report stated that the uranium in tap water was very low, which he attributes to the fact that their tap water is produced from desalinated seawater. Although the report did not specify where the ambient air sampling was conducted, the report concluded, "these uranium concentrations in the surface air do not represent any substantial radiological hazard for the Kuwait population." The total annual intake of uranium by inhalation in Kuwait was reported to be less than 0.2% of the recommended annual limit on intake for members of the general population.[31]

B. Developmental Testing and Evaluation of DU Munitions – Post Gulf War

The M919 25mm APFSDS-T cartridge that entered service in 1995 for use in Bradley fighting vehicles is the only new DU munition to be fielded by the US since the Gulf War. The results of the environmental sampling conducted during the hazard classification testing on the M919 were consistent with hazard classification testing performed on other DU munitions with certain

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[28] Problem Definition and Assessment (PDA) Team Activities During Operation Vigilant Warrior - 94, Final Report, US Army Medical Research Institute of Infectious Diseases, May 8, 1995, p. 20.

[29] Kuwait Oil Fire Health Risk Assessment No. 39-26-L192-91, Final Report, 5 May - 3 December 1991, Appendix H, Radiological Analysis, February 1994, p. H-2, H-6, H-7 and Enclosure 2.

[30] Kuwait Oil Fire Health Risk Assessment No. 39-26-L192-91, Final Report, 5 May - 3 December 1991, Appendix H, Radiological Analysis, February 1994, p. H-6

[31] Firyal Bou-Rabee, Estimating the Concentration of Uranium in Some Environmental Samples in Kuwait After the 1991 Gulf War, Applied Radiation Isotopes, Volume 46, Number 4, p 217-220, 1995, Elsevier Science LTD, Great Britain.

caveats (see Tab E).[32] The report concluded, "no measurable DU became airborne as a result of the External Fire Stack Test."[33] During hard impact testing, less than 10% of the DU was aerosolized and less than 0.1% of the initial mass of the penetrator was in the respirable range. Eighty-three percent (83%) of the oxide formed was insoluble.[34]

In order to evaluate real-life hazards of a fire involving a fully loaded Bradley Fighting Vehicle (BFV), the Army also conducted a burn test of a BFV equipped with TOW anti-tank missiles and 1,125 M919 25mm cartridges in 1994. The BFV was completely engulfed by the fire and burned vigorously for about an hour. The fire subsided after an hour, but continued to emit a plume over the next five hours with smoldering hot spots into the next day.[35] Of the 1,125 DU penetrators, 625 were accounted for, including nine live rounds found within a few meters of the test pad. Although 500 rounds were unaccounted for, the report indicated that a large percentage was trapped within the melted remains and a significant amount of the DU oxide was mixed within the ash and settled inside and around the hull of the vehicle. Although a small amount of DU oxide was released during the fire and subsequent explosions, only trace amounts were detected on the air monitoring filters placed at various distances from the Bradley during the 29 hours of air sampling.[36] The major difference between the Bradley Burn test and previous stack test burns was that six readily accessible piles of DU oxide were discovered in the burned out remains of the BFV. The BFV burn test was the first burn test that actually involved a vehicle fire. Previous burn tests were conducted in conjunction with hazard classification tests and involved metal and wooden storage crates. The results of the BFV fire may be more "life-like" and representative of actual battlefield results than previous hazard classification tests under less realistic conditions. The final report is scheduled to be released in the Fall of 1998.

Depleted uranium hard impact aerosolization testing was conducted in various foreign armored vehicles in June 1995 at the US Army Research Lab Test Facility located at the Department of Energy's Nevada Test Site as a piggyback to a Joint Live Fire Lethality Test of 120/25 mm DU munitions versus Soviet-produced armored vehicles. Both source term and resuspension testing of DU aerosols were conducted. Several technical and procedural difficulties seriously affected the data and limited the conclusions that could be drawn from this testing. In spite of these drawbacks, there were several key findings:

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[32] M.A. Parkhurst, J. Mishima, D.E. Hadlock, and S.J. Jette, Hazard Classification and Airborne Dispersion Characteristics of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7232, Richland, WA: Battelle Pacific Northwest Laboratory, April 1990.

[33] M.A. Parkhurst, J. Mishima, D.E. Hadlock, and S.J. Jette, Hazard Classification and Airborne Dispersion Characteristics of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7232, Richland, WA: Battelle Pacific Northwest Laboratory, April 1990, p. vi.

[34] M.A. Parkhurst, J. Mishima, D.E. Hadlock, and S.J. Jette, Hazard Classification and Airborne Dispersion Characteristics of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7232, Richland, WA: Battelle Pacific Northwest Laboratory, April 1990, p. vi.

[35] M.A. Parkhurst, M.H. Smith, and J Mishima, Bradley Fighting Vehicle Burn Test. Final Draft Report, Richland, WA: Battelle Pacific Northwest Laboratory, October 1997, p. 6.1.

[36] M.A. Parkhurst, M.H. Smith, and J Mishima, Bradley Fighting Vehicle Burn Test. Final Draft Report, Richland, WA: Battelle Pacific Northwest Laboratory, October 1997, p. 6.1-6.5.

- DU aerosols, containing particles of respirable sizes, are generated inside impacted armored vehicles by DU penetrator impact. The concentration of DU aerosol decreases with time, but measurable concentrations of respirable particles remain suspended hours later.
- Measurable quantities of DU oxide particles can be resuspended during routine personnel re-entry activities, and that the resuspended aerosols contain particles of respirable sizes.[37]

C. DoD and VA Medical Surveillance Programs for Gulf War Veterans

In 1993, the Office of the Army Surgeon General reviewed medical records of soldiers who had been hospitalized for wounds sustained in friendly fire incidents in the Gulf War. This review identified 22 soldiers whose records indicated retained metal fragments that might contain DU. Thirteen additional soldiers were identified as having been injured and potentially exposed to DU by friendly fire, but were not specifically identified as having metal fragments. Since 1993, the Baltimore Veterans Affairs (VA) Medical Center DU Follow-up Program has followed thirty-three of these individuals who were manning US Army vehicles at the time they were struck by DU munitions.

The 33 individuals evaluated at the Baltimore VAMC in 1993 and 1994 underwent a comprehensive medical and psychological evaluation. They also underwent a full-body x-ray survey, looking for retained metallic fragments. While these veterans have very definite medical afflictions resulting from their wartime injuries, they are not sick from the heavy metal or radiological toxicity of DU. Some veterans have multiple tiny fragments of DU scattered in their muscles and soft tissues. These fragments cannot be surgically removed without causing extensive damage to the surrounding tissues. Individuals who demonstrated increased excretion of uranium in the urine had evidence of retained DU fragments on X-rays. No detectable adverse effects on the kidneys were observed. No cases of cancer have been diagnosed in these participants; nor would one expect any at this point since the latency period for the onset of cancers possibly related to environmental exposure is at least twenty years. Since the Gulf War, all babies fathered by the veterans in the DU Program were born without observable birth defects.

In 1997, this group of DU-exposed servicemen returned to the Baltimore VA Medical Center for a three-day follow-up evaluation. Again, no detectable adverse effects on the kidneys were observed. Urine uranium excretion was still elevated above normal levels for the individuals retaining embedded DU fragments.

Another VA follow-up program was initiated in 1993 to evaluate the exposures of the 144th Service and Supply Company, the Army National Guard unit from New Jersey, which operated

[37] Depleted Uranium (DU) Hard Impact Aerosolization Test Summary Report (Source Term and Resuspension Estimates), U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, January 1998.

the damaged equipment yard at King Khalid Military City. Twenty-seven members of this unit were exposed to DU for a period of several weeks before being informed that some of the equipment in the yard had DU contamination. A cohort of 12 volunteers was medically evaluated at the Boston VA Medical Center in 1992. Eight of these servicemen volunteered to undergo urine testing and whole-body radiation counting, and four others underwent only the whole-body radiation counting. Although these individuals were potentially exposed to DU dust on and off over several weeks, the test results showed no residual body-burdens of DU.[38]

In July, 1998, the Department of Defense (DoD) and the Department of Veterans Affairs (DVA) instituted a medical follow-up program to evaluate veterans who received the largest DU exposures during the Gulf War. The follow-up program is aimed at ensuring that Gulf War veterans with higher-than-normal levels of uranium in their bodies are identified and given appropriate monitoring and treatment. The follow-up will be executed in phases. It is likely that most soldiers will have normal levels of uranium in their bodies. This program will provide reassurance to them. The program requires a 24-hour urine collection for urine uranium level and a detailed DU exposure questionnaire in addition to the examination Gulf War veterans receive through the Comprehensive Clinical Evaluation Program (CCEP) or the Department of Veterans Affairs (VA) Gulf War Registry. The notification and medical evaluation components of the program are described below.

1. Identification and Notification of Gulf War Veterans with Potential DU Exposures

As discussed in Section III and depicted in Table 1, the investigation by the Office of the Special Assistant has classified possible Gulf War DU exposures into 13 separate activities, which are in turn categorized into three levels. This investigation was intended to determine how many US service personnel may have been exposed to DU, to what degree, and the possible health impact of these exposures. Underlying all of the Gulf War illnesses investigations is the responsibility to provide useful information to Gulf War veterans and their health care providers.

Initially, the Office of the Special Assistant's investigators will concentrate on locating the soldiers in Level I. Level I includes approximately 113 soldiers who were in or on top of a vehicle at the time it was penetrated by DU munitions, plus an estimated 30 to 60 more who entered burning DU-contaminated US vehicles to perform rescue operations. This group (especially the ones with retained DU fragments) is considered to have had the highest exposure to DU.

Trained interviewers will contact these 140 to 180 individuals by telephone, for two major purposes. First, the veterans will be informed about the availability of the DoD and VA DU medical screening programs, and they will be encouraged to enroll in the VA or DoD's Comprehensive Clinical Evaluation Program (CCEP) program for which they are eligible. They will be informed that a follow-up letter will be sent within a week of the initial phone contact.

[38] Facsimile from Department of Veterans Affairs, Medical Center and Outpatient Clinics, Boston, MA: May 14, 1997.

This letter will contain additional information on how to enroll in the medical programs and who to call for further assistance at the Office of the Special Assistant. Copies of the follow-up letter and a fact sheet on DU, as well as more detailed information about the phases of the follow-up program, are presented in Tab K. Thirty-three of the Level I individuals are already being followed by the Baltimore VA.

Second, the Office of the Special Assistant has analyzed friendly fire incidents in order to identify surviving troops who may have been exposed to DU. These veterans will be contacted by the Office of the Special Assistant and asked to provide information about their relevant experiences in order to reconstruct possible DU exposure levels and to establish a fuller accounting of personnel who were in or on the vehicles, or who performed immediate rescue operations.

After the initial emphasis on locating the individuals in Level I, the Office of the Special Assistant will expand its efforts to contact individuals from Level II whose duties required them to make numerous trips into equipment contaminated with DU (an estimated 115 to 183 individuals). This group includes 12 members of the Battle Damage Assessment Team, 6-12 Logistics Assistance Representatives, 27 members of the 144th Service and Supply Company, 30-60 unit maintenance personnel who performed maintenance on or in DU-contaminated systems, 30-60 EOD and unit personnel who downloaded equipment and munitions from DU-contaminated equipment, and 10-12 Radiation Control team members.

If after evaluating the groups described above, there is medical justification for looking at lesser exposed groups, the notification and medical follow-up will be extended to groups, such as the estimated 600 soldiers involved with the cleanup of the North Compound of Doha. In any case, veterans who are not among those to be notified and are concerned about their possible DU exposures will be able to obtain a DU medical evaluation from a DoD or VA physician, at the appropriate facility that is closest to them.

Should any health problems be detected, there will be an opportunity for a medical follow-up with a local primary care physician and/or specialists. The staff at the Baltimore VA is available to consult with primary care physicians about how to assess DU exposures clinically, how to interpret the results of tests for urinary uranium, how to educate veterans who have concerns about DU, and other relevant clinical questions.

2. DoD and VA Medical Evaluation Program for Gulf War Veterans with Potential DU Exposures

The DU medical evaluation program consists of three elements:

- the Phase I registry exam, which is currently used by DoD's Comprehensive Clinical Evaluation Program and VA's Gulf War Registry;
- an additional detailed questionnaire, designed to evaluate potential DU exposure; and
- a 24-hour urine collection for uranium level.

The Phase I registry exam includes: several questionnaires on demographics, Gulf War-related exposures, and medical history; a thorough physical examination; routine laboratory tests; and consultations with specialists, if needed. An additional exposure questionnaire will be added, which includes questions on the dates and locations of deployment, specifics about the potential type and duration of DU exposure (i.e., friendly fire vs. inspection of DU-contaminated vehicles), and whether the individual was wounded.

Each individual in the DU surveillance program will be asked to provide a 24-hour urine collection in a special container. Each of these urine specimens will be shipped to the Baltimore VA and analyzed by a single laboratory used for the uranium monitoring. The Baltimore VA will mail the results and their interpretation to the individual veteran, with a copy to the examining physician. Recommendations for follow-up will depend on whether the urinary uranium level is normal or increased.

Based on the ongoing monitoring of the 33 participants in the Baltimore program, the vast majority of individuals who enroll in the DU medical surveillance program are expected to demonstrate normal urinary uranium levels. These individuals should receive education and reassurance through appropriate communication from their primary care physicians.

If an individual demonstrates an elevated urinary uranium level, he or she will be referred to the Baltimore VA for further evaluation. Based on the results of the thirty-three participants in the Baltimore program, a high urinary level is a likely indication of previously unrecognized, retained DU fragments. Any individual showing elevated levels of uranium in their urine will be encouraged to receive follow-up in the Baltimore VA program. This follow-up will include periodic medical exams and urinary uranium determinations.

Based on more than 103,000 exams that have been performed in the CCEP and VA Gulf War Registry, many previously unrecognized or asymptomatic health problems have been detected (e.g. hypertension or diabetes mellitus). Therefore, it is likely that some of the veterans who enroll in the DU medical evaluation program will have health problems unrelated to DU exposure. Using appropriate clinical terms, physicians should carefully explain and interpret these health problems to veterans. Veterans who have chronic health problems should receive follow-up primary care at the appropriate military Medical Treatment Facility or VA Medical Center.

Some Gulf War veterans have expressed concerns about potential DU exposures, which were at much lower levels than those experienced by the veterans involved in the Level I or Level II categories. For example, some veterans are concerned about potential exposures from climbing on board damaged Iraqi vehicles, or from being present in the South Compound during the fire at Doha, in July 1991. While they are considered to have a much lower risk than the veterans in the friendly fire incidents, veterans with these lower exposures may still have questions for their physicians. Veterans in these lower exposure categories will not be specifically identified or contacted by the Office of the Special Assistant, but they may refer themselves to the DoD or

VA for medical advice. If these individuals and/or their physicians believe it is warranted, they will receive a DU medical evaluation. The physicians who perform the CCEP exams and the VA Gulf War Registry exams at each of the Medical Treatment Facilities and VA Medical Centers nationwide have been trained to perform DU medical evaluations. These medical evaluations are modeled on the evaluations developed by the Baltimore VA.

D. Postwar Research

There are two major, ongoing laboratory investigations of the health effects of DU, at the Armed Forces Radiobiology Research Institute, and at the Lovelace Respiratory Research Institute.

The Armed Forces Radiobiology Research Institute (AFRRI) in Bethesda, Maryland, is currently assessing the toxicity of embedded depleted uranium (DU) in the Sprague-Dawley rat. This research has relevance to Gulf War veterans who have retained DU fragments, which cannot be removed because the surgery would cause significant tissue damage. In previous studies in experimental animals, the major effect of short-term, high doses of uranium was cellular damage in the kidneys.

The goal of the AFRRI study is to evaluate kidney, behavioral, neurological, and reproductive toxicity associated with DU pellets implanted in the muscles of male and female Sprague-Dawley rats. Tissues are also assessed for uranium concentrations and cellular changes. There are two groups of comparison rats, animals implanted with tantalum pellets, a control metal, and animals that do not receive implants. The final evaluations of the animals, at 18 months after implantation, will be completed in 1998.

The uranium pellets appear to be dissolving very slowly over time, leading to high levels of uranium in the kidney, urine, and bone. Despite the high DU levels in the kidney, there is no evidence of kidney toxicity, based on several assays. These results indicate that kidney toxicity may be less of a hazard than anticipated.

These experiments demonstrate that uranium can cross the blood-brain barrier, similar to other heavy metals. Despite this, there is no evidence for behavioral neurotoxicity in male rats. They have been tested with a functional observational battery, and evaluated for passive avoidance and spontaneous locomotor activity.

The potential effects of DU on reproduction have been evaluated with pregnant rats. The female rats with the DU implants did not show any effects on ability to become pregnant or to carry the litter to term. There were no adverse maternal effects of DU, such as effects on maternal pregnancy weight gain or food and water intake. There were no effects of DU on the litters, such as the number of pups per litter, or weight of the pups. There was a correlation between DU levels in the maternal kidney, placental tissue, and fetal tissue. The possible effects of DU on the development of the offspring are now being investigated.[39]

In another study, the Lovelace Respiratory Research Institute (formerly Inhalation Toxicology Research Institute), Albuquerque, NM, is conducting similar studies on rats implanted with three dose levels of DU munitions alloys. The studies will attempt to assess potential carcinogenicity of the implanted materials as well as to assess various cellular and biophysical/biochemical effects.

V. LESSONS LEARNED AND RECOMMENDATIONS

DU appears destined to play a major role on future battlefields. The Services need to ensure that all personnel who could be deployed into theaters where DU may be used are aware of its potential environmental and occupational hazards. This would include non-combat medical and support personnel who could find themselves treating DU casualties or repairing DU-contaminated vehicles.

A. Improvements in Training and Awareness

In recognition of the unease with which many people view all things radiological, training and education must address DU's radiological and toxicological properties, as well as ways to minimize any possible risk. All military members should be required to attend annual training courses on DU, preferably incorporated into existing annual Nuclear Biological and Chemical (NBC) initial or refresher training courses. Since DU ammunition is now available to other nations, contamination from DU could be widespread on future battlefields. Therefore, the knowledge, expertise, and equipment to prevent or mitigate exposures must be equally widespread.

In addition to education and training, Service guidance must reflect an elementary recognition of DU as a hazardous material and battlefield contaminant. Regulations, checklists, operating instructions, field standard operating procedures, medical emergency and surgical treatment standards, and other guidance must reflect sound, accurate, and current guidance regarding procedures to be followed in a DU environment in keeping with the principle that exposures should be prevented or minimized whenever possible.

The test and evaluation programs that paved the way for the fielding of DU munitions and armor acknowledged the potential for creating battlefield DU contamination. The Department of Defense (DoD) recognized the need to protect troops who might have to operate in such

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[39] Kimberly A. Benson and Terry Pellmar. Neurotoxicity and Reproductive Effects of Embedded Depleted Uranium in the Rat (abstract). Conference on Federally Sponsored Gulf War Veterans' Illnesses Research; Program and Abstract Book, page 51; Washington, DC, June 17-19, 1998.

environments. Unfortunately, most of the guidance issued before and during the war was oriented toward peacetime accidents on US military installations, rather than addressing the very different demands of wartime and contingency operations. A number of memorandums and advisories (described in Tab O) containing simple, field expedient precautions and advice were sent to the theater, but often failed to reach units and troops who had to respond to accidents and events involving DU contamination.

The DoD has acknowledged that pre-war DU awareness training was inadequate. Abrams crewmen received a brief block of training on the peacetime, regulatory requirements for handling DU munitions. More extensive training was provided to Nuclear-Biological-Chemical (NBC) response personnel assigned to most units, as well as EOD, RADCON, and safety personnel.[40] In general, this information was not shared outside these units or agencies. The lack of DU awareness was identified as a deficiency, as evidenced by a May 24, 1991, memorandum from the Armament Munitions and Chemical Command (AMCCOM) to the Training and Doctrine Command (TRADOC) recommending that DU safety training be given to all armor and infantry soldiers and officers who required it.[41]

On September 9, 1997, the Special Assistant for Gulf War Illnesses wrote a memorandum to the Chief of Naval Operations, Chief of Staff of the Air Force, and Commandant of the US Marine Corps directing them to "ensure that all Service personnel who may come in contact with DU, especially on the battlefield, are thoroughly trained in how to handle it." The US Army's Training and Doctrine Command published Training Support Packages (TSPs) for respective training schools in September 1997. It is too early to evaluate the effectiveness of this training.[42]

On January 7, 1998, John J. Hamre, Deputy Secretary of Defense sent a follow-up memorandum to the Service Secretaries requesting that they provide him with an outline of the Services' depleted uranium training program. This program required identification of personnel categories to receive the training, a schedule for full implementation, and plans for periodic retraining.[43] The Services responded in March 1998, outlining their respective plans along with implementation schedules. Although the Services are expanding their DU training efforts, their actions to date have only marginally improved their ability to contend with DU hazards. Full implementation of the various training programs will be underway during the summer of 1998. The Office of the Special Assistant will continue to monitor the status of the Services' DU training efforts.

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[40] Operation Desert Storm - Army Not Adequately Prepared to Deal With Depleted Uranium Contamination, GAO/NSIAD-93-90. Washington, DC: United States General Accounting Office, Report to the Chairman, Subcommittee on Regulation, Business Opportunities, and Energy, Committee on Small Business, House of Representatives, January 1993, p. 34.

[41] Memorandum from AMCCOM to TRADOC, Subject: Depleted Uranium (DU) Contamination, May 24, 1991.

[42] Memorandum for Chief of Naval Operations, Chief of Staff of the Air Force, and Commandant of the US Marine Corps, "Depleted Uranium Ammunition Training," September 9, 1997.

[43] Memorandum for Secretaries of the Military Departments, "Depleted Uranium Training," January 7, 1998.

B. Developing Medically and Operationally Appropriate Guidance

During and after the Gulf War, the primary source of guidance concerning DU accidents was US Army Technical Bulletin (TB) 9-1300-278, "Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium." This TB was developed for peacetime accidents and not intended for direct application to combat scenarios. It needs to be rewritten to reflect the realities that will be encountered in operational or battlefield situations. TB 9-1300-278 currently emphasizes the use of MOPP 4 personal protective equipment when operating in a DU-contaminated environment. In reality, MOPP 4 is inappropriate given the actual hazard, creates significant heat stress problems and degrades personal performance and operational efficiency.

This issue has been recognized by the Army, which has taken steps to remedy the situation. A meeting was conducted in April 1998 to discuss organizational roles and responsibilities relative to low level radioactive hazards in operational settings. An Integration Process Team (IPT) was formed to review low-level radiation as well as nuclear, biological, and chemical hazards, and associated environmental issues. At the soldier level, the Army has developed a new training task "Respond to Depleted Uranium /Low-Level Radioactive Materials (DULLRAM) Hazards". All soldiers must receive this training and demonstrate the appropriate knowledge of the hazard and how to respond to it before they are considered combat-ready. This training, due to commence in FY99, should produce a dramatic, sustained improvement in troop awareness of DU. This new training and its anticipated benefits are detailed in Tab O, Guidance for Protecting Troops.

C. Timely, Effective Dissemination of Information

In addition to instilling awareness of DU in troops, leaders, and units, advisories or warning messages issued by agencies such as AMCCOM must be disseminated in a timely, effective manner to the troops and units requiring that information. Specific reporting procedures and points of contact must also be established and institutionalized so that the information "disconnects" that occurred during the Gulf War are not repeated. Currently, agencies such as the Army Safety Office and the Army Medical Command have well-developed channels for issuing alerts and advisories that reach soldiers through the chain of command as well as unofficial channels like Armed Forces Radio. Many of these existing channels could be used to reinforce and expand servicemembers' ability to operate safely in DU-contaminated environments.

D. Responsive Support to Tactical Ground Units

With few exceptions, most tactical ground units lack the requisite resources or training to effectively respond to large-scale incidents or events involving the uncontrolled release of DU. These units are, of necessity, structured, manned, equipped, and trained to execute a wartime mission. It is not reasonable or realistic to force these units to assume primary responsibility for health physics/industrial hygiene requirements, particularly at deployed locations. Instead, tactical commanders should be able to count on timely, effective support from dedicated radiation control (RADCON) teams and other specialists, as required.

The post-war ammunition explosion at Camp Doha, Kuwait is an instructive object lesson concerning the need for more rapid, responsive health physics/industrial hygiene support for deployed units. In the first week following a fire that damaged or destroyed 660 DU rounds and three M1A1 Heavy Armor tanks, the unit commander and his staff were forced to rely on the unit's integral NBC assets for advice and assistance in dealing with DU contamination. Unfortunately, these NBC assets were trained and equipped to respond to battlefield nuclear contamination, not accidents involving DU. Although they were familiar with DU and could carry out limited surveys and cleanup efforts, their effectiveness in this role was limited. Although RADCON teams were dispatched to Doha, they did not reach the base until a week after the fire—a week during which the unit leadership, with insufficient knowledge about DU or how to respond to DU contamination, sent troops into an area in which DU contamination was present without any personal protective equipment or DU awareness training. In addition, the RADCON teams deployed to Doha were not sent to support the unit or installation, per se, but rather to decontaminate and remove three contaminated M1A1 tanks and any exposed DU penetrators found in the immediate vicinity. The teams had little interface with the Commander and his staff, and left the installation when their mission was complete. Before, during, and after the RADCON teams' arrival, hundreds of soldiers conducted clearing and cleanup operations in an area with localized DU contamination, without being told about the potential hazard from DU or simple, field-expedient ways to prevent or minimize potential exposures. In future deployments, the Commander, his staff, and unit personnel should be supported by a more robust and responsive in-theater health physics/industrial hygiene capability.

E. Clear and Unambiguous Division of Responsibility

Given the likelihood of future decontamination/recovery scenarios, executive agents need to be clearly identified and the scope of their duties sufficiently delineated to clearly establish responsibility and accountability for all aspects of the radiation control effort. Most fixed facilities such as Air Force bases have designated specialty teams, e.g., disaster preparedness and bioenvironmental engineering teams with well-defined roles of responsibilities. The responsibilities within operational units, as described above, are not as well defined.

F. Collection and Reporting of Survey and Monitoring Results

Post-exposure assessments are difficult to quantify in the absence of specific data such as radiation readings. Much of the current anxiety surrounding DU might have been allayed if survey and monitoring efforts had been better documented, and medical testing (e.g. 24-hour or spot urines) accomplished as necessary. According to Army Regulation 40-5, "The necessity, frequency, and methodology for performing bioassay procedures will depend on the radionuclide(s), their chemical and physical form, and the amount of material potentially available for entry into the human body."[44] Memories corroborated by anecdotal evidence are insufficient to provide conclusive answers to troops who may or may not have been exposed to DU. In the future, radiation control and related medical efforts must be documented in sufficient detail to determine who was exposed, and to what degree.

G. Equipment

The AN/PDR-27, AN/PDR-77 and AN/VDR-2 RADIAC instruments were primarily designed for battlefield nuclear exposures and are less than ideal for detecting and measuring the weak emissions given off by DU. Although improved RADIAC equipment has been deployed with US forces in Bosnia, its availability is limited. Radiation detection equipment must be readily available in combat units to expedite the identification of DU-contaminated vehicles.

The Services need to review their current Personal Protective Equipment (PPE) to ensure that personnel are able to operate safely in a DU environment. Current MOPP-4 gear, while affording protection in most chemical, biological, or radiological environments, can cause a rapid degradation in personal performance, especially in desert conditions and is excessive for most situations involving DU. Since DU contamination appears to be more likely than chemical, biological, or nuclear weapons scenarios, the Services should assess their current requirements to determine if supplemental, lightweight respirators and similar DU-suitable protective equipment could be acquired to replace MOPP-4 in the DU remediation (but not NBC protection) role.

In response to the wartime NBC hazard, procedures have been developed to mark contaminated vehicles or to create chemical hazard areas. Similar procedures should be considered for marking DU-contaminated vehicles and areas.

H. Medical

Considerable research was conducted on the environmental and medical implications of DU munitions during their developmental cycles. However limited research was devoted to establishing the medical effects from embedded DU fragments. Postwar efforts to fill this gap have been initiated through AFRRI's research (described earlier in Section IV.D) and the Department of Veterans Affair's surveillance and follow-up program (the Baltimore DU Program described in Section IV.C). The objective of this follow-up program is to determine whether the current criteria for removal of metal fragments applies to embedded DU fragments. While results to date indicate no requirement to change existing criteria, continued follow-up is required.

Current and future military munitions and equipment development efforts must evaluate all potentially harmful materials (including tungsten and lead) in the full context of operational exposures. While there are ongoing efforts aimed at fratricide prevention, development efforts must recognize fratricide related exposure scenarios as well as the probability of the enemy

[44] *Preventive Medicine,* Army Regulation 40-5, October 15, 1990, Paragraph 9-6.a.(2)(a), p. 189.

possessing and using potentially harmful materials. It is clear that DU will be used by future adversaries.

Research is needed to develop better estimates of the amount of depleted uranium that may be internalized by personnel entering vehicles after fires involving depleted uranium, or entering vehicles struck by depleted uranium. This information is required to determine and/or validate peacetime standards of practice and to help in establishing standards of practice for all military operations involving these munitions. This research is the foundation upon which technical bulletins and regulations prescribing DU precautions, exposure reporting, and medical monitoring must be based.

Because bio-monitoring of troops immediately after potentially significant exposure to DU (i.e. friendly fire incidents, immediate rescue efforts and working inside DU contaminated vehicles) was not done during the Gulf War, there are no medical data from such exposures for scientific evaluation. While peacetime bio-monitoring programs are in place, standards and guidance for specific bio-monitoring during combat must be developed and implemented. This monitoring must be tailored to the operational setting, recognizing that data collection during combat would be more difficult than in the postwar cleanup phase.

VI. CONCLUSION

In this report, the Office of the Special Assistant for Gulf War Illnesses has presented a history of depleted uranium development, its use during the Gulf War, and resulting exposures. The investigation examined DU's properties—chemical and radiological—and what the potential health risks of those properties could mean to an exposed individual.

Each of the DU-exposure incidents reported to date was investigated and analyzed in detail. Investigative efforts were aimed at establishing the facts and circumstances surrounding each incident and determining who might have been exposed. This effort is still ongoing, but the investigation has determined the essential facts of the most serious (Level I and II) exposure incidents and scenarios, as well as identifying many of the participants.

The report acknowledges that many American soldiers were exposed to DU through wounds, inhalation, ingestion, or bare skin contact. It also identifies and addresses significant shortcomings in the way US troops were trained to operate in environments where DU contamination was present, and identifies lessons learned that can be applied to future operational deployments. Further, it outlines steps this Office has taken to ensure that DU training and awareness receives proper emphasis from all Service components.

This report notes past inconsistencies between peacetime guidance and wartime practices. It explains why much of the guidance in place at the time of the Gulf War was excessive or disproportionate to the actual exposure hazard. It makes the case that future guidance must be practical and applicable to battlefield operations where contact with DU, under uncontrolled conditions, can occur over a broad range of environments.

The report outlines the new, expanded medical follow-up program aimed at identifying, evaluating, and providing medical follow-up, if need be, to personnel likely to have incurred the highest DU exposures. Although the focus of the notification effort is on these participants, soldiers who had lesser exposures can also request an evaluation for DU exposure.

In tandem with efforts to identify exposed personnel, efforts were undertaken to assess the possible health risks and medical significance of various exposure groups. Experts in relevant fields were consulted and expert literature was reviewed. The US Army Center for Health Promotion and Preventive Medicine (CHPPM), is currently performing DU dose assessments in an effort to apply refined data (from computer modeling and live-fire test results) to the study of DU's health effects. The RAND Corporation is doing an independent review of medical and scientific literature on known medical and health effects. Although CHPPM and RAND efforts are ongoing, preliminary estimates of worst case exposures do not indicate a significant radiological hazard. The medical significance of the preliminary chemical (heavy metal) estimates in humans is more difficult to determine and may be clarified once the RAND effort is completed.

Since 1993, the Department of Veterans Affairs has been monitoring 33 vets who were seriously injured in friendly fire incidents involving depleted uranium. These veterans are being monitored at the Baltimore VA Medical Center. While these veterans have very definite medical afflictions resulting from their wartime injuries, they are not sick from the heavy metal or radiological toxicity of DU. About half of this group still have depleted uranium metal fragments in their bodies. Those with higher than normal levels of uranium in their urine since monitoring began in 1993 have embedded DU fragments. These veterans are being followed very carefully and a number of different medical tests are being done to determine if the depleted uranium fragments are causing any health problems. The veterans being followed who were in friendly fire incidents but who do not have retained depleted uranium fragments, generally speaking, have not shown higher than normal levels of uranium in their urine.

Previous research has demonstrated that the organ that is most susceptible to damage from high doses of uranium is the kidney. For the 33 veterans in the program, tests for kidney function have all been normal. In addition, the reproductive health of this group appears to be normal in that all babies fathered by these veterans between 1991 and 1997 had no birth defects.

For the broader veteran population, data derived from the DoD's Comprehensive Clinical Evaluation Program that has evaluated tens of thousands of Gulf War veterans might be more applicable. Thus far, very few Gulf War veterans have been diagnosed with types of kidney damage for which depleted uranium would be on the list of possible causative agents. The rates of these diagnoses in this self-selected population (participation in the CCEP is voluntary) are consistent with the rates of similar kidney problems found in the general US population. By definition, those veterans with undiagnosed illnesses have not had any evidence of kidney damage. Therefore, there is no evidence that Gulf War veterans are experiencing adverse health effects from DU's chemical toxicity.

The report's bottom-line conclusion, based on a comprehensive review of available data and a science-based methodology, is that exposures to DU's heavy metal (chemical) toxicity or low-level radiation are not a cause of the undiagnosed illnesses afflicting some Gulf War veterans.

This case is still being investigated. As additional information becomes available, it will be incorporated. If you have records, photographs, recollections, or find errors in the details reported, please contact the DoD Persian Gulf Task Force Hot Line at 1-800-472-6719.

Tab A - List of Acronyms/Glossary

This tab provides a listing of acronyms found in this report. Additionally, the Glossary section provides definitions for selected technical terms, which are not found in common usage.

Acronyms

ACGIH .... American Conference of Governmental Industrial Hygienists
ACR .... Armored Cavalry Regiment
AD .... Armor Division
AED .... Aerodynamic Equivalent Diameter
AEPI .... US Army Environmental Policy Institute
AFRRI .... Armed Forces Radiobiology Research Institute
AHA .... Abrams Heavy Armor
ALARA .... As Low As Reasonably Achievable
AMC .... Army Materiel Command
AMCCOM .... Armament Munitions and Chemical Command
ANG .... Army National Guard
ANSI .... American National Standards Institute
AP .... Armor Piercing
APFSDS .... Armor-Piercing Fin Stabilized Discarding Sabot
APFSDS-T .... Armor-Piercing Fin Stabilized Discarding Sabot with Tracer
API .... Armor Piercing Incendiary
ASTM .... American Society for Testing Materials
AT .... Anti-tank
BDAT .... Battle Damage Assessment Team
BEIR .... Biological Effects of Ionizing Radiation
BFV .... Bradley Fighting Vehicle (tracked)
BMP .... Soviet made armored fighting vehicle (tracked)
BTR .... Soviet made armored personnel carrier (wheeled)
CFR .... Code of Federal Regulations
CFV .... Cavalry Fighting Vehicle
CHPPM .... Center for Health Promotion and Preventive Medicine
CIWS .... Close-In Weapon System (20mm Air Defense Gun); also called Phalanx
DoD .... Department of Defense
DU .... Depleted Uranium
DULLRAM .... Depleted Uranium /Low-Level Radioactive Materials
EOD .... Explosive Ordnance Disposal
FASCAM .... Family of Scatterable Mines
GAO .... General Accounting Office
HE .... High Explosive

HEAT .... High Explosive Antitank
HEI .... High Explosive Incendiary
IARC .... International Agency for Research on Cancer
ICRP .... International Commission on Radiological Protection
ID .... Infantry Division
IEEE .... Institute of Electrical and Electronic Engineers
IOC .... Industrial Operations Command
JTCG/ME .... Joint Technical Coordinating Group for Munitions Effectiveness
KE .... Kinetic Energy
KKMC .... King Khalid Military City, Saudi Arabia
LAR .... Logistics Assistance Representatives
MOPP .... Mission Oriented Protective Posture
mrem .... millirem (one thousandth of a rem)
NAS .... National Academy of Science
NBC .... Nuclear, Biological and Chemical
NCRP .... National Council on Radiation Protection and Measurements
NJANG .... New Jersey Army National Guard
NRC .... Nuclear Regulatory Commission
ODS/DS .... Operation Desert Shield/Desert Storm
OSHA .... Occupational Safety and Health Administration
PEL .... Permissible Exposure Limit
PPE .... Personal Protective Equipment
RADCON .... Radiation Control
RADIAC .... Radiation Detection, Identification and Computation
RHS .... Rolled Homogenous Steel
RPG .... Rocket Propelled Grenade
RPO .... Radiation Protection Officer
SWA .... Southwest Asia
T-72 .... Soviet-made main battle tank
TB .... Technical Bulletin
TLV® .... Threshold Limit Value
UXO .... Unexploded Ordnance
VA .... Department of Veterans Affairs
WA .... 97.5% tungsten/2.5% binder in tungsten alloy
μm .... micron (one millionth of a meter)

Glossary

Absorbed Dose: The energy imparted by ionizing radiation per unit of mass irradiated material. The units of absorbed dose are the rad and gray (Gy).

Activity: The number of nuclear transformations occurring in a given quantity of material per unit of time. (see Curie)

ALARA: Acronym for "as low as reasonably achievable." The Nuclear Regulatory Commission defines ALARA as making every reasonable effort to maintain radiation exposures to as far below the dose limits as is practical considering the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to the benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and license materials in the public interest.

Alpha Particle (α): A charged particle emitted from the nucleus of an atom having a mass and charge equal in magnitude to a helium nucleus; i.e., two protons and two neutrons with a +2 charge.

Atom: Smallest particle of an element, which is capable of entering into a chemical reaction.

Atomic Mass: The mass of a neutral atom of a nuclide, usually expressed in terms of "atomic mass units." The "atomic mass unit" is one-twelfth the mass of one neutral atom of carbon-12; equivalent to 1.6604 X 10^{-24} gm. (Symbol: u).

Atomic Number: The number of protons in the nucleus of a neutral atom of a nuclide.

Atomic Weight: The weighted mean of the masses of the neutral atoms of an element expressed in atomic mass units.

Background Radiation: Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

Beta Particle (β): A charged particle emitted from the nucleus of an atom with a mass and charge equal in magnitude to that of an electron.

Carcinogenic: Capable of producing cancer.

Class: Also referred to as Lung Class or Inhalation Class. This refers to a classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lungs. Materials are classified as D, W, or Y, which apply to a range of clearance half-times. Class D (Days) are cleared in less than 10 days. Class W (Weeks) are cleared between 10 and 100 days and Class Y (Years) are cleared in greater than 100 days. Recent recommendations in International Commission on Radiological Protection Report #66 have replaced classes D, W, and Y with F (fast), M (moderate), and S (slow).

Curie: The special unit of activity. One curie is the amount of material in which 3.700×10^{10} atoms transform per second. (Abbreviated Ci.) Becquerel (Bq) is replacing it. One Bq is equal to 2.7 X 10-11 Ci (or 1.0 disintegrations per second).. Several fractions of the curie are in common usage:

> Millicurie: One-thousandth of a curie (3.7×10^{7} disintegrations per second.). Abbreviated mCi.
>
> Microcurie: One-millionth of a curie (3.7×10^{4} disintegrations per second.). Abbreviated µCi.
>
> Picocurie: One millionth of a microcurie (3.7×10^{-2}disintegrations per second or 2.2 disintegrations per minute). Abbreviated pCi.

Disintegration (Nuclear): A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus. When numbers of nuclei are involved, the process is characterized by a definite half-life.

Dose: A general term denoting the quantity of radiation or energy absorbed.

Dose Equivalent: The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert.

Dosimeter: Instrument to detect and measure accumulated radiation exposure. During the Gulf War, two types of dosimeters were used: a pencil-sized ionization chamber with a self-indicating electrometer and a wrist watch dosimeter, which requires a separate reader. The wrist watch dosimeter detects both gamma and neutron radiation and is intended to measure high doses, e.g., following tactical employment of nuclear weapons (rather than DU contamination) on the battlefield.

External Dose: That portion of the dose received from radiation sources outside the body.

Gamma Ray (γ): Short wavelength electromagnetic radiation of nuclear origin (range of energy from 10 keV to 9 MeV) emitted from the nucleus. A gamma ray is essentially equivalent to a x-ray. Both are photons of energy—the difference being that gamma rays originate in the nucleus of the atom and x-rays originate in the extranuclear part of the atom, but x-rays are typically of lower energy.

Gray (Gy): Standard international unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule/kilogram or 100 rads.

Half-life (Biological): The time required for the body to eliminate one-half of an administered dosage of any substance by regular process of elimination. Approximately the same for both stable and radioactive isotopes of a particular element.

Half-life (Radioactive): The time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

Internal Dose: That portion of the dose received from radioactive material taken into the body.

Isotope: Atoms having the same number of protons in their nuclei, and hence the same atomic number and element, but differing in the number of neutrons, and therefore in the mass number. All isotopes of an element have identical chemical properties. The term should not be used as a synonym for nuclide.

Joule: The unit of work, equal to one Newton expended along a distance of one meter ($1J = 1N \times 1m$).

Kilo Electron Volt (keV): One thousand electron volts or 10^3 volts.

Newton: The unit of force, which when applied to a one kilogram mass will give it an acceleration of one meter per second per second ($1N = 1kg \times 1m/s^2$).

Nonstochastic Effect: Health effect, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect. Also called a deterministic effect.

Occupational Dose: The NRC defines occupational dose as the dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and/or radioactive material from licensed and unlicensed sources of radiation. Occupational dose does not include dose received from background radiation, from any medical administration the individual has received, from voluntary participation in medical research programs, or as a member of the public.

Oxide: A binary chemical compound in which oxygen is combined with a metal or nonmetal.

Public Dose: The NRC defines public dose as the dose received by a member of the public from exposure to radiation and/or radioactive material released by a licensee, or to any other source of radiation under the control of the licensee. Public dose does not include occupational dose or doses received from background radiation, from any medical administration the individual received, or from voluntary participation in medical research programs.

Rad (radiation absorbed dose): A unit of absorbed dose. One rad is 0.01 Joule absorbed per kilogram of any material. Also defined as 100 ergs per gram. It is being replaced by gray (Gy). One rad equals 0.01 of a gray.

RADIAC Equipment Radiation detection, identification and computation equipment, or equipment that measures radiation.

Radioactive/ Radioactivity: The property of the nuclei of certain atoms spontaneously emitting particles or gamma radiation or of emitting x radiation following orbital electron capture or of undergoing spontaneous fission. Atomic nuclei are of two types, stable and unstable. Unstable nuclei are said to be radioactive and eventually are transformed by radioactive decay into the stable nuclei. One or more of the three types of radioactive emissions (α or β particles or γ-rays) occur during each stage of the decay.

Radioisotope: Those isotopes of an element, which are radioactive.

Rem (roentgen equivalent man or mammal): A unit of measure that takes into account the biologic effectiveness of various types of radiation. The rem is numerically equal to the rad multiplied by a Radiation Weighting Factor (formerly a "quality factor"). The Radiation Weighting Factor (RWF) reflects differences in the amount of each type of radiation necessary to produce the same biologic effect. For beta, gamma, and X radiation, RWF is 1.0, making their effect on tissue equivalent. The RWF for alpha particles is 20, indicating its biologic effect is 20 times greater that the effect of beta, gamma, or X radiation. Sievert (Sv) is replacing rem. One Sv is equal to 100 rem.

Roentgen: The amount of ionization in air caused by X and gamma radiation. One roentgen of exposure will produce about 2 billion ion pairs per cubic centimeter of air. A roentgen is only a measure of the ionization that radiation produces in air. It does not provide exact information about the amount of energy that is actually absorbed by a medium, or about the effects of the radiation on the medium.

Sabot A lightweight carrier designed to center a projectile of a smaller caliber in the gun barrel. The sabot is normally employed to fire the smaller caliber projectile from a large caliber main gun; it usually is discarded a short distance from the muzzle.

Sievert (Sv): Standard international unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the radiation weighting factor (1 Sv=100 rems).

Specific Activity: The activity of the radionuclide per unit mass of that nuclei. See radioactive.

Solubility: Capability of being dissolved. The amount of a substance that can be dissolved in a given solvent (i.e., lung fluid) under specified conditions.

Stochastic Effect: Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

Tritium: Isotope of hydrogen with one proton and two neutrons in the nucleus. Beta emitter.

Tab B - Units Involved

7th Corps
- 1st Infantry Division
  - 1st Brigade
    - **1-34 Infantry**
    - **2-34 Armor.**
  - 3rd Brigade (from 3rd Brigade, 2nd Armored Division)
    - **1-41 Infantry**
    - **3-66 Armor**
- 1st Armored Division
  - 1st Brigade (3rd Brigade, 3rd Infantry Division)
    - **4-66 Armor**
  - 3rd Brigade
    - **1-37 Armor**
- 3rd Armored Division
  - **4-7 Cavalry**
- 2nd Armored Cavalry Regiment
  - **2-2 Cavalry**

18th Airborne Corps
- 24th Infantry Division
  - 2nd Brigade
    - **3-15 Infantry**
    - **3-69 Armor**

11th Armored Cavalry Regiment
- **1-11 Cavalry**
- **2-11 Cavalry**
- **58th Combat Engineer Company**
- **54th Chemical Troop**

146th Ordnance Detachment (EOD)

USS Missouri

Tab C - Properties and Characteristics of DU

Natural uranium (extracted from uranium ore) is processed to form enriched uranium for nuclear power. Depleted uranium (DU) is the by-product of this uranium enrichment process. Natural uranium is composed of three isotopes, uranium-238 (^{238}U), uranium-235 (^{235}U) and uranium-234 (^{234}U). Although the exact percentages vary slightly, natural uranium typically is composed of approximately 99.28% ^{238}U, 0.71% ^{235}U, and 0.0055% ^{234}U (See Figure 10). Isotopes of an element have essentially the same chemical and physical properties because they have the same number of protons (92) in their atoms. They differ only in the number of neutrons per atom. For example, ^{234}U, ^{235}U, and ^{238}U have 142, 143, 146 neutrons in each atom, respectively. It is this variation in the number of neutrons that gives the different isotopes their radiological properties. Isotopes differ in the types of radiation emitted during the nuclear decay process, decay rate, interactions with nuclear particles, and ability to undergo nuclear fission.[45]

The relative radioactivity of isotopes is measured by their specific activity, which is defined as the number of transformations or disintegrations per second per unit of mass. The unit of measurement of specific activity is microcuries per gram with a microcurie equal to 3.700 x 10^4 disintegrations per second. Although by weight ^{234}U is only 0.005% of the natural uranium, it accounts for 48.9% of the radioactivity of uranium. ^{235}U and ^{238}U account for the remaining 2.3% and 48.8% of the radioactivity of uranium, respectively.

To be used as nuclear fuel or weapons grade uranium, natural uranium must be enriched through a process that increases the ^{235}U content to approximately 3% for power reactor fuel, or over 90% for weapons grade uranium. This decreases the ^{238}U content to 97% or less than 10%, respectively, leaving "depleted uranium" with approximately 0.2% ^{235}U and 99.8% ^{238}U. ^{234}U is generally ignored because it is present in such small quantities. In the gaseous diffusion process a gaseous compound of uranium and fluorine, UF6, is separated into two fractions – one enriched in ^{235}U and one depleted in ^{235}U. The depleted fraction is then chemically transformed into a uranium metal derby. This is the first stage at which the depleted material is in the state necessary for further processing by ammunition manufacturers.

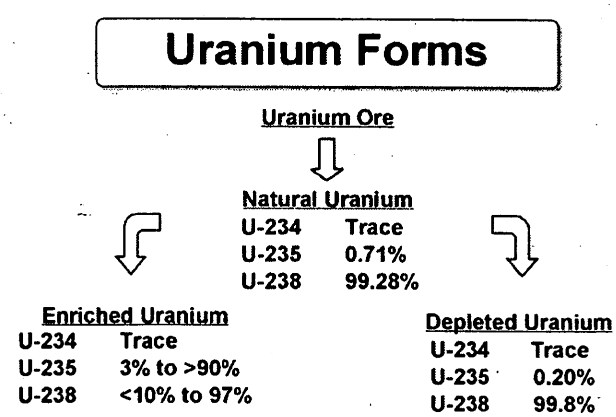


Figure 10 - Content by mass of uranium forms

[45] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 7-8.

The Nuclear Regulatory Commission (NRC) defines "depleted uranium" as uranium in which the weight percentage of the ^{235}U isotope is less than 0.711%. Military specifications mandated by the Department of Defense (DoD) require that the percentage of ^{235}U be less than 0.3%. In actuality, DoD uses DU with a ^{235}U content of approximately 0.2%.[46] DU is 40% less radioactive than the raw uranium-bearing ores found in nature; but its material content is still uranium. All isotopes of uranium are essentially identical chemically and, since depleted and natural uranium are just different mixtures of the same three isotopes, they have the same chemical properties.

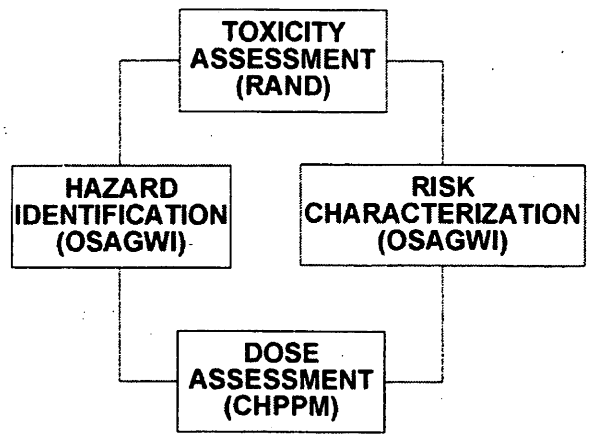
All isotopes of uranium are radioactive. Each has its own unique decay process emitting some form of ionizing radiation: alpha, beta or gamma radiation (or a combination). Alpha and beta radiations are actually discrete particles, whereas gamma radiation is essentially a photon of energy similar to an x-ray but from the nucleus. An alpha particle consists of two protons and two neutrons and is positively charged (+2). Most alpha particles are not energetic enough to penetrate skin and are not considered to be an external hazard. Alpha particles, however, can be a health hazard if inhaled or ingested in sufficient quantities. A beta particle is an electron (charge -1) emitted during the radioactive decay of an atom and is more penetrating than an alpha particle. Beta particles are able to penetrate skin a few millimeters and can pose both an internal and external health risk. Since a gamma ray is a photon of energy with no mass and no charge, it is extremely penetrating, and can be both an internal and external health hazard.[47]

^{238}U—which by weight makes up almost 99.8% of DU—is an alpha emitter. ^{238}U has a half-life of 4.5×10^9 years. ^{238}U decays into two short-lived "daughters:" thorium-234 (^{234}Th, half-life of 24.1 days) and protactinium-234m (^{234m}Pa, half-life of 1.17 minutes)—which are beta and weak gamma emitters. Because of this constant nuclear decay process, very small amounts of these "daughters" are always present in DU. ^{235}U (half-life of 7.0×10^8 years) decays into protactinium-231 (^{231}Pa, half-life of 3.25×10^4 years), which is an alpha, beta, and gamma ray emitter.[48] The ^{238}U and ^{235}U chains continue through a series of long-lived isotopes before terminating in stable, non-radioactive lead isotopes ^{206}Pb and ^{207}Pb, respectively.

[46] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 23.
[47] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 8-9.
[48] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 12.

Tab D - Methodology

To estimate the health risks from such exposures, DoD adopted a health risk assessment methodology based on that used by the US Environmental Protection Agency. This process, illustrated in Figure 11, estimates the health risk from contaminant concentrations, site exposure, and contaminant toxicity characteristics. It consists of four steps: Hazard Identification, Dose Assessment, Toxicity Assessment, and Risk Characterization.



Modified From Quantitative Health Risk Assessment Model, National Research Council, "Risk Assessment in the Federal Government: Managing the Process," 1983.

Figure 11 - Health Risk Assessment Process

Hazard Identification determines who was exposed and how. This includes identification of: a) the possible contaminants (DU); b) individuals exposed to that contaminant; c) exposure pathways (such as inhalation); and d) which incidents need to be evaluated. *Dose Assessment* estimates the intensity, frequency, and duration of exposures to DU and what the chemical and radiological intakes these doses represent. *Toxicity Assessment* involves researching the medical effects of exposure to DU and at what levels of exposure these effects occurs. *Risk characterization* is the "bottom line" of the health risk methodology. Using both dose-assessment and toxicity assessment data, the risk assessment provides an explanation of the health risk from a given activity or exposure scenario. To arrive at this assessment, the Office of the Special Assistant for Gulf War Illnesses (OSAGWI) developed an investigation and validation process that includes:

- A detailed reconstruction of the conditions and circumstances surrounding the various exposure scenarios.
- Evaluation of available, pertinent environmental factors—e.g., radiological surveys, air quality monitoring, and other data as appropriate.
- Eyewitness testimonies.
- A review of operative policies, guidance, and directives in place at the time of the incidents in question.
- A review of actual practices and compliance with policies, guidance, and directives in force during the events in question, and identifying issues not adequately addressed by that guidance.
- A review of the existing body of scientific and medical data relative to known Gulf War exposure conditions and variables.
- Identification of information gaps and essential elements of information.

- Review of the current body of scientific and medical information on the health effects of DU.
- Preparation of detailed health risk assessments for each of the activities identified with potential DU exposure.

Performing this assessment for DU involves the cooperative efforts of several organizations, specifically;

- The Office of the Special Assistant for Gulf War Illnesses - Hazard Identification and Risk Characterization.
- US Army Center for Health Promotion and Preventive Medicine (USACHPPM) – Exposure and Risk Assessment.
- RAND Corporation - Toxicity Assessment.

Tab E - Development of DU Munitions

1. Operational Requirements and the Development of DU Munitions

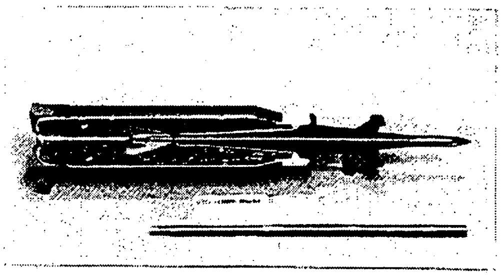


Figure 12 – DU Sabot round with penetrator

During the late 1950s, the primary material used for kinetic energy, armor-piercing projectiles was tungsten carbide. When first fielded, tungsten carbide represented a quantum improvement over its nearest competitor, high carbon steel. Its higher density (approximately 13 gm/cc) gave it superior penetration performance against existing armor targets. With the advent of double and triple plated armor in the 1960s, however, tungsten munitions showed a tendency to break up before penetrating the layered armor. This deficiency spurred the development of new alloys and materials capable of defeating any armored threats.

In response to the new operational requirements, a succession of metal alloys were evaluated. Initially, the UK Government developed a higher density tungsten alloy consisting of 93 percent tungsten and 7 percent binder tungsten alloy (WA). The new WA alloy had a density of 17 gm/cc versus 13 gm/cc for tungsten carbide. From 1965 to 1972, the US Army conducted a parallel development program for the 152mm XM578 cartridge which was co-developed with the MBT-70 Tank. The XM578 cartridge used a tungsten alloy that was slightly denser than the British alloy consisting of 97.5 percent tungsten and 2.5 percent binder, which had a density of 18.5 gm/cc.[49]

Throughout the 1960s and early 1970s, the Army developed a successive series of improved 105 mm rounds (the primary main gun caliber on M-60 and developmental XM-1 series tanks) using the denser 97.5% tungsten alloy. The first of these rounds were the XM735 and XM774 cartridges derived from the XM578 cartridge program. These alloys proved sufficient to meet the Army's operational requirements. At the same time, the Army continued to investigate applications for DU.

One of the Army's first uses of DU was as a ballistic weight in the spotting round for the Davy Crockett missile warhead. Additionally, in the early 1960s, the Army tested a four-alloy "UQuad" containing DU in experimental tests on the 105mm and 120mm Delta Armor Piercing Fin Stabilized, Discarding Sabots (APFSDS). Tungsten continued to be favored over DU, however, for two main reasons: 1) DU was still developmental, and inconsistencies with the alloys in the manufacturing process were a persistent problem; and 2) penetration tests against

[49] Richard P. Davitt, A Comparison of the Advantages and Disadvantages of Depleted Uranium and Tungsten Alloy As Penetrator Materials, Tank Ammo Section Report No. 107, Dover, NJ: US Army Armament Research and Development Command, June 1980, p. 3.

older Soviet tanks and similar targets failed to show the clear penetration superiority of the DU round.[50]

In the mid-1970s, as it became clear that the latest-generation armors might prove impervious to tungsten carbide penetrators, the Army's focus on improved tungsten alloys began to shift. At the same time, parallel Air Force and Navy tests using smaller-caliber (20-, 25-, and 30mm) ammunition had demonstrated quite convincingly the clear penetration superiority of DU rounds.


Figure 13 - 105mm DU sabot round

In 1973, the Army evaluated alternatives for improving the lethality of its 105mm M68 tank gun. This effort grew into the XM774 Cartridge Program which, after an extensive developmental testing and evaluation program, selected depleted uranium alloyed with ¾ percent by weight titanium (U-3/4Ti). The selection of U-3/4Ti derived in part from improved designs and alloys that allowed the DU core to withstand high acceleration without breaking up. In the 1960s, tungsten alloys used in the XM578 projectile had to be encased in a steel jacket to withstand the extreme firing velocities of the 152mm gun, reducing the penetrating effectiveness of the tungsten cartridge.[51] The new U-3/4Ti alloy overcame these early limitations for large caliber munitions.

Development of U-3/4Ti ushered in a new generation of penetrators for the Army. Since the selection of DU for the XM774 cartridge, all major developments in tank ammunition have selected DU, including the 105mm M833 series and the 120mm M829 series (the latter being the primary anti-armor round used in the Gulf War). This pattern continues today, with the latest generation of the 105mm M900 series and the 25mm M919 for the Bradley Fighting Vehicle.

[50] Richard P. Davitt, A Comparison of the Advantages and Disadvantages of Depleted Uranium and Tungsten Alloy As Penetrator Materials, Tank Ammo Section Report No. 107, Dover, NJ: US Army Armament Research and Development Command, June 1980, p. 5.

[51] Richard P. Davitt, A Comparison of the Advantages and Disadvantages of Depleted Uranium and Tungsten Alloy As Penetrator Materials, Tank Ammo Section Report No. 107, Dover, NJ: US Army Armament Research and Development Command, June 1980, p. 3, 6.

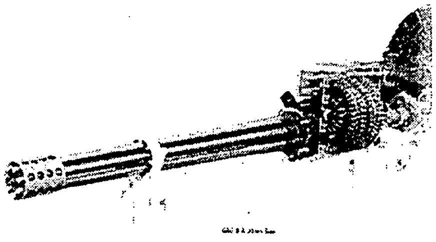


Figure 14 - GAU-8 cannon

In the early 1970s, the Air Force developed the GAU-8/A air to surface gun system for the A-10 close air support aircraft. This unique aircraft, designed to counter the massive Soviet/Warsaw Pact armored formations spearheading an attack into NATO's Central Region, was literally designed and built around the GAU-8. This large, heavy, eight-barreled 30-mm cannon was designed to blast through the top armor of even the heaviest enemy tanks. To further exploit the new cannon's tremendous striking power, the Air Force opted to use the depleted uranium U-3/4Ti, a 30mm API round. A comprehensive Environmental Assessment of the GAU-8 ammunition was released on January 18, 1976. The report stated that the proposed action was expected to have no significant environmental impact and that the "biomedical and toxicological hazards of the use of depleted uranium (DU) in this program are practically negligible."[52] The A-10 aircraft was deployed to United States Air Forces in Europe (USAFE) in 1978.[53]

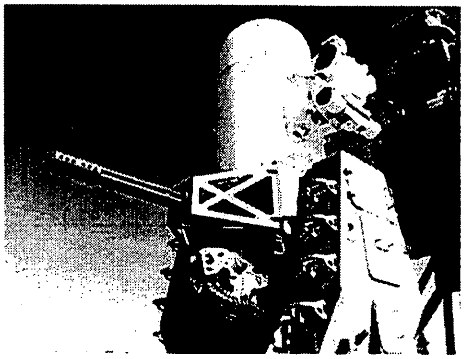


Figure 15 - CIWS system

The Navy's Phalanx Close-In Weapon System, or CIWS was designed for terminal (last-ditch) defense against sea-skimming missiles. The Navy evaluated a wide range of materials before deciding on DU alloyed with 2 percent molybdenum (DU-2Mo).[54] Phalanx production started in 1978, with orders for 23 USN and 14 Foreign Military Sales systems; however, subsequent budget cuts reduced these numbers. In 1988 the Navy opted to transition the CIWS 20mm round from DU to tungsten. The Navy made the decision based on live fire tests that showed that tungsten met the Navy's performance requirements while offering reduced probabilities of radiation exposure and environmental impact.[55] It should be noted that the "soft" targets the CIWS was designed to defeat—anti-ship missiles at close range—are far easier to destroy than "hard" targets like tanks. Substantial stocks of DU ammunition delivered prior to that date remain in the inventory.

[52] Environmental Assessment, Depleted Uranium (DU) Armor Penetrating Munitions for the GAU-8 Automatic Cannon, Development and Operational Test and Evaluation, AF/SGPA, April 1975, p. 1.
[53] Richard P. Davitt, A Comparison of the Advantages and Disadvantages of Depleted Uranium and Tungsten Alloy As Penetrator Materials, Tank Ammo Section Report No. 107, Dover, NJ: US Army Armament Research and Development Command, June 1980, p. 5.
[54] "Phalanx Close-In Weapons System," US Navy Fact File Sheet, Public Affairs Office of the Naval Sea Systems Command (OOD), Washington, DC, 1997.
[55] Letter to the Office of the Special Assistant for Gulf War Illnesses from the Commander, Crane Division, Naval Surface Warfare Center, subject: "Navy/Marine Corps Responses to Questions on Depleted Uranium Ammunition." March 17, 1998, Enclosure 1, p. 1.

2. Developmental Tests and Evaluations of the Medical and Environmental Implications of the Use of DU Munitions.

Although specific requirements have continuously evolved since most current DU weapon systems were in the developmental process, DoD's current acquisition system typifies the highly regulated, deliberate process that these systems followed in their development. Critical components of this process are the comprehensive hazard classification tests, radiological assessments, and life-cycle environmental assessments required by the acquisition process.

The acquisition process is governed by DoD Directive (DoDD) 5000.1, Defense Acquisition; DoD Instruction (DoDI) 5000.2, Defense Acquisition Management Policies and Procedures; and DoD Manual (DoDM) 5000.2-M, Defense Acquisition Management Documentation and Reports. These documents prescribe a comprehensive, iterative process that must be followed in the procurement of defense systems. Starting with a determination of operational requirements, the process proceeds through concept exploration and definition, demonstration and validation, engineering and manufacturing development, production and deployment, and operations and support. Built into the process is the requirement to assess the potential environmental impact and to document system safety, health hazards, and hazardous material that the system design cannot mitigate or eliminate.[56]

The development of the current family of DU weapon systems followed procedures established in the early 1970s. On October 3, 1973, the Office of the Director of Defense Research and Engineering requested that the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) evaluate the medical and environmental implications of the use of DU and alternatives in a variety of conventional munitions. The task force was specifically asked to evaluate the GAU-8A, PHALANX, and BUSHMASTER weapons. This was the first of several medical and environmental assessment of DU. The task force consisted of environmental and medical personnel from the three services and the Atomic Energy Commission. The purpose of the study was to provide a comprehensive medical and environmental evaluation of DU related to the manufacture, transport, storage, use, and disposal of DU munitions.[57]

The overall finding was that the development of DU munitions was expected to have no significant environmental impact. However, depending on local conditions, the uncontrolled release of DU, such as the crash of an A-10 with DU munitions, could have significant impact. JTCG/ME also recommended several follow-on tests to fill in data gaps, in part to assess the environmental impact of uncontrolled release. These tests, conducted in the late 70's, are addressed in Tab L (Research Report Summaries). The following is a summary of JTCG/ME's findings:

[56] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report. Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, Section 3.3 (Acquisition); pp. 26-32.

[57] Medical and Environmental Evaluation of Depleted Uranium, JTCG/ME Special Report, Vol I, Joint Technical Coordinating Group for Munitions Effectiveness, April 1974, p. v-vi.

a. The report stated that the pharmacological and toxicological investigation of uranium compounds had resulted in the most thorough and extensive study ever undertaken for this class of weapon. The investigation concluded that uranium was less toxic to humans than originally assessed, and that the toxicity of uranium was due primarily to its chemical rather than radiological properties. It also concluded that uranium did not appear to be any more toxic than lead or other heavy metals. Fragment kinetic energy effects are more significant than any long-term toxicity considerations. The report concluded that the biomedical and toxicological hazards of the use of DU were practically negligible.
b. The report addressed considerations during the DU manufacturing and transportation process, and concluded that established industrial hygiene practices and safeguards minimized concerns in these areas.
c. The report acknowledged that in combat situations, the widespread use of DU munitions could create a potential for inhalation, ingestion or implantation (via fragments) problems. However, these problems were viewed as insignificant when compared to the other dangers of combat.
d. The catastrophic destruction of weapon systems was evaluated for four scenarios: 1) loss of a ship carrying the PHALANX Close-In Weapons System, 2) loss of an ammunition ship carrying DU munitions, 3) loss of an ammunition storage magazine containing DU munitions, and 4) loss of an A-10 aircraft carrying 1,350 DU rounds. The loss of the ships and the magazine were considered to have negligible impact. In the case of the ships, the amount of potential DU release was much less than the amount of uranium normally present in seawater; in the case of the magazine, the structure is designed to contain effects produced by the destruction of the contents. On the other hand, the loss of an A-10 could disperse up to 0.4 metric ton of DU onto the crash site. Removal of the DU could be time consuming and costly depending on the location and circumstances of the crash.[58]

Paragraph c has been cited out of context to bolster claims that the DoD downplayed a known health hazard in order to secure the advantages offered by DU. Comparing "problems resulting from the use of DU" to "the other dangers of the battlefield" does little to promote an understanding of the two very different types of hazards. Whereas the danger from enemy "shooters"—tanks, artillery, etc.—is obvious, the hazard posed by the release of DU requires more thoughtful explanation. Contemporary documentation and studies indicate that while DU could pose a battlefield exposure hazard, that hazard could be prevented or mitigated through simple, field-expedient precautions. Moreover, DU's operational benefits—realized on the Gulf War battlefields—vastly outweigh the risks of exposures encountered during the campaign.

Specific radiological, health, and environmental assessments augmented the JTCG/ME report as the various weapon systems were developed. For example, the Air Force prepared a study titled, *Environmental Assessment, Depleted Uranium (DU) Armor Penetrating Munition for the GAU-8*

[58] Medical and Environmental Evaluation of Depleted Uranium, JTCG/ME Special Report, Vol I, Joint Technical Coordinating Group for Munitions Effectiveness, April 1974, p. vi-x.

Automatic Cannon, Development and Operational Test and Evaluation (April 1975). The environmental assessment (EA) was prepared in accordance with Air Force Regulation 19-2, which complied with the National Environmental Policy Act of 1969. The EA stated that the "biomedical and toxicological hazards of the use of depleted uranium (DU) in this program are practically negligible."[59] Other assessments of the GAU-8 round included a *Hazard Classification Test of GAU-8 Ammunition by Bonfire Cookoff with Limited Air Sampling* (dated February 1976) by Los Alamos Scientific Laboratory (Report # 3 in Tab L) and a study, *External Radiation Hazard Evaluation of GAU-8 API munitions*, performed by the USAF Occupational and Environmental Health Laboratory in 1978 (Report # 4 in Tab L).[60,61]

To support the development of the new generation 105mm armor-piercing cartridge, the Army conducted a series of studies recommended by the JTCG/ME to fill gaps in the existing body of information. The initial three studies were: *Characterization of Airborne Uranium From Test Firings of XM774 Ammunition*, November 1979, (PNL-2944)[62] (Report # 6 in Tab L) *Radiation Characterization, and Exposure Rate Measurements from Cartridge, 105mm, APFSDS-T, XM774,* November 1979 (PNL-2947)[63] (Report # 5 in Tab L); and *Radiological and Toxicological Assessment of an External Heat (Burn) Test of the 105mm Cartridge, APFSDS-T, XM 744* [sic], 1978 (PNL-2670).[64]

The aforementioned tests were only the initial investigations into the ecological, environmental, radiological, safety, and health concerns associated with the early DU munitions. For example, the US Army Environmental Policy Institute (AEPI) report on the *Health and Environmental Consequences of Depleted Uranium Use in the US Army* cited three other reports [M.E. Danesi, 1990; US Army Pierre Committee, 1979; and the NMAB of the National Academy of Sciences National Research Council, 1979] that reached similar conclusions to the JTCG/ME report on the health effects of the military use of DU.[65]

In addition to formalized hazard assessments required by DoD directives, the Nuclear Regulatory Commission (NRC) regulates the peacetime handling and use of DU. Currently, the NRC has issued single Master Materials Licenses to the Navy and the Air Force. The Navy and Air Force Radioisotope Committees then issue radioactive material permits to the individual Service

[59] Environmental Assessment, Depleted Uranium (DU) Armor Penetrating Munition for the GAU-8 Automatic Cannon, Development and Operational Test and Evaluation. AF/SGPA, April 1975, Executive Summary, p. i.
[60] J.C. Elder, M.I. Tillery, and H.J. Ettinger. Hazard Classification Test of GAU-8 Ammunition by Bonfire Cookoff with Limited Air Sampling, LA-6210-MS. Los Alamos, NM: Los Alamos Scientific Laboratory of the University of California, February 1976.
[61] Captain Karl L. Prado, External Radiation Hazard Evaluation of GAU-8 API Munitions, TR 78-106. Brooks AFB, TX: USAF Occupational and Environmental Health Laboratory, 1978.
[62] *Characterization of Airborne Uranium from Test Firings of XM774 Ammunition* (PNL-2944), November 1979.
[63] *Radiation Characterization, and Exposure Rate Measurements from Cartridge, 105mm, APFSDS-T, XM774,* (PNL-2947), November 1979.
[64] *Radiological and Toxicological Assessment of an External Heat (Burn) Test of the 105mm Cartridge, APFSDS-T, XM 744* [sic], (PNL-2670) 1978.
[65] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report. Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 92-93.

activities handling DU. On the other hand, the Army currently has 14 individual NRC licenses issued directly to each organization responsible for the management of DU. The individual Services and the NRC monitor compliance with NRC regulations and the license-specific requirements through periodic, on-site inspections. Although specific requirements vary from site to site, typical requirements include supervision and oversight of procedures involving DU by qualified radiation protection officers, the posting of areas containing DU munitions, and periodic leak testing of stored munitions.

Throughout the development of the DU weapons program, DoD has followed its acquisition directives and conducted extensive hazard assessment. The Services fielded DU munitions and armor only after rigorous testing and evaluation that carefully considered their environmental impact and potential for battlefield contamination. The fact that DU exposures took place during the Gulf War is not indicative of a haphazard or incomplete development, testing, or evaluation regime. Rather, exposure issues were typically the result of the Services' failure to properly disseminate cautionary information and warnings to the decision-makers and operators whose duties might expose them to DU contamination, and to practice better risk management.

3. Current Uses of DU

DU is currently used in kinetic cartridges for the Army's 25mm BUSHMASTER cannon (M2/3 Bradley Fighting Vehicle), the 105mm cannon (M1 and M60 series tanks) and the 120mm cannon (M1A1 and M1A2 Abrams Tank). The Heavy Armor variant of the M1A1, the M1A1 (HA), also employs layered DU for increased armor protection. Army Special Forces also use small caliber DU ammunition on a limited basis. The Marines use DU tank rounds in their own M1-series tanks as well as a 25mm DU round in the GAU-12 Gatling gun on Marine AV-8 Harriers. The Army uses small amounts of DU as an epoxy catalyst for two anti-personnel mines: the M86 Pursuit Deterrent Munition and the Area Denial Artillery Munition.[66] The Air Force uses a 30mm DU round in the GAU-8 Gatling gun on the A-10. The 20mm DU round developed by the Navy for use in its shipboard PHALANX Close In Weapons System (CIWS) remains in service; however, since FY 1990, the Navy has procured only tungsten rounds for the CIWS. The 20mm DU rounds remaining in the inventory will be used until the supply is exhausted or ages beyond its service life.[67]

[66] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 25.
[67] Letter to the Office of the Special Assistant for Gulf War Illnesses from the Commander, Crane Division, Naval Surface Warfare Center, subject: "Navy/Marine Corps Responses to Questions on Depleted Uranium Ammunition." March 17, 1998, Enclosure 1, p. 1.

DU is also used in numerous commercial applications:[68, 69]

- ballast and counterweights
- balancing control services on aircraft (civilian and military)
- balancing and vibration damping on aircraft
- machinery ballast and counterweights
- gyrorotors and other electromechanical counterweights
- neutron detectors
- radiation detection and shielding for medicine and industry
- shielding for shipping containers for radiopharmaceuticals, radioisotopes, and spent nuclear fuel rods
- chemical catalyst
- X-ray tubes
- glass and ceramics for brilliant colors

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[68] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 25.
[69] Reed C. Magness. Environmental Overview for Depleted Uranium, CRDC-TR-85030, Aberdeen Proving Ground, MD: Chemical Research & Development Center, October 1985, p. 10-12.

Tab F - DU Use in the Gulf War

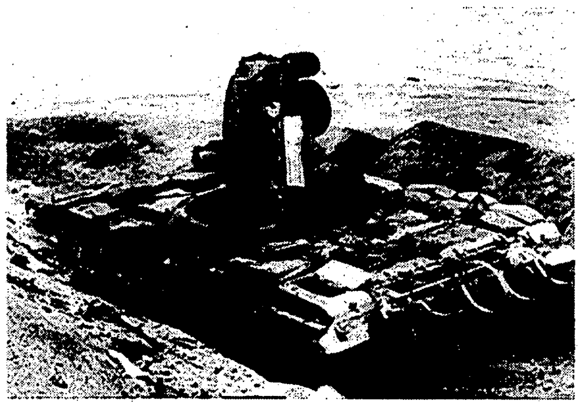

Figure 16 - Iraqi T-72 hit with DU sabot

Operation Desert Storm was the first conflict to see the extensive use of DU munitions and armor packages. The new rounds gave coalition forces a marked operational advantage. Unit histories from the Gulf War contain many anecdotes attesting to the effectiveness of DU "silver bullets." One armor Brigade Commander described looking on in "amazement" as his soldiers (who in training had never fired at targets beyond 2,400 meters [1.5 miles]) routinely scored first-shot kills on targets out to 3,000 meters (1.9 miles) and beyond.[70] DU armor gained an equally impressive reputation. A story illustrating DU's offensive and defensive renown involves a heavy armor M1A1 tank that had become mired in the mud.

> The unit (part of the 24th Infantry Division) had gone on, leaving this tank to wait for a recovery vehicle. Three T-72's appeared and attacked. The first fired from under 1,000 meters, scoring a hit with a shaped-charge (high explosive) round on the M1A1's frontal armor. The hit did no damage. The M1A1 fired a 120mm armor-piercing round that penetrated the T-72 turret, causing an explosion that blew the turret into the air. The second T-72 fired another shaped-charge round, hit the frontal armor, and did no damage. The T-72 turned to run, and took a 120mm round in the engine compartment and blew the engine into the air. The last T-72 fired a solid shot (sabot) round from 400 meters. This left a groove in the M1A1's frontal armor and bounced off. The T-72 then backed up behind a sand berm and was completely concealed from view. The M1A1 depressed its gun and put a sabot round through the berm, into the T-72, causing an explosion.[71]

The Army, Air Force, Navy and Marines all used DU to some extent in the Gulf.

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[70] Robert H. Scales, Jr., Certain Victory: The US Army in the Gulf War. Simon & Schuster, Pocket Books, 1992, p. 293.

[71] James F. Dunnigan and Austin Bay, From Shield to Storm: High-Tech Weapons, Military Strategy, and Coalition Warfare in the Persian Gulf. William Morrow & Company, 1992, p. 294-295.

A. Army

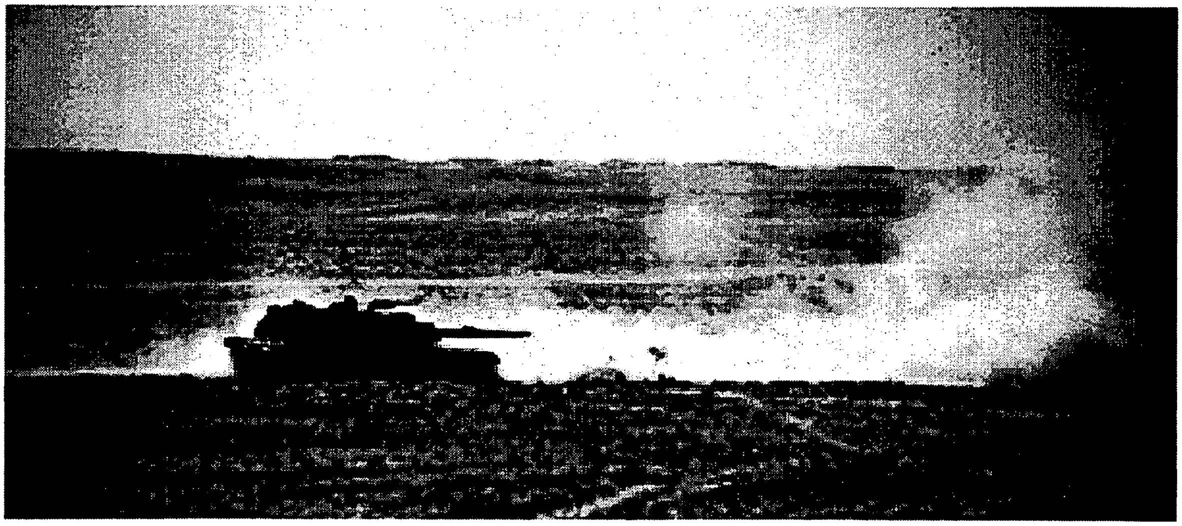

Figure 17 - M1A1 tank engages a target

During the Gulf War, the Army used DU for both defensive and offensive purposes. According to DoD's report to Congress, *Conduct of the Persian Gulf War*, 594 of the 1,772 M1A1 series tanks deployed to the Gulf were heavy armor Abrams variants.[72] DU armor packages on these heavy armor tanks provided their crews with added protection. During Operation Desert Storm, there were no penetrations of DU armor by Iraqi fire.[73]

The Army used 105mm (M900) and 120mm (M829 and M829A1) ammunition with DU penetrators, in addition to non-DU rounds such as High Explosive Anti Tank (HEAT) shells, in Abrams tanks. Since DU rounds are not fired in training, the Gulf War was the tankers' first chance to fire the round. As word of the DU sabot round's effectiveness spread, it quickly became the round of choice for US tankers.

The number of DU rounds expended in combat has not been determined. Units requested ammunition as needed, and were not required to record cumulative expenditures. However, the total quantity of DU rounds used in the Gulf before (during pre-combat live-fire training), during, and after the Gulf War was recorded and allows a reasonable estimate of rounds expended. The officer in charge of all ground force ammunition in theater tracked the numbers of rounds by type shipped, rounds returned after the war, and rounds left in theater as war reserve stocks. Table 5 shows ground force ammunition usage as reported by the Theater Ammunition Officer. Tank ammunition consumed by the US Marines does not show up on the graphic, since the Marines had tank ammunition pre-positioned on ships. As they expended this initial allocation, the Marines were resupplied from Army stocks. Numbers in Table 5 include these

[72] Final Report to Congress, Conduct of the Persian Gulf War, Washington, DC: Department of Defense, April 1992, p. 750.
[73] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report. Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 76.

diverted rounds, but not the initial Marine stocks, whose quantities are currently unknown. As indicated in Table 5 below, the US Army fired 9,552 DU tank rounds, totaling approximately 50 tons of DU. This amount of DU would fit in a box with length, width and height dimensions all equal to four and a half feet.

Table 5- DU Consumed by Army in the Gulf During ODS/DS[74]

Ammunition Type (rounds)	Shipped (rounds)	Left on Ship (rounds)	Left with Reserve Stock (rounds)	Returned after Gulf War (rounds)	Consumed in the Gulf (rounds)	DU used in the Gulf (tons)[75]
M900 (105mm)	2,314	0	0	1,810	504	2.14
M829 (120mm)	141,247	5,900	1,800	126,847	6,700	35.85
M829A1 (120mm)	89,473	0	0	87,125	2,348	12.56
Total	233,034	5,900	1,800	215,782	9,552	50.55

B. Air Force

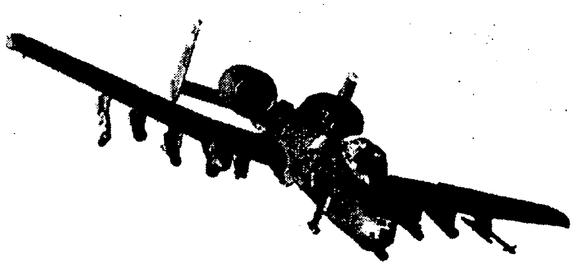

Figure 18: - A-10 "Warthog" in the Gulf

The Air Force fired 30mm Armor Piercing Incendiary (API) munitions using a DU penetrator slug from the GAU-8 Gatling gun mounted on the A-10 Aircraft (Figure 18). The 148 A-10s that deployed to Saudi Arabia flew 8,077 combat sorties. A typical combat load would include 1,100 rounds of 30mm high explosive or armor piercing ammunition for the GAU-8.[76] 30mm API is mixed with 30mm High Explosive Incendiary (HEI) at the factory and is called Combat Mix Ammunition. The ratio of API to HEI rounds in the Combat Mix is 4:1. The Air Force fired a total of 783,514 rounds of 30mm API in the Gulf War.[77] Since each round contains approximately 0.66 pounds of DU, the Air Force expended a total of 259 tons of DU in the Gulf.

[74] "Estimated Expenditure" spreadsheet faxed to investigators by former Theater Ammunition Officer, February 3, 1992, p. 4.

[75] Based on weights per round of 8.5 pounds of DU for the 105mm and 10.7 pounds for the 120mm, taken from: Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report. Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 39.

[76] Final Report to Congress, Conduct of the Persian Gulf War, Washington, DC: Department of Defense, April 1992, p. 664.

[77] Memorandum from Headquarters Ogden Air Logistics Center, Department of the Air Force, Subject: "Gulf War Depleted Uranium DU Munitions Expenditure" April 30, 1997.

C. Navy

The Navy deployed its shipboard Phalanx CIWS (Close-In Weapon System) to the Gulf. The Phalanx's 20mm cannon used both DU and tungsten rounds. The weapon was test fired over the Gulf, and during an accidental discharge of 4-5 shells that took place as Navy ships were responding to the launch of a shore-based anti-ship missile.[78] The errant firing marked the only time the CIWS was fired "in anger" during the Gulf War.[79]

Figure 19 – CIWS in the Gulf

D. Marines

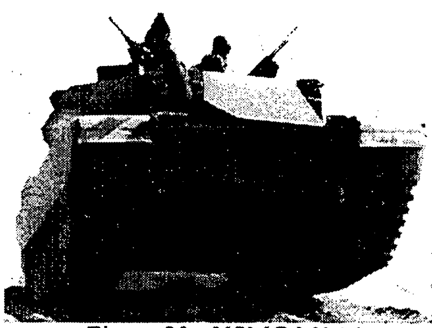

Figure 20 - USMC M1A1

The USMC deployed to the Gulf with older M-60 tanks. To augment their armor capabilities, the Marines borrowed 60 heavy armor M1A1 Abrams tanks from the US Army. In addition, the Marines took early delivery of 16 M1A1s already on order, rushing the new tanks to the Gulf and conducting transition training for former M-60 tank crews. The 2nd Tank Battalion and elements of the 4th Tank Battalion employed a total of 76 M1A1 tanks.[80] Initially, these tanks drew on pre-positioned, shipboard munitions stocks that included DU. As these stocks were expended, the Marines drew resupply rounds from Army munitions stocks.

Eighty-six AV-8B Harrier aircraft deployed to the Gulf, flying 3,342 sorties.[81] According to HQ Marine Corps, Department of Aviation, the Marine Corps fired 67,436 rounds of PGU/20 (a 25mm DU round) in the Gulf War.[82] The AV-8B fired an equal mix of DU and HE rounds. Each 25mm DU round contains 148 grams (.33 pounds) of DU, so the Marine aviators expended 11 tons of DU in the Gulf War.[83]

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78 Lead Sheet # 14246, Interview of former USS Missouri Executive Officer, January 23, 1998.

79 US Navy Fact File, "Phalanx Close-In Weapons System," Public Affairs Office, Naval Sea Systems Command, Washington, DC, May 1996.

80 M1A1 Main Battle Tank, USMC Fact File, HQ USMC, Division of Public Affairs, Washington, DC, May 1991.

81 Final Report to Congress, Conduct of the Persian Gulf War, Washington, DC: Department of Defense, April 1992, p. 671-2.

82 Lead Sheet # 5683, Interview of an officer from the HQ Marine Corps, Department of Aviation, Aviation Support Logistics, May 9, 1997.

83 Lead Sheet # 5684, Interview of Master Sergeant from the HQ Marine Corps, Department of Aviation, Aviation Support Logistics, May 9, 1997.

E. Use by Other Countries

The only other country known to have fired DU munitions in the Gulf War is the United Kingdom. The UK Ministry of Defence's latest assessment is that its Challenger tanks fired fewer than 100 120mm Armor Piercing Fin Stabilized Discarding Sabot (APFSDS) rounds against Iraqi military forces during hostilities, although additional rounds were fired during earlier work-up training in Saudi Arabia. This equates to less than one (US) ton of DU.[84]

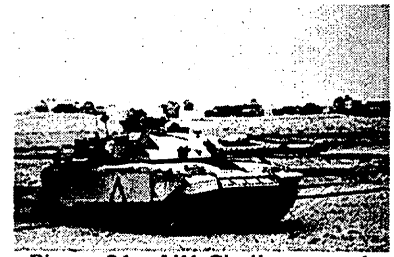
Figure 21 – UK Challenger tank

In 1990-1991, the US had a near-monopoly on the use of DU. When this report attributes damage or destruction to DU, it can be assumed that US systems were responsible. No Coalition vehicles or personnel were engaged or struck by DU munitions fired from US tanks and aircraft. Iraq did not have DU armor or munitions in its inventory.

[84] Fax from Gulf War Veteran's Illnesses Unit, UK Ministry of Defence, London, July 16, 1998, p. 1.

Tab G – DU Exposures in the Gulf

Gulf War personnel were exposed to DU in a number of ways. Some US combat vehicles were mistakenly destroyed or damaged by US tanks using DU sabot rounds. Personnel worked inside US vehicles contaminated with DU fragments and particles. Several accidental tank fires and an ammunition explosion/fire at Camp Doha, Kuwait, resulted in DU rounds being burned, oxidized, or fragmented, which created a potential exposure hazard to troops operating in the vicinity. Other troops entered Iraqi armor disabled by DU. Determining the medical consequences of these exposures, if any, requires a systematic, scientifically sound evaluation. The exposure scenarios observed during ODS/DS and in months following, were categorized into three levels based on the activities of the soldiers involved, and the resulting potential for direct contact with DU. These three exposure levels provided a prioritized approach to describing and evaluating the potential exposures that occurred:

Level I - Soldiers in or near combat vehicles at the time these vehicles were struck by DU penetrators, or who entered vehicles immediately after they were struck by DU munitions. These soldiers could have been struck by DU fragments, inhaled DU aerosols, ingested DU residues, or had DU particles land on open wounds, burns, or other breaks in their skin.

Level II - Soldiers and a small number of DoD civilian employees who worked in and around vehicles containing DU fragments and particles (mostly friendly fire wrecks). These soldiers may have inhaled DU residues stirred up (resuspended) during their activities on or inside the vehicles, transferred DU from hand to mouth, thus ingesting it, or spread contamination on their clothing. Soldiers who were involved in cleaning up DU residues remaining on Camp Doha's North Compound after the July 11, 1991, explosion and fires are also included in this group.

Level III - An "all others" group whose exposures were largely incidental (fleeting). This group includes individuals who entered DU-contaminated Iraqi equipment, troops downwind from burning Iraqi or US equipment struck by DU rounds, or downwind from burning DU ammunition, such as soldiers at Doha during the July 11 fire. While these individuals could have inhaled airborne DU particles, the possibility of receiving an intake high enough to cause health effects is extremely remote.

As research progressed, 13 categories of possible DU exposure were identified and classified within the three levels as shown in Table 1 (page 8). These categories are described below.

A. Level I Participants

Eight friendly fire incidents involving DU munitions are known to have occurred during the Gulf War. These incidents (distinct from non-DU friendly fire incidents or cases where friendly vehicles were evacuated and then deliberately destroyed to prevent their capture) resulted in the contamination of six M1/M1A1 tanks and 15 Bradley Fighting Vehicles. Another M1A1 was hit by a large shaped-charge round, believed to be a Hellfire missile fired from an Apache helicopter, that ignited an on-board fire. This incident is described in the "Tank Fires" section. Darkness and low visibility caused by heavy rains, sandstorms, etc., were major contributing factors in all of these incidents.[85]

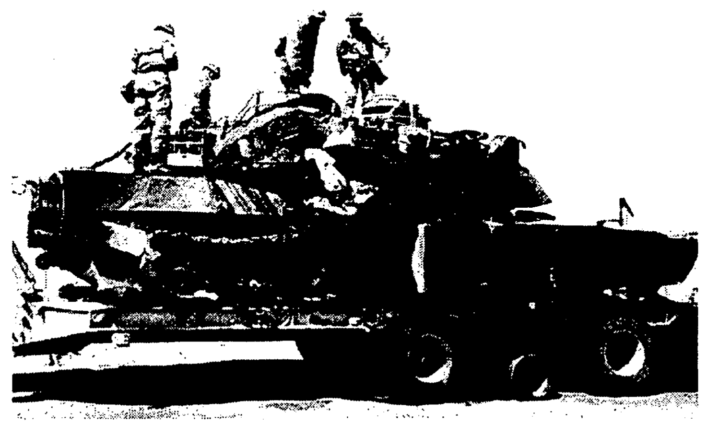

Figure 22 - M1A1 lost to friendly fire

In most cases, owing to battlefield confusion, soldiers manning the targeted vehicles initially believed that the Iraqis had fired the shots that penetrated their armor. The distinctive radioactive trace DU leaves on the entrance and exit holes allowed a team of battle damage assessment experts to determine (after the fact) which vehicles had been hit by DU sabot rounds fired from Abrams tanks. After-action investigations and word-of-mouth reporting among the units involved generally resulted in the affected soldiers learning that they had been victims of friendly fire. Not all of these soldiers, however, were aware of the potential health effects associated with DU. Therefore, the investigation of friendly fire incidents is being accompanied by an effort to identify, locate, and contact all surviving soldiers who were in or on vehicles at the time they were penetrated by DU rounds.

Level I soldiers, injured or not, were in or around combat vehicles at the time they were struck by DU sabots, or immediately afterward. Besides the embedded fragments from wounds, these individuals may have inhaled DU aerosols generated by fires or by the impact of the DU projectile penetrating the target. The following discussion describes the circumstances under which Level I soldiers were mistakenly targeted by US tank crews

As the "spearpoint" of the ground campaign, US armored crews were often forced to make very rapid "friend or foe" decisions, where failure to engage could allow enemy gunners to take a fatal shot. Invariably, given the swirling meeting engagements and close-in fights that erupted between friendly and enemy units, tragic misidentifications occurred. A total of 21 US combat vehicles (6 Abrams tanks and 15 Bradley Armored Fighting Vehicles or Cavalry Scout vehicles) were struck by 120mm DU sabot rounds fired from US M1A1 tanks. Some of these vehicles were struck once, others, several times. Based on typical manning configurations for the Abrams tanks and Bradleys[86] as well as information gathered from veterans, an estimated 113 soldiers

[85] "Military Probes Friendly Fire Incidents" Washington, DC: Office of the Assistant Secretary of Defense, Public Affairs: News Release, August 13, 1991.

[86] M1A1 Abrams tanks have a four-man crew (commander, driver, gunner, loader). Bradleys configured as armored fighting vehicles (M2 variant) carry a crew of three (commander, driver, gunner) and six "dismount" infantry in the rear compartment. Bradleys configured as M3 cavalry scout vehicles carried two observers in the rear, in addition to the three-man crew (commander, gunner, driver).

were on board these combat vehicles at the time that they were struck by DU penetrators. Actual manning at the time of the friendly fire incidents varied, since crewmembers and dismount infantry often left the vehicle, or vehicles picked up the occupants of disabled vehicles. Table 6 lists the individual systems struck by DU and their estimated manning. Reports have suggested that at least one vehicle was struck initially by enemy fire, evacuated, and subsequently struck by a DU round. If these reports are verified, the numbers reported in Table 6 may go down.

Table 6 - Summary of US vehicles hit by DU tank rounds

Army Unit	Vehicle Type	Bumper Numbers	Estimated Soldiers Onboard
4-7 Cavalry	Bradley	A-24, A-31, & A-22	15
1-37 Armor	Abrams	C-12	4
1-41 Infantry	Bradley	B-21, B-26, B-33, D-21 & D-26	30
3-66 Armor	Abrams	B-66, B-22, A-14, A-31 & A-33	20
3-15 Infantry	Bradley	C-11, C-22 & C-23	25
4-66 Armor	Bradley	HQ-55 & HQ-54	9
1-34 Infantry	Bradley	HQ-232	5
2-2 Cavalry	Bradley	G-14	5
		Total	113

Level I participants are separated into two categories: soldiers who were in or on combat vehicles at the time they were struck by DU rounds, and soldiers who entered those vehicles immediately afterwards to rescue wounded comrades. Since the former are believed to have incurred the highest risk from embedded DU fragments and/or inhalation of the DU aerosols resulting from penetrator impact, this group will be discussed first.

1. Soldiers in Vehicle on Impact.

Armor crewmen and the "dismounted" infantry transported in Bradley Fighting Vehicles supplied the offensive striking power for Operation Desert Storm. The highly mechanized US armored and mechanized infantry units counted on the speed, mobility, and firepower of their Bradleys and Abrams to maintain a rapid rate of advance while engaging and neutralizing enemy formations standing between Coalition troops and their objectives.

2. Soldiers Entering Vehicles Immediately After Impact.

Friendly fire incidents were usually witnessed by other US soldiers who in most cases served in the same platoon or company as the struck combat vehicle. Typically these troops would rush to the aid of the stricken vehicle's occupants to perform emergency first aid and rescue operations. The responding troops often entered damaged or destroyed vehicles moments after they had been hit, raising concerns that they may have been exposed to DU residues or oxides still airborne from impacts, or stirred up by the activities of survivors and rescuers inside and outside the vehicles. An estimated 30-60 soldiers are currently believed to be included in this category.

B. Level II Participants

This category includes soldiers who worked in and around DU-contaminated vehicles (mostly friendly fire wrecks). It also includes personnel who took part in the cleanup of DU contamination from the motor pool pads at Camp Doha, Kuwait, after several hundred rounds of DU sabot ammunition were detonated or burned in an explosion and fire on July 11, 1991.

A total of 16 Abrams and 15 Bradleys (Table 7) were contaminated with DU in the Gulf during 1990-1991. In addition to the accidental friendly fire vehicles mentioned earlier, three bogged-down Abrams were deliberately destroyed by other US tanks (after their crews had evacuated) to prevent them from falling into Iraqi hands. The Level II group also includes personnel whose maintenance or salvage duties required them to frequently enter and exit, or spend extended periods of time working in, contaminated vehicles. Finally, soldiers who cleaned up DU residues or spent penetrators inside Camp Doha's North Compound following the July 1991 ammunition supply point explosion/fire, fall under this classification.

Table 7 - DU Contaminated Vehicles

Reason for Contamination	Abrams	Bradleys
Accidental Friendly Fire	6	15
Intentional Friendly Fire	3	0
Tank Fire Caused by Hellfire	1	0
Accidental Tank Fires	3	0
Tanks Burned in Doha Fire	3	0
Total	16	15

1. Downloading Munitions.

Explosive Ordinance Disposal (EOD) personnel entered DU-contaminated vehicles. This group should have been aware of DU hazards. EOD personnel were trained and equipped to operate in a nuclear as well as DU-contaminated environment. Unfortunately, the EOD troops may not have been aware in every case that the vehicles they were working in had been struck by DU. The exposure of EOD personnel remains under investigation by this office.

2. Inspection and Maintenance Operations

A number of individuals entered US equipment contaminated with DU within hours or days of penetrator impact. Unit personnel usually entered destroyed or damaged systems to recover sensitive equipment or to salvage undamaged system components. These individuals were not only potentially exposed to DU dust, but also may have inadvertently spread parts and equipment containing trace amounts of DU to other vehicles. One member of the Battle Damage Assessment Team said that more that 27 major components had been removed from the first four Bradleys he inspected (three of the Bradleys were considered contaminated with DU).[87]

[87] Lead Sheet #15330, Interview of a Major in the Battle Damage Assessment Team, March 5, 1998, p. 2.

Investigators are currently compiling a list of maintenance soldiers who entered contaminated tanks or Bradleys. At least one or two maintenance personnel are believed to have entered each contaminated vehicle.

3. Logistics Assistance Representatives (LARs)

In addition to unit maintenance personnel, a number of LARs (Logistics Assistance Representatives) also entered damaged or destroyed vehicles. Civilian systems experts deployed to the Gulf Theater on behalf of the Department of the Army. These personnel were often called upon to determine the disposition of knocked-out equipment. Because the LARs had more direct communication with the Army Munitions and Chemical Command (AMCCOM), they were more aware of DU hazards and the proper procedures for mitigating those hazards. A December 20, 1990, message to the LARs advised them on the proper assessment, repair and recovery techniques:

> The number of personnel who take part in the vehicle recovery should be kept to an absolute minimum. They are to be dressed in protective coveralls, gloves, rubberized boots, and they are to also wear the M25 or M17A2 protective mask with M13A2 filter element and the accompanying head covers (i.e., Mission Oriented Protective Posture [MOPP] level 4). The coverall pant legs are to be worn over the rubber boots and sealed with tape at the ankles. Likewise, the sleeves are to be slipped over the gloves and taped. The edges of the hood are to be draped over the coveralls and taped to them and the place where it contacts the respirator. Also, any remaining openings are to be sealed with tape.[88]

Despite this guidance, at least one LAR has stated that he entered contaminated systems in a tee shirt and without a respirator.[89] When interviewed, the deputy to the officer in charge of M1-series tank LARs stated that, despite warning messages that highlighted the potential exposure risks to DU, he had received numerous reports after the war of his LAR personnel entering damaged Abrams tanks without proper protective equipment.[90] Efforts are continuing to identify, interview, and assess the DU exposure potential of these LARs.

4. Battle Damage Assessment Teams

A group from the US Army Ballistics Research Laboratory (BRL) at Aberdeen, Maryland, conducted battle damage assessments on damaged or destroyed US ground combat vehicles. This 12-man BDAT (Battle Damage Assessment Team) looked at damaged and destroyed US combat vehicles to determine how they had been knocked out, what damage had been sustained, the type of weapon/munition used, the effectiveness of survivability features, etc. These close, in-depth inspections entailed frequent entry into disabled, often DU-contaminated vehicles. The

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[88] Memorandum from the Chief of the Log Ops. Branch, Subject: "Safe Response to Incidences Involving Depleted Uranium Armor/Ammo," December 20, 1990.
[89] Lead Sheet #5685, Interview of a LAR from 1st AD, July 8, 1997.
[90] Lead Sheet #5742, Interview of an AMCCOM (now IOC) representative, July 9, 1997.

BDAT Team was trained in proper handling procedures and safeguards for DU-damaged equipment.[91] Some members of the BDAT followed the prescribed precautions and only entered DU-contaminated tanks after donning yellow radiation suits including dust masks, gloves, and boots. Other members were not as rigorous in taking protective measures. Assessments typically took between six and eight hours to complete.[92] The BDAT arrived in the Gulf on or about January 21, 1991, and were attached to combat elements prior to the ground war. Because the BDAT personnel had more technical expertise with DU than most soldiers, they were sometimes called in to help evaluate potential crew and equipment radiation contamination and to assist in friendly fire investigations.

5. Processing Damaged Equipment

Disabled or destroyed US combat vehicles were transported to King Khalid Military City (KKMC), the central receiving and storage site for all damaged/destroyed US combat vehicles (and many Iraqi "trophy tanks"). The 144th Service and Supply Company, a National Guard unit from New Jersey, was tasked to assess battle damage and prepare the vehicles for shipment back to the US. Although their mission did not include maintenance or repair, members of the 144th have indicated that they periodically re-entered the contaminated vehicles to cannibalize equipment for other units.[93] The 144th personnel were not familiar with proper procedures for handling DU-contaminated M1-series tanks or Bradleys. Because their original mission did not involve tanks with DU armor, the unit did not have any copies of Army Technical Bulletin (TB) 9-1300-278[94] that contained guidance for handling DU-contaminated M1 tanks.[95]

The 144th worked on DU-contaminated equipment without taking any precautions (e.g., wearing dust masks). They reportedly had no knowledge that some of the damaged equipment was contaminated with DU until after March 11, 1991. In many cases, contaminated equipment was interspersed with uncontaminated vehicles. Until the arrival of a radiation control (RADCON) team from the Armament Munitions and Chemical Command (AMCCOM), access to the equipment was not controlled. As many as 27 soldiers in the 144th worked in or around damaged Bradleys and Abrams without protective gear for an undetermined period of time.[96] Although the BDAT commander stated that he informed personnel from the unit about the hazard from contaminated vehicles on or about March 11, 1991, various members of the 144th have questioned the date they were actually notified, and stated that they continued to enter

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[91] Lead Sheet #5681, Interview of the BDAT Officer in Charge, August 1, 1997.

[92] Lead Sheet #15330, Interview of a Major in the Battle Damage Assessment Team, March 5, 1998, p. 2.

[93] Lead Sheet # 14316, Interview of 144th Services and Supply Company NJANG NCO, January 28, 1998.

[94] This is the US Army "Guidelines For Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium, Department of the Army"

[95] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 81.

[96] Operation Desert Storm - Army Not Adequately Prepared to Deal With Depleted Uranium Contamination, GAO/NSIAD-93-90, Washington, DC: United States General Accounting Office, Report to the Chairman, Subcommittee on Regulation, Business Opportunities, and Energy, Committee on Small Business, House of Representatives, January 1993, p. 17.

contaminated equipment after this date.[97] The exact date will probably never be confirmed due to the intervening time period and lack of documentation.

6. Radiation Control Activities.

After completing their initial battlefield assessments, the Battle Damage Assessment Team went to KKMC on March 11, 1991, to see if any equipment they had missed had been evacuated to the vehicle collection point, which was being managed by the 144th Service and Supply Company. Finding many DU- contaminated vehicles at KKMC, the BDAT requested on-site AMCCOM personnel to arrange for an AMCCOM radiation control (RADCON) team to be sent to KKMC.[98]

AMCCOM deployed RADCON teams to identify, assess, and respond to incidents involving DU contamination. RADCON teams performed their duties primarily at King Khalid Military City (KKMC) and at Camp Doha, although limited excursions to other locations occurred.

On March 24, 1991, a RADCON team of health physicists from AMCCOM arrived to assume responsibility for identifying, collecting, and surveying DU-contaminated equipment.[99] Much of this equipment was already at KKMC. The AMCCOM RADCON team segregated the DU-contaminated vehicles, set up a guarded perimeter to restrict access, and instructed 144th personnel in the proper handling of DU. The team examined the vehicles at the site and concluded that their DU radiological and chemical contamination levels, while low, required basic protective equipment, such as surgical gloves and dust masks, and strict personal hygiene measures.[100] Their work, completed around April 12, 1991, cleared the way for contract personnel to inspect, decontaminate, package, and retrograde the contaminated systems to the US.[101] In all, 15 Bradleys and 10 Abrams at KKMC were contaminated with DU. Some merely had DU "splatter" and could be returned to duty after decontamination. Others had to be sealed to contain the contaminant, then shipped to the US for final processing and disposal.[102]

The AMCCOM personnel also surveyed captured Iraqi equipment being prepared for shipment to the US. According to the person in charge of the survey operation, the most acute radiological hazard on these Soviet-built tanks was radium used in their gauges, which were often leaking.

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[97] Lead Sheet #14200, Interview of the Platoon Leader of the Operations Center of the 144th Services and Supply Company NJANG Storage Yard at KKMC, January 19, 1998.

[98] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 10-11.

[99] Memorandum for AMSMC-TM from the DU Team SWA, Subject: "DU Team Accomplishments," April 12, 1991.

[100] Radiological Team Report, AMCCOM (US Army Armaments, Munitions, and Chemical Command). Undated.

[101] Memorandum for Deputy Chief of Staff for Readiness, Headquarters, US Army Material Command, Subject: Depleted Uranium (DU) Contaminated Equipment, April 24, 1991.

[102] Memorandum for AMCCOM-SWA from AMSMC-SF, Subject: "Contaminated Vehicle Retrograde Actions," May 23, 1991.

These gauges had to be removed prior to shipping. One T-72 tank had substantial internal and external DU contamination.[103] It was not shipped, but its ultimate fate is unknown.[104]

An AMCCOM recovery team deployed to Camp Doha, Kuwait, from July 19 until early August 1991. The team did a radiological survey in and around four M1A1 tanks that were damaged or destroyed in the July 11 fire. After determining that three of the tanks contained low-level contamination, the AMCCOM team did an initial decontamination of their exteriors and prepared them for shipment to the port of Dammam. A sizeable quantity of spent DU penetrators and fragments were also collected from the 2nd Squadron motor pool pad, and deposited in the tanks' interior, which were then sealed. On August 6 the tanks were shipped from Dammam and returned to the US for processing at the Defense Consolidation Facility at Snelling, SC.[105]

On July 24, a RADCON Emergency Response Team from the US Army's Communications-Electronics Command (CECOM) Safety Office at Ft. Monmouth, NJ, arrived at Camp Doha.[106] The CECOM team was headed by the Project Director for the US Army Radiological Control Team. The team conducted what one member called a "site characterization survey."[107] This was not a grid-by-grid survey, but rather a more general survey, mostly in and around the motor pool. Nevertheless, the CECOM team was able to survey and clear an estimated two acres of the motor pool (which was the size of several football fields).[108,109]Investigators have interviewed several members of the AMCCOM and CECOM RADCON teams. All interviewed used some form of personal protection, although only about half routinely used respiratory protection while working in and around contaminated vehicles.[110] Based on studies done before the war, the likelihood of stirring up DU dust was thought to be negligible. All team members interviewed said that they were careful to survey each other with a RADIAC meter at the end of each work day to ensure that they were not tracking DU residues away from the taped-off portion of the 2nd Squadron motor pool pad. Ten to twelve personnel performed radiation control activities at one time or another. Investigators from the Office of the Special Assistant are continuing their efforts to locate and interview these personnel.

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103 Memorandum for SCR AMC-SWA, Subject: "Decontamination and Retrograde Movement of Destroyed T-72 Tank," (Undated).
104 Lead Sheet #5680, Interview of US Army Major in charge of surveying captured Iraqi equipment designated for shipment to the US, August 1, 1997.
105 Lead Sheet 5698, Interview of former AMCCOM team member, August 8, 1997; and Lead Sheet 5699, Interview of AMCCOM Team Chief, July 25, 1997.
106 Letter to US Army CECOM Office of the Chief of Staff, July 26, 1991.
107 Lead Sheet 5993, Interview of former CECOM Team Member, August 7, 1997.
108 Lead Sheet 5993, Interview of former CECOM Team Member, August 7, 1997 and Lead Sheet 5997, Interview of former CECOM Team Chief, July 16, 1997.
109 Memorandum for Commander, Task Force Victory (Fwd), Subject: "Camp Doha Accident Survey Update," August 2, 1991, p. 1.
110 Lead Sheet # 5513, Multiple interviews of former Theater health physicist, between July 1997 and March 1998, and RADCON personnel deployed to the Gulf (Lead Sheets 5698, 5699, 5700, 5701, 5703, and 5719).

7. Camp Doha Cleanup Activities.

A July 11, 1991 fire in Camp Doha's motor pool complex (the North Compound) destroyed or damaged tons of ammunition as well as 20-30 combat loaded vehicles and dozens of trucks and other support vehicles and equipment. One M1A1 tank was damaged and three destroyed in the fire. The three destroyed tanks were also contaminated since their "combat load" of DU rounds (an estimated 37 M829 sabot rounds per tank) had cooked off. In addition to the estimated 111 rounds in the tanks, more than 500 M829 rounds stored in nearby conexes (metal shipping containers) were also damaged or destroyed. Most of these rounds had detonated, leaving behind a scorched, exposed DU penetrator rod. In most cases these exposed rods showed little oxidization; however, a number were oxidized or fragmented to various degrees.

Within the North Compound, almost all of the DU penetrators, fragments, and oxides were concentrated in the 2nd Squadron motor pool and wash rack area. Between July 14-23, an EOD detachment and a company of Combat Engineers cleared approximately 1/3 of the 2nd Squadron motor pool. While the area with the heaviest concentration of DU—the burned M1A1s—was cleaned up by AMCCOM and CECOM personnel, the surrounding motor pool pads may have contained residual DU. In addition, many exposed or "spent" DU penetrators were scattered and in some cases partially burned in and around the MILVANS or conex containers.[111] As sections of the concrete pad were cleared of unexploded ordnance and DU, regular troops were brought in to do a final cleanup using brooms and other hand tools. These soldiers could have inhaled or ingested residual DU stirred up by sweeping, and could also have picked up DU fragments.[112]

A more comprehensive discussion of the Camp Doha Explosion and fires and the cleanup and recovery operations can be found in Tab I.

D. Level III Participants.

This group comprises "all others." It includes soldiers downwind of burning DU-contaminated equipment, exposed to smoke or resuspended particles from burning or burned (oxidized) DU, and personnel who entered DU-contaminated Iraqi equipment. It also includes personnel who were present at Camp Doha during and after the motor pool fire, but who did not take part in cleaning operations in the North Compound. Based on existing research, this entire group probably received minimal exposures.

[111] Lead Sheet # 6653, Interview of former Contracting Officer's Representative overseeing final cleaning and clearing at Doha, October 29, 1997, para 3, p. 3.

[112] Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998, p. 3-4.

1. Camp Doha

This group consists of individuals who were at Camp Doha during the fire and subsequent cleanup activities, but were not directly involved in the sweeping operations or with picking up spent DU penetrators, fragments, or oxides in the North Compound. Individuals in the North Compound when the fire and initial explosions started are also included in this group. An M992 ammunition carrier loaded with non-DU 155mm shells burned for approximately 30 minutes before the explosions started, giving most soldiers time to evacuate the area. Cleanup activities in the South Compound are included in Level III because all of the known DU contaminant remained in the North Compound, except for a number of penetrators transported to an off-base trash dump.

2. Tank Fires

During Operation Desert Storm/Desert Shield (ODS/DS), three accidental tank fires caused onboard DU munitions to "cook off" (detonate). In addition, a large shaped charge weapon, most likely a Hellfire missile fired from an Army Apache helicopter, struck an Abrams, setting it on fire. In all of these incidents, the crews escaped without injury. Some individuals, however, may have been exposed to DU aerosols from these fires, or to DU oxides or residues stirred up during clean up or equipment salvage operations. Individuals who were potentially exposed to fumes from the fires and related incidental contact with DU are included in this category. Those who performed cleanup, equipment processing, and similar activities are included in the appropriate categories of Level II. TAB J contains an incident-by-incident account reflecting our current knowledge of these incidents.

3. Entering DU-contaminated Iraqi or Coalition Equipment.

This is believed to be one of the largest groups of people potentially exposed to DU. US troops often entered destroyed Iraqi armor out of curiosity or to collect souvenirs, despite express warnings against this practice from AMCCOM and other environmental health agencies. The 7th Corps Deployment After Action Report said:

> War trophy hunting became a problem. Many soldiers and leaders did not recognize the hazards in war trophy hunting. Booby traps, radiation [*sic, i.e., radioactive*] contamination from depleted uranium, and unexploded ordnance combined to make this practice dangerous. In addition, units wanted to take home pieces of enemy equipment. This equipment can have gauges and other items that contain radium-226. We also found some Iraqi tanks with asbestos blankets. We never thought we would have to worry about the occupational health considerations of enemy equipment.[113]

[113] "VIIth Corps Deployment After Action Report, Defense of Northern Kuwait," (Undated), p. 11.

A March 11, 1991 message stipulating the Army requirements for captured Iraqi vehicles warned that "many of these captured vehicles pose a radiation hazard, either because devices on the vehicles do not meet US safety standards, or because of damage or destruction by depleted uranium munitions."[114]

Many soldiers had legitimate operational requirements to enter Iraqi equipment, such as checking for survivors, completing the destruction of the vehicles, or looking for items of intelligence value. Exposures of individuals searching enemy equipment would depend on their activity level inside the vehicle (how much dust they stirred up), as well as the time spent inside the vehicle.

Radioactive items in various foreign vehicles are typically sealed sources contained in chemical agent detectors, radiation monitors, and radiation instrument sources. Instrument dials painted with luminous paints containing radium, tritium, or promethium are noted exceptions to this rule. However, these radioactive materials are normally in very small quantities and would not present a hazard unless the source was damaged. Examples of radioactive sources in Iraq's Soviet-made equipment include the following:[115]

- Chemical Agent Detector found on T-72 tank, BMP infantry fighting vehicle, and BTR-series wheeled armored personnel carrier, - Plutonium-239 (185 to 260μg)
- Various instrument dials and switches designed to glow in the dark - Radium 226, tritium, and promethium 147.
- The case of the RWA 72K Radiation Warning and Detection Kit has a cesium 137 source on one of the straps (5.9 μCi).

4. Exposure to Smoke from Equipment Struck by DU.

US personnel often operated in close proximity to burning enemy equipment knocked out by DU rounds. These exposures could be fleeting, such as driving past burning wrecks, or longer-term, such as extended operations near sites where multiple enemy vehicles had been set afire by DU rounds. A large number of US troops fall into this category.

E. Other Activities under Investigation But Not Yet Categorized.

The Office of the Special Assistant is often contacted by veterans who wish to report incidents that they believe could have exposed them to DU contamination. The incidents they describe are often relatively isolated or unique events, and the available information is incomplete or unsubstantiated. Each of these reports is investigated and analyzed, but in the following cases the Office of the Special Assistant does not have enough information to conclusively determine

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[114] Message to ARCENT, Subject: Army Requirements for Captured Iraqi Materiel, March 11, 1991.
[115] Identification Guide for Radioactive Sources in Foreign Material, AST-1500Z-100-93, US Army Foreign Science and Technology Center, Charlottesville, VA, March 1993.

that DU exposures did or did not occur. Hence, they remain uncategorized and under investigation. The following cases fit this description.

1. Welders

Several members of the Alabama-based 900th Maintenance Company, Army National Guard, deployed to the Saudi port of Dammam to support an upgrade program for M1 tanks. This refit operation was implemented to bring earlier-model M1-series tanks to a more survivable M1A1 standard. Part of the upgrade involved welding armor panels (approximately an inch thick) to the frontal turret armor of the Abrams tanks. Some of the welders involved in the refit operations told OSAGWI investigators that they had been told the armor panels were DU.[116,117,118] In addition, two former members of a New Equipment Training Team offered similar accounts, with one saying that he had seen radiation warning symbols on the panels, which he described as machined, solid slabs of DU that were much heavier than steel.[119,120]

Other personnel, including fellow welders and senior personnel involved in the refit program, have contradicted these accounts. The Program Manager for Ground Systems Integration in Warren, Michigan, indicates that he had no knowledge of any such activity.[121] A retired Colonel, interviewed on August 7, 1997, stated that there were a few dozen workers welding ¾ inch RHS plates on the left and right glacis (the part of the turret to the right and left of the main gun) of M1 tanks in Dammam. He also said that he was involved in ordering the plates and knows they were not DU.[122] The production manager at Dammam likewise insists that the plates were RHS. He says that the RHS plates were shipped to him directly from the contractor by airfreight.[123] Fellow welders and unit members who worked alongside the individuals reporting the panels as DU recalled the add-on armor being either steel or titanium. The belief that the panels were DU may have originated with informal remarks by civilian co-workers that the M1A1 tanks contained DU armor (factory-sealed inside the turret armor, not retrofitted later). A welding supervisor noted that that when he and other welders were preparing to leave the Gulf Theater in March 1991, they were told their medical records would be annotated to reflect the fact that they had worked around depleted uranium armor.[124,125,126] This may have contributed to the belief that the add-on armor was DU. A metalurgist who participated in research and development efforts that led to the decision to put additional armor protection on the front glacis of some of the Abrams vehicles recalled that the Abram's manufacturer, General Dynamics, had

[116] Lead Sheet # 17782, Interview of former 900th Maintenance Co. E-7, July 6, 1998.
[117] Lead Sheet # 17792, Interview of former 900th Maintenance Co. E-5, July 6, 1998.
[118] Lead Sheet # 17817, Interview of former 900th Maintenance Co. E-6, July 6, 1998.
[119] Lead Sheet #5737, Interview of former New Equipment Training Team E-7, July 24, 1997.
[120] Lead Sheet #5738, Interview of former New Equipment Training Team E-6, July 24, 1997.
[121] Lead Sheet #5979, Interview of the Program Manager for Ground Systems Integration at Warren, MI July 9, 1997.
[122] Lead Sheet #5679, Interview of former Colonel involved in Friendly Fire investigations, August 7, 1997, p. 2.
[123] Lead Sheet #5697, Interview of production manager of Dammam welding operation, August 14, 1997, p. 1.
[124] Lead Sheet # 14141, Interview of New Equipment Training Team E-6, January 14, 1998.
[125] Lead Sheet # 17784, Interview of former 900th Maintenance Co. Section Chief, July 6, 1998.
[126] Lead Sheet # 17789, Interview of former 900th Maintenance Co. E-5, July 6, 1998.

fabricated the armor from steel plate. Asked to comment on the feasibility of welding the pyrophoric DU onto regular armor, he said, "Metallurgically, welding a uranium plate to steel would be a disaster." After giving a technical explanation for his remark, he concluded: "Bottom line is that no welding engineer, metallurgist, vehicle designer, or armor designer would ever want a DU plate welded to the vehicle."[127] Although this allegation remains under investigation, the initial assessment is that DU was not involved.

2. Reported Ammo Truck Explosion

A veteran reported seeing a US ammunition truck explode in the area of the 1st Infantry Division on the third or fourth day of the ground war. The incident reportedly occurred about 75 to 100 miles northwest of Hafar Al Batin and was witnessed from a distance of 1 to 2 kilometers. According to the veteran, a mixed load of high explosive and DU rounds exploded. He reported finding blue sheaths on the ground which he believed (erroneously) to be characteristic of DU rounds.[128]

Other soldiers in the platoon also recall the incident but thought the vehicle was carrying artillery rounds[129] or powder bags for 155mm artillery rounds.[130] The veteran's platoon leader remembers hearing that the vehicle's brakes caught on fire and the driver, unable to extinguish the flames, drove the truck off Main Supply Route (MSR) Blue into the desert to reduce the hazard to other soldiers. After the explosion there was nothing left but the engine block.[131] A munitions expert at Picatinny Arsenal stated that the color blue is not indicative of DU munitions, but rather is associated with training rounds.[132]

The theater ammunition officer was unaware of any truckload of DU, which blew up during the war. He is fairly certain he would have heard of it if it had happened.[133] Civilian ammunition experts[134] in theater, including one from the 2nd Corps Support Command, that was responsible for transportation in the area, had no knowledge of a load of DU munitions exploding.[135] An officer commanding an ordnance storage area in the vicinity of the explosion recalled seeing the explosion at around 3 AM. He later heard that a truck's brakes had gotten stuck and caught on

[127] Electronic Mail from Metallurgist involved in M1 upgrade R&D efforts, subj.: Welding Uranium, July 8, 1998,
[128] CMAT Report # 1997261-0000022, Interview of combat engineer from 61st Combat Support Detachment, October 16, 1997.
[129] Lead Sheet 7013, Interview of former platoon leader in 61st Combat Support Detachment November 14, 1997.
[130] Lead Sheet 7092, Interview of radio telephone operator from 61st Combat Support Detachment, November 18, 1997.
[131] Lead Sheet 7013, Interview of former platoon leader in 61st Combat Support Detachment November 14, 1997.
[132] Lead Sheet 14251, Interview of munitions expert from Picatinny Arsenal, January 26, 1998.
[133] Lead Sheet 6892, Interview of theater ammunition officer, November 6, 1997.
[134] These Quality Assistance Specialists Ammunition Specialists (QUASAS) were experts in the storage and transportation of ammunition.
[135] Lead Sheet 6991, Interview of the head QUASAS in theater, November 12, 1997; Lead Sheet 6996, Interview of the 2nd COSCOM QUASAS, November 12, 1997.

fire and caused a trailer load of artillery rounds to explode.[136] The former battalion commander of the 101st Ordnance Battalion confirmed this story.[137]

Information regarding this incident is still being sought.

3. Airmen Responding to A-10 Crash.

An A-10 aircraft reportedly crashed and burned while trying to recover at KKMC.[138] The crash could have exposed emergency response personnel (firefighters, security policemen, rescue personnel) to smoke and DU oxides from burning 30mm DU rounds carried as part of the A-10's combat ammunition load. In addition, cleanup crews might have been exposed as well, if they did not wear proper personal protective equipment. This case is under investigation.

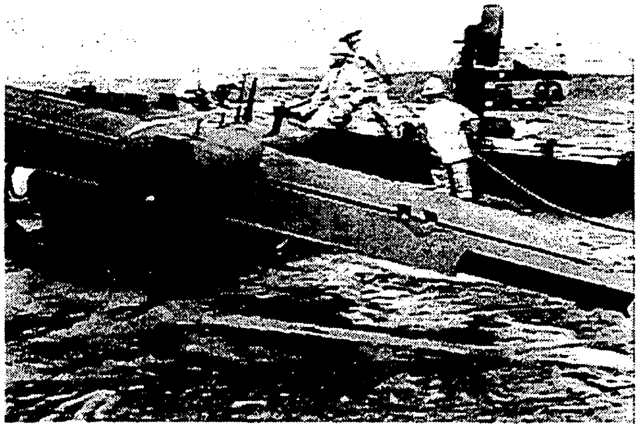

Figure 23 – Crashed A-10 at KKMC

4. "Hot gun" response for A-10 Aircraft

30mm DU rounds sometimes misfired in the A-10's GAU-8 cannon. These "hangfires" would have to be cleared and removed from the gun barrel, potentially exposing ground crews to airborne DU.[139] This office is still investigating these incidents.

[136] Lead Sheet 7072, Interview of commander of ordnance storage area, November 17, 1997.
[137] Lead Sheet 7155, Interview of commander of 101st Ordnance Battalion, November 25, 1997.
[138] CMAT No. 1998085-5, Callback Interview of USAF bomb disposal specialist, March 27, 1998.
[139] CMAT No. 1997190-1045, Callback Interview of USAF munitions specialist, August 19, 1997.

Tab H - Friendly Fire Incident Descriptions

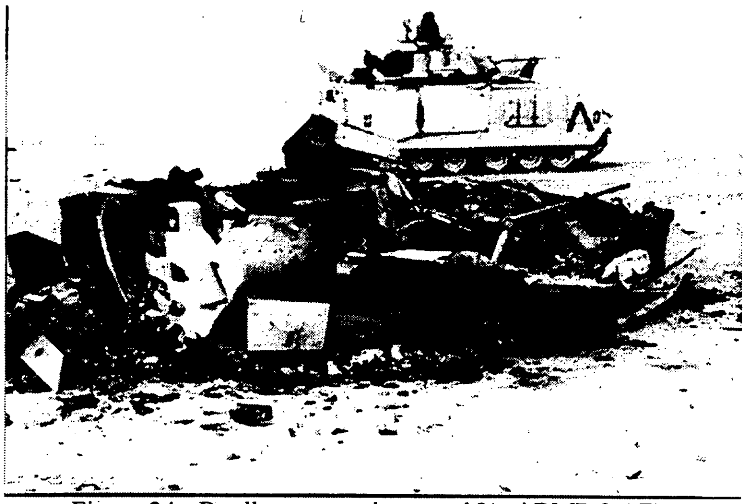

Figure 24 - Bradley passes destroyed Iraqi BMP-2 AFV

The "100 hour" Desert Storm ground campaign illustrated the ferocity and high operational tempo of modern warfare. Almost one million coalition combatants and over ten thousand armored vehicles engaged in intense and sustained combat operations around the clock and in all weather. Unlike previous conflicts where the front lines remained relatively fixed, Operation Desert Storm was characterized by a dynamic, often confused battlefield where individual combat vehicle crews and units, caught up in the rapid advance punctuated by pitched skirmishes and battles, sometimes lacked "situational awareness" regarding the precise whereabouts of surrounding enemy and friendly forces.

On the modern battlefield, success tends to favor the side that can see, engage, and neutralize the enemy first. US combat vehicles enjoyed important technological advantages over Iraq's older, mostly Russian-designed armored vehicles. Superior sighting and sensor equipment almost invariably allowed US crewmen to see and engage the Iraqis first, especially during night combat or in bad weather. US cannon systems were stabilized, so they could fire accurately while on the move. They could select, load, and fire munitions far more rapidly than their Iraqi counterparts. Finally, the use of DU rounds allowed US tanks to engage the enemy with unprecedented range and effect. While Iraqi Republican Guard T-72s—Saddam's most formidable armored threat—boasted a 125mm cannon with a maximum effective range of 1,800 meters, US M1A1 tanks routinely scored kills at twice that distance.[140] In addition, Iraqi tanks, anti-tank guided missiles, and infantry anti-tank weapons failed to penetrate the DU armor of any of the 594 Heavy Armor M1A1s that saw action in the Gulf War, even when firing from well within their supposed "lethal" engagement parameters and scoring direct hits.[141] The result was one of the most lopsided victories in modern military history—Iraq lost in excess of 4,000 armored vehicles to US air and ground fire, while US ground forces sustained fewer than 25 combat vehicle losses from hostile fire.

[140] Atkinson, Rick. Crusade: The Untold Story of the Persian Gulf War. New York, NY: Houghton Mifflin, 1993, p. 466.

[141] Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report. Atlanta, GA:US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995; p. 76.

Tragically, "fog of war" situations caused by the rapid advance of American forces, coupled with the use of long-range, highly lethal weapons, led to a number of friendly fire incidents in which US combat vehicles, usually M1A1 tanks, fired on fellow US combat vehicles or units. At least eight friendly fire incidents involving DU munitions occurred during the Gulf War. These incidents resulted in the contamination of six M1 or M1A1 tanks, and 15 Bradley Fighting Vehicles. Another M1A1 was hit by a large shaped-charge round, believed to be a Hellfire anti-armor missile fired from an Apache helicopter, that ignited an on-board fire. This incident is described separately in the "Tank Fires" section. The major contributing factors in all of these incidents were darkness or low visibility from heavy rains, sandstorms, etc.. In most cases, owing to battlefield confusion, the soldiers manning the targeted vehicles initially believed that the Iraqis had fired the shots that penetrated their armor. A team of battle damage assessment experts was later able to ascertain which vehicles had been engaged by Abrams tanks, since the DU round leaves a distinctive radioactive trace on the entrance and exit holes. In most cases, after-action investigations and word-of-mouth reporting among and between the units involved resulted in the affected soldiers learning that they had been victims of friendly fire. Not all of these soldiers, however, were aware of the potential health effects associated with internalized DU. Accordingly, the investigation of friendly fire incidents is being accompanied by a comprehensive effort to identify, locate, and contact all surviving soldiers who were in or on vehicles at the time they were penetrated by DU rounds.

Figure 25 –Bradley patrol at dusk

a. The 4th Squadron of the 7th Cavalry Regiment: Between 3 and 5:30 PM, February 26, 1991

Three Bradleys configured as Cavalry Fighting Vehicles (CFVs) were struck by DU rounds fired from Abrams tanks between 3:00 and 5:30 PM on February 26. The vehicles were hit during a large-scale tank battle. Visibility was poor due to dusk and blowing sand and smoke.[142] The vehicles were either mistaken for Iraqi vehicles or caught in the crossfire of a "nonlinear" (shifting and confused) battlefield.[143]

At the time of the incident, the 3rd Armored Division was attacking to the east with the 1st Brigade on the right and the 2nd Brigade on the left, with the 3rd Brigade following. The 4-7th Cavalry was protecting the Division's right flank. Alpha troop of the 4-7th Cavalry was

[142] Memorandum for the Commanding General, 3rd Armored Division, Subject: Investigation of the Circumstances Surrounding the Combat Damage to Alpha Troop 4-7 CAV, March 14, 1991.
[143] Memorandum for Commanding General, VII Corps, Subject: Investigation of Possible Fratricide by 3rd Armored Division Units, March 16, 1991.

screening on line with the lead elements of the 1st Brigade. Alpha troop was arrayed with the 3rd platoon on line, followed by the 2nd platoon on line 500 meters behind. Upon contact with six enemy tanks and 18 light armored vehicles (BMPs), the 2nd platoon split and sent three of its Bradleys to the right and left flanks of the 3rd platoon. The Bradleys of Alpha Troop were exchanging direct fire with the enemy tanks and BMPs at ranges from about 100 to 800 meters. The Bradleys employed their 25mm HEI (High Explosive Incendiary) and tungsten armor piercing (AP) munitions, as well as Tube-launched, Optically-tracked, Wire-guided (TOW) antitank missile systems. The following information is known about each Bradley (Cavalry Fighting Vehicle configurations) hit by DU rounds during the confused engagement.[144]

A Troop 4-7th Cavalry, Bradley (Bumper # A-24): A-24 was the first Bradley to be hit, struck by a 120mm DU sabot round fired from an Abrams tank.[145] At sundown, with wind-blown sand further reducing visibility, 3rd Platoon, to which A-24 was assigned, came over a rise in the terrain and saw a "target rich environment" with enemy ground troops and BMP armored fighting vehicles. A-24 engaged the enemy with TOW missiles and fire from their 25mm turret gun. When the gun jammed, the "track" commander attempted to pull the Bradley out of the fight to fix the gun and reload the top-mounted TOW missile launcher. As the loader was half-in, half-out of the vehicle attempting to reload the TOW, the vehicle was struck by a single DU sabot round and almost immediately was engulfed in flames. The DU sabot round entered the left front center of the turret section and exited the right rear center. The gunner was killed, and the vehicle commander received a serious leg wound. Two of the three remaining crewmen had minor injuries (flash burns); the third was unwounded, but reentered the Bradley to remove personal equipment and to recover the body of the gunner. Another Bradley, A-26, came to their aid, but apparently did not enter A-24.

A Troop 4-7th Cavalry, Bradley (Bumper # A-31): This Bradley, one of four in the 3rd Platoon, was part of the lead element to go into battle. After a heavy machine gun bullet that struck its transmission disabled BFV A-36, its crew was ordered to abandon the vehicle. As they were exiting through the hatches, the Bradley was struck again by a shell that the crew believes was fired from a T-72. The round "exploded" against the side of the Bradley, in the words of one crewman, wounding several of the evacuating soldiers. Shortly afterwards, BFV A-31 pulled alongside and picked up its crew. Minutes later, two 120mm DU sabots[146] struck A-31 in the right hull under the turret, exiting the left hull behind the driver's seat. Seven of the eight soldiers onboard were wounded, with some suffering severe burns and/or fragment wounds. During and after the battle, combat lifesavers were on the scene to extract the wounded from the damaged but still operable vehicle. Approximately 30 minutes after the battle had ended, the

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[144] Battle scenario and damage information were taken from Memorandum for the Commanding General, 3rd Armored Division, Subject: Investigation of the Circumstances Surrounding the Combat Damage to Alpha Troop 4-7 CAV, March 14, 1991.

[145] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 352.

[146] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 371.

Platoon Sergeant and his observer, who had earlier gone into the two BFVs to help the wounded, returned to the scene and retrieved A-31, driving it back to their base camp.[147] All of the wounded survived, and the DU follow-up program in Baltimore is currently monitoring those with embedded fragments.

A Troop 4-7th Cavalry, Bradley (Bumper # A-22): This Bradley was the last vehicle hit by friendly fire in this battle. It was oriented east and the DU round[148] entered the left rear turret section and exited the right front turret. The gunner was killed, and three other soldiers (the commander and two dismount troops) received fragment wounds, including a Sergeant First Class (SFC) who was on top of the vehicle and was blown clear.[149] Two other soldiers entered the vehicle after it was hit to rescue the surviving crewmen. The BFV could still be driven, but was not combat-capable. Within hours of the incident, soldiers entered A-22 to salvage its radio, munitions, and other sensitive equipment, which were reused within the battalion. The SFC who was ejected from the vehicle has stated that it was common knowledge within the unit that A-22 had been struck by friendly fire; however, the SFC, at least, was unaware that DU munitions were involved. The SFC is currently enrolled in the Baltimore DU follow-up treatment program for soldiers exposed to DU.[150, 151]

Fifteen or more soldiers may have been exposed to DU dust since they were in these three Bradleys at the time the vehicles were struck by DU rounds. A Headquarters and Headquarters Troop (HHT) M113 medical ambulance evacuated the wounded soldiers to the Squadron Aid Station by at least three medics.[152] Additionally, an unknown number of soldiers may have been exposed when they entered the vehicles shortly after the vehicles were hit.

b. Task Force 1-37 Armor: Evening of February 26, 1991

At around 8:00 PM on February 26th, Task Force 1-37 Armor conducted a night attack on an Iraqi position defended by portions of the Talwakana Division, Republican Guard, equipped with T-72 tanks and BMPs. The attack was part of a coordinated division attack, with 1-37 Armor being the southernmost task force. 1-37 Armor was connected with the 3rd Armored Division in 7th Corps' attack in the south. One tank, bumper #B-23, was hit by a shaped charge weapon

[147] CMAT No. 1997289-234, Callback Interview of platoon sergeant of 3rd platoon, A troop, 4/7th Cavalry, October 14, 1997.

[148] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 361.

[149] Battle scenario and damage information were taken from Memorandum for the Commanding General, 3rd Armored Division, Subject: Investigation of the Circumstances Surrounding the Combat Damage to Alpha Troop 4-7 CAV, March 14, 1991.

[150] CMAT No. 1997293-074, Callback Interview of A-22 Bradley commander, A troop, 4/7th Cavalry, October 20, 1997.

[151] Chandler, Jr., Captain E. Allen. Historical Report Format: "A Troop, 4/7th Cavalry, Contact with Iraqi Tanks, February 26, 1991." Fort Leavenworth, KS: Center for Army Lessons Learned, Gulf War Collection, SSG AAR4-147, May 29, 1991.

[152] "USAAVNC Army Aviation in Desert Shield-Storm 13, Recon and Security" (Fort Leavenworth, KS: Center for Army Lessons Learned, Operations Desert Shield - Desert Storm - Gulf War, 1990-1991, p. 307.

(most likely a Hellfire missile), causing an on-board fire. This incident is described in the section on tank fires. At the time of the attack, low, heavy clouds and rain obscured visibility. The following information is known about the tank (Bumper # C-12) hit by a DU round.

C Co., Task Force 1-37 Armor, Abrams Tank (Bumper # C-12): This tank was struck in the rear by a 120mm DU round[153] which caused a loss of power. As the crew was evacuating, an antitank (AT) missile struck the rear of the bustle rack, causing the rucksacks, duffel bags, and associated equipment fastened there to catch fire. There was no damage to the turret's interior, and no secondary explosions of stored ammunition or fuel. No injuries were reported among the crewmembers, and the tank was recovered on March 4, 1991. The identities of the crewmembers are unknown at this time. It is assumed that the tank had its normal four-man crew.[154]

c. Battle of Norfolk: Early Morning Hours of February 27, 1991

The largest friendly fire incident of the war involved the soldiers of the 3rd Brigade of the 2nd Armored Division (Fwd) during a February 27, 1991 night attack on the 37th Brigade of the Iraqi 12th Armored Division. This 2nd AD brigade was brought in from Germany to form the 3rd Brigade of the 1st Infantry Division in Operation Desert Storm. The tank battle that ensued was a tumultuous, 360-degree action. Overcast skies and wind-driven rain and smoke compounded the confusion of the pre-dawn, swirling battlefield. The US combat vehicles were using thermal sights, making identification of friend or foe more challenging. The battle resulted in the damage or destruction of five Bradleys and five Abrams Tanks, with nine of the ten US vehicles hit directly by 120mm DU sabots fired from M1 tanks. In addition, several of these vehicles were also struck by enemy fire.[155]

The action began following the Battle of 73 Easting in which the 2nd Armored Cavalry Regiment (ACR) located and destroyed elements of the Iraqi 12th Armored Division and the Tawalkana Division. The 2nd ACR halted their advance and allowed the two brigades of the 1st Infantry Division (ID) to pass through their positions on the night of February 26th. Most units do not train in peacetime to do a night passage of lines (while firing live ammunition) because it is considered too hazardous. Despite the fact that many of the soldiers had had little or no sleep in the previous 36 hours, the passage of lines was performed flawlessly. Following the passage, the two brigades were attacking east as part of a division coordinated attack with the 1st Brigade in the north and the 3rd Brigade in the south. Since there were no obvious terrain features to separate the forces, the dividing line between brigade sectors was the 92 East/West grid line.

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153 Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 162.

154 Battle scenario and damage information were taken from "Analysis of 1-37 Armor's Battle Damage Incident," Aberdeen Proving Ground, MD: Ballistic Research Laboratory, (Undated).

155 All battle scenario and damage information for the Battle of Norfolk (except as otherwise noted) was taken from: Memorandum for the Commanding General, 1st Infantry Division, Subject: "Informal Investigation of the Night Attack Conducted by 3rd Brigade on February 26-27, 1991," March 10, 1991.

The Third Brigade attacked with three battalions on line to clear the zone of the enemy. Although the night was clear, with plenty of starlight to optimize the performance of night vision devices, the battlefield was far from ordered. In spite of its leaders' best efforts, the battalions of the 3rd Brigade did not maintain a line-abreast formation. To further complicate matters, pockets of enemy infantry became interspersed among the attacking US combat vehicles. The shifting battlefield contributed greatly to the ensuing confusion. Two Bradleys of Bravo Company, Task Force 1-41 Infantry were the first to be engaged. Equipment problems forced the company commander to switch vehicles and the company momentarily lost contact with the rest of the battalion. In their effort to reestablish contact, Bravo Company entered an Iraqi bunker complex and was engaged by rocket propelled grenades (RPGs) at around 2:00 AM on February 27th. Following the initial RPG attacks, Bravo Company was fired on by US Abrams tanks. Here is what is known about the three Bradleys damaged in this action:

B Co. Task Force 1-41 Infantry, Bradley (Bumper # B-21): This Bradley was struck by two 120mm DU sabot rounds,[156] killing three soldiers and wounding at least three of the ten crewmen and infantry soldiers aboard. At least two of the wounded had embedded fragments; a third suffered severe burns in the incident.

B Co. Task Force 1-41 Infantry, Bradley (Bumper # B-26): This was the vehicle commandeered by the company commander after his Bradley malfunctioned. A 120mm sabot struck the Bradley,[157] killing one soldier. The crew from another BFV (#B-32) pulled up alongside B-26 and assisted its occupants in evacuating the vehicle. The same personnel also removed sensitive items of equipment from B-26. A Sergeant Major in B-32 who responded to the incident believes his exposure to DU was minimal, since he was only in the struck vehicle for a very short period of time.[158]

B Co. Task Force 1-41 Infantry, Bradley (Bumper # B-33): This Bradley was struck by a 120mm sabot round.[159] No soldiers were killed. It is unknown who, or how many, soldiers were onboard at the time it was struck, or the number and extent of injuries. Parts had been stripped from the vehicle after it was knocked out.

The numbers and identities of soldiers who entered the Bradleys to rescue fellow soldiers or for other reasons are currently unknown. Following the attack, the wounded were evacuated and

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[156] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 136.
[157] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p.85.
[158] CMAT No. 1997294-006, Callback Interview of B-32 Bradley commander, B company, 1-41st Infantry, October 21, 1997.
[159] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 145.

soldiers with combat lifesaving certification rendered first aid. Their efforts were hampered by enemy mortar fire, which fortunately did not produce additional casualties.

Later that morning, between 4:00 AM and 5:00 AM, two Bradleys from Delta Company, Task Force 1-41 Infantry came under a combination of friendly and enemy fire. The Bradleys had become separated from the rest of the battalion, initially because one of the Bradleys was stuck in a revetment (three-sided earthworks or berms built by the Iraqis to shelter their armor while allowing them to engage hostile forces). Later, the unit halted when they encountered surrendering Iraqi troops. They were ordered to point the Iraqis in the right direction and catch up with the rest of the company. Some time later they were engaged by Iraqi rocket-propelled grenades (RPGs), and returned fire. This drew the attention of soldiers from the 1-34th Armor who thought they were drawing fire. After receiving authorization to fire, the tanks destroyed the two Bradleys. A subsequent plotting of their location indicated that the Bradleys were about 1 km into the 1st Brigade's sector. A bunker complex with unfired RPGs was discovered approximately 300 meters to the front of the two Bradleys. The following is known about the two Bradleys damaged in this action:

D Co. Task Force 1-41 Infantry, Bradley (Bumper # D-21): After driving all night (until around 4:00 AM) this BFV, with at least seven occupants, drove into a bomb crater. In the process of extricating itself, D-21 became separated from the rest of the company. Shortly afterward, the BFV and its squad moved into a bunker area, where they rounded up about 20 Iraqi EPWs. At this point they were spotted and engaged by M1A1 tanks from another unit. D-21 was stuck in the side hull by three 120mm sabot rounds,[160] two of which passed through both sides of the vehicle and struck another BFV (D-26) parked 20 feet away. The driver of D-21 was killed; the other three soldiers still in the vehicle were wounded. The vehicle caught fire and was totally destroyed. A scout unit from the 1st Infantry Division that had also fired on the two BFVs, apparently without effect, realized its error and came to their aid, evacuating the wounded crewmen to a nearby medical aid station. No one attempted to remove anything from either D-21 or D-26, since the two BFVs were on fire when responding personnel arrived, and were too badly gutted to be salvageable. Several members of the crews or associated infantry fled into the desert after the second volley, fearing the vehicles would explode.[161]

D Co. Task Force 1-41 Infantry, Bradley (Bumper # D-26): This Bradley was struck by two 120mm sabot rounds[162] that had just passed through D-21, in the incident described above. The sole occupant of D-26, the driver, sustained severe leg wounds and other injuries from the projectiles. Seven other crewmen or "dismount infantry" (troops who ride the Bradley into the battle area, then "dismount" the vehicle to engage the enemy), had earlier left the BFV to secure

[160] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 189.
[161] CMAT No. 1997289-197, Callback Interview of former SFC in D Company, 1-41st Infantry, October 16, 1997.
[162] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 202.

enemy prisoners of war (EPWs) and to clear captured bunkers. The driver, though badly wounded, was able to get out of the vehicle on his own, and once outside was aided by fellow platoon members. After being struck, D-26 caught fire and "melted to the ground," in the words of its driver, making it unlikely that any troops would have entered it. Both D-21 and D-26 were left in place until after the ground war.[163]

The five tanks damaged or destroyed at the Battle of Norfolk were the last of the friendly fire victims to be engaged in this battle. These tanks, which were from 3-66 Armor, were attached to Task Force 1-41 for this mission. The first tank to be destroyed (B-66) was initially struck by an RPG. When an RPG strikes a tank, it produces a shower of flames and smoke. To soldiers viewing the event through thermal sights, it may appear as if the struck tank has fired in their direction. This may have been the case in this incident, because shortly after the RPG impact, B-66 came under fire from one or more tanks. Four additional tanks rushing to the aid of B-66 were subsequently fired on and struck as well. Here is what is known about the five Abrams tanks damaged in this action:

B Co. 3-66 Armor, Abrams (Bumper # B-66): This was the Bravo company commander's tank. It was hit by three 120mm DU rounds[164] with one striking just below the turret, killing the gunner. None of these rounds penetrated the DU armor panels. At the time it was hit, it was moving in a different direction than the rest of the company. This may have contributed to the misidentification. Three soldiers survived this attack, at least two of them with severe burns. One of the survivors had fragment wounds as well.

B Co. 3-66 Armor, Abrams (Bumper # B-22): This tank, reacting to the fire that engaged B-66, turned in the direction of fire and was hit on the front slope by a 120mm DU round.[165] There was no internal damage to this tank.[166] The driver was wounded. It is presumed that this tank had its full crew of four at the time it was struck.

A Co. 3-66 Armor, Abrams (Bumper # A-14): This tank was struck by a 120mm sabot round fired from an Abrams tank.[167] Three soldiers were wounded. It is presumed that this tank had its full crew of four when it was struck.

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[163] CMAT No. 1997295-004, Callback Interview of former Bradley driver in D Company, 1-41st Infantry, October 28, 1997.

[164] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 116.

[165] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 70.

[166] Memorandum for SRC, AMCCOM-SWA, Subject "Vehicle Assessment Report Depleted Uranium Contamination," May 14, 1991, p. 7, paragraph A.

[167] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 95.

A Co. 3-66 Armor, Abrams (Bumper # A-31): This tank was struck in the left rear by pieces of a 120mm DU round.[168] A report prepared by the Radiation Control (RADCON) Team from KKMC states that the four-crew members of this tank all received fragment wounds and were evacuated back to Germany. The Company Commander, who relayed this information to the team in late April 1991, also stated that numerous individuals were exposed to smoke during the resulting fire. One member of the RADCON Team advised the Company Commander that all individuals involved in the DU incident should receive an appropriate medical exam. The commander was given a copy of a health hazard message dated April 11, 1991 and a copy of TB522[169]

A Co. 3-66 Armor, Abrams (Bumper # A-33): At approximately 4:30 AM on the morning of 27 February, A-33 was struck in the engine compartment by a TOW anti-tank guided missile probably fired from a Bradley Fighting Vehicle. The uninjured crew were evacuating their disabled tank when it was hit again, this time by two DU sabot rounds[170] that hit the vehicle in the left side and exited through its right side. The tank commander, driver, and gunner sustained injuries from fragments. The loader, who was already outside the tank, was apparently uninjured, but may have been at risk from inhaling DU aerosols created on impact. At least one of the individuals involved in this incident is enrolled in the VA's DU Follow Up Program.[171]

In summary, a total of 50 soldiers were exposed to DU fragment wounds and DU aerosols inhaled or ingested during the Battle of Norfolk. Additionally, an unknown number of soldiers could have been exposed to DU residues when they entered the vehicles shortly after the damage occurred.

d. Battle for Jalibah Southeast Airfield: Around 6:00 AM, February 27, 1991

On February 27th the 2nd Brigade of the 24th Infantry Division was attacking the heavily defended Jalibah Airfield, the last major obstacle between the 24th Infantry Division and the Euphrates River. Satellite imagery and reconnaissance aircraft indicated the presence of 20 enemy tanks and more than 1,000 dug-in Iraqi soldiers. Task Forces 1-64 Armor and 3-69 Armor were to "overwatch" (provide covering fire) from the southwest and southeast corners of the airfield respectively. A north-south road was to be the boundary between the two overwatching forces. Meanwhile, Task Force 3-15 Infantry was to sweep the airfield from west to east.

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168 Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 77.

169 Memorandum for SRC, AMCCOM-SWA, Subject "Vehicle Assessment Report Depleted Uranium Contamination," May 14, 1991, p. 10, paragraph J.

170 Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 101.

171 CMAT No. 1997280-031, Callback Interview of former A-33 tank commander, A Company, 3-66th Armor, October 23, 1997.

As the two overwatching task forces were moving into position, a platoon from the 3-69 Armor crossed to the west of the boundary road. At this point, Company C of 3-69 Armor came under direct and indirect fire from the Iraqis at the airfield. As the C Company tanks moved in on what they thought was an Iraqi defensive belt, Bradley vehicles from Task Force 1-15 Infantry appeared about 2,000 to 2,500 meters in front of them. The C Company tanks mistook the Bradleys for Iraqi armored vehicles and engaged them with eight to sixteen 120mm armored piercing (DU) rounds. The following is what is known about these Bradleys:[172]

C Co. 3-15 Infantry, Bradley (Bumper # C-11): In the early morning hours of February 27, BFV C-11 was on the right flank of a four-company task force formation closing in on Jalibah Southeast Airfield in southern Iraq. After changing direction to evade incoming enemy artillery, C-11 was hit from behind by a 120mm DU sabot round fired from an Abrams tank.[173] The round entered the Bradley through the ramp, passed through the troop compartment, and exited the left side of the vehicle. An antitank weapon (AT4) stowed inside the Bradley detonated, inflicting severe injuries to several personnel in addition to the wounds produced by DU fragments and shrapnel. A PFC was killed and at least five of the remaining seven personnel were injured, most seriously. Two NCOs aboard the stricken vehicle provided emergency first aid, then drove the damaged Bradley filled with wounded soldiers for about three miles to a medical aid station. They removed salvageable equipment from the shot-up BFV, then drove the still-serviceable vehicle back to their company's forward operating location. While en route they picked up two other soldiers from another disabled combat vehicle. The two NCOs continued to man C-11 for another three days before it was taken away from them and sent back to KKMC with other DU-contaminated systems.[174]

C Co. 3-15 Infantry, Bradley (Bumper # C-22): This Bradley was struck on the right side, just below the turret, by a 120mm sabot round.[175] The round exited the vehicle on the front left side after passing through the driver's compartment, killing the driver. Only one other soldier on this vehicle has been identified to date.

C Co. 3-15 Infantry, Bradley (Bumper # C-23): Two 120mm sabot rounds entered the vehicle[176] on the right side and crossed through the engine compartment, exiting on either side of the

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[172]Battle scenario and damage information (except where otherwise noted) were taken from: Memorandum from 3d Battalion, 15th Infantry to AC of S, G3, 24th ID, M FSGA, 32314. Subject: "Battle Damage Assessment" June 14, 1991.

[173] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 319.

[174] CMAT No. 1997288-057, Callback Interview of former Bradley driver in C Company, 3-15th Infantry, October 23, 1997.

[175] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 339.

[176] Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 328.

driver. Nine soldiers were probably in this Bradley, three of whom—all wounded—have been identified.

There could have been as many as 25 soldiers onboard the three Bradleys at the time they were struck at Jalibah. The number of soldiers who entered the contaminated vehicles to rescue fallen comrades is unknown at this time.

e. 4-66th Armor: Around 4:30 PM, February 27, 1991

On February 27th the scout platoon of 4-66th Armor was ordered to provide flank security and maintain contact with elements of 1-35th Armor on the battalion's left flank. The unit was attacking an Iraqi ammunition storage area. Light rain and dense smoke from a nearby burning ammunition dump obscured the visibility. The operation went smoothly until around 4:30 PM, when the advance of 1-35th Armor stalled, leaving the flanks of 4-66th Armor exposed. Within minutes, Bradleys from the scout platoon came under fire from dug-in Iraqi rocket propelled grenade teams. During the ensuing fight, two of the scout platoon's Bradleys were struck by DU rounds. The following is known about these Bradleys:

<u>HQ Co. 4-66th Armor, Bradley (Bumper # HQ-55)</u>: This Bradley was hit by a 120mm DU sabot round on the lower right side, just above the road wheel.[177] All five soldiers onboard evacuated without injury and have been identified.

<u>HQ Co. 4-66th Armor, Bradley (Bumper # HQ-54)</u>: This was the scout Platoon Sergeant's Bradley. To cover the evacuation of HQ-55, the Platoon Sergeant placed his track between the damaged Bradley and the enemy. He had just opened fire on the Iraqis when two DU rounds struck his Bradley, killing his driver and wounding the commander and gunner.[178]

f. 1-34th Armor

Just after midnight on February 27, the 1-34 Armor Battalion of the 1st Brigade, 1st Infantry Division, was doing a night passage of lines through the US 2nd Armored Cavalry Regiment. The 2nd ACR had been engaging the Republican Guard Tawalkana Division. An Abrams mistook the Bradley, which was stationary at the time, for an Iraqi combat vehicle and fired a single round from about 1,500 meters. The DU sabot went in the Bradley's left rear door on a centerline trajectory. The hit set off TOW missiles, 25mm rounds, and other munitions stored in HQ-232's interior. The blast ejected the driver and gunner through their respective hatches, which were open. They were extremely fortunate, escaping with only minor flash burns. The commander also escaped without injury. Two observers in the rear of the vehicle were wounded. One lost his heel (probably to the DU round itself, not the secondary explosion); the other suffered a serious leg injury. HQ-232 was completely destroyed. Another Bradley, HQ-231,

[177] Battle scenario and damage information were taken from Fratricide Assessment # 1-27: 4-66 Armor. Fort Leavenworth, KS: Center for Army Lessons Learned, Operation Desert Shield - Desert Storm - Gulf War, Undated.
[178] Fratricide Assessment # 1-22: 4-66 Armor. Fort Leavenworth, KS: Center for Army Lessons Learned, Operation Desert Shield - Desert Storm - Gulf War, Undated.

was hit by a 25mm (non-DU) round while moving forward to assist HQ-232. Other than the surviving crewmembers of HQ-232, no other personnel entered the vehicle.[179,180]

g. 2nd Squadron of the Second Cavalry Regiment

A friendly fire incident involving Bradley bumper # G-14 occurred on 27 February 1991. At approximately 4:00 PM local time a shell, type or source unknown, struck G-14 in the left rear. The round struck and penetrated the turret, killing the gunner. The four other crewmembers received only minor injuries, and were returned to duty later that evening. The round passed through the turret without igniting any secondary explosions or fires. Later, at approximately 10:00 PM, an M1A1 that was part of a US armored unit coming forward to relieve G Troop was apparently startled by the sudden appearance of G-14, and fired a 120mm DU round into the empty vehicle from an estimated range of 50 meters. The shell set off an onboard fire that completely destroyed G-14. The BFV melted, making it difficult to determine the number and type of shells that struck it, although at least one was assessed as DU by the BDAT team. Corroborating information is still being sought by this office.[181, 182]

h. Air-to-Ground Incidents

On January 22, 1991, US Air Force A-10 "Warthog" close air support aircraft mistakenly strafed the abandoned town of Hamel Pyat, just inside the Saudi border opposite southern Kuwait, while a patrol from the Marine 1st Force Reconnaissance Company was stopped at the location. The errant attack did not cause any casualties, since the 12-15 Marines who witnessed the incident were on the opposite end of the empty town. The A-10 involved in the incident made a single short strafing run from a very high altitude. Because of the threat from Iraqi surface-to-air missiles, A-10s had been ordered to stay at least 8,000 feet above ground level. The A-10 is most effective at lower altitudes, and the great firing distance caused a wide dispersion of the 30mm rounds. Although the cyclic (firing) rate of the A-10's Gatling gun is extremely high (6,000 rounds per minute), it typically fires a two-to-three second burst, meaning 200-300 shells might have impacted the target area. One shell in five is a non-DU tracer round. Fortunately, none of the Marines were close enough to the impacting DU rounds to be wounded or potentially exposed.[183]

On January 23, 1991, an A-10 inadvertently strafed a Marine observation post, also manned by 1st Marine Force Recon personnel, near the border town of Khafji, Saudi Arabia, abutting the eastern tip of Southern Kuwait. No casualties resulted. The squad-sized team had set up a

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179 Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 245.

180 Lead Sheet # 16645, Interview of former 1-34 Bradley crewman, May 19, 1998, p. 1-2.

181 Richard A. Koffinke, Jr. and Frederick T. Brown. US Army Battle Damage Assessment Operations in Operation Desert Storm, Vol. II (U) ARL-TR-104, Aberdeen Proving Ground, MD: Army Research Laboratory, March 1993, p. 349.

182 Lead Sheet # 7178, Interview of former G Troop Commander, December 8, 1997.

183 Lead Sheet # 14195, Interview of former Commander, Marine First Force Recon Company, January 19, 1998.

forward observation post, OP 8, to gather intelligence and targeting information on Iraqi forces across the border. OP 8 consisted of a reveted HUMVEE configured as a reconnaissance vehicle dug into a sand dune, manned by a squad of Marines and a smaller number of Navy SEALs. At dusk, the Marine forward air controller at OP 8 spotted an Iraqi artillery position two kilometers to his front, and requested an orbiting A-10 on an "armed reconnaissance" mission to attack the enemy position. The A-10 pilot misidentified OP 8 as his target, and fired a single burst of 30mm DU shells that impacted in and around the post. No Marines were injured in the incident, and no vehicles or equipment were struck. The soft surface, wide dispersion of the shells, and the distance from which they were fired would have reduced the likelihood of an aerosol-forming impact. The Marines remained at the site for at another day or so, but did not disturb the buried or exposed DU projectiles.[184]

A more serious incident, once again involving the Force Recon Company, occurred on January 24, 1991. A pair of A-10s working a "kill box" just over the Kuwaiti border targeted a Marine platoon that was driving east along a road that parallels a man-made anti-smuggling sand berm that runs the length of the southern Saudi-Kuwait border. At the time of the attack, the Marines were about 30 kilometers west of Khafji, Saudi Arabia, which had recently been the scene of the first large-scale ground clash between Coalition and Iraqi forces. The convoy, consisting of three five-ton trucks and a pair of HUMVEEs, was two kilometers inside the Saudi border, south of the Fire Support Coordination Line (FSCL) intended to protect forward US and Coalition forces from friendly air, ground, and naval firepower. Despite the fact that the vehicles were south of the berm delineating the FSCL, and that the noontime skies were bright and clear, the pair of A-10s made four strafing passes from an altitude of about 4,000 feet. While the first two passes missed by a wide margin, the third and fourth strafing runs knocked the wheel off a HUMVEE, peppered other vehicles with fragments, and caused two casualties.

A Marine corporal had a small shard of aluminum, apparently from the metal jacket of a 30mm DU projectile, puncture his forearm, while a Navy Chief serving as a corpsman had a very small metal fragment lodged in his wrist. In both cases, the fragments were completely removed. When the unit returned to the United States in May 1991, the medic who had treated both casualties referred the Navy Chief to a special Radiation Physical to verify that he had not been exposed to DU or was not carrying any residual DU.[185] Contacted for this investigation, the Chief (now retired) said that he had not undergone a Radiation Physical, but the fragment had been removed the day after the incident. A series of X-rays a year later (when he was getting a MRI examination) did not reveal any embedded fragments.[186]

[184] Lead Sheet # 14145, Interview of former Marine Force Recon Captain, January 14, 1998.
[185] Lead Sheet # 14195, Interview of former Commander, Marine First Force Recon Company, January 19, 1998.
[186] Lead Sheet # 15421, Interview of former Navy SEAL Corpsman attached to Marine First Force Recon Company, March 10, 1998.

i. Ship-to-Ship Incident

A ship-to-ship friendly fire incident involving the USS Jarrett (FFG-33) and the USS Missouri took place on February 25, 1991. Three US Navy warships and one UK Royal Navy warship (HMS Gloucester) were shelling Iraqi-occupied Faylakah Island. An incoming Silkworm anti-ship missile fired from a shore-based Iraqi missile launcher was destroyed by a Seadart missile fired from HMS Gloucester. During the engagement sequence, the USS Missouri fired off one or more chaff bundles (a standard countermeasure against radar-guided missiles). The Phalanx Close In Weapons System (CIWS) on the USS Jarrett, which was 2-3 miles off the Missouri's port side, experienced an anomaly that caused the system, which was operating in the "automatic engagement" mode, to fire a quick burst at the chaff. The former Executive Officer (XO) aboard the USS Missouri estimated that four of the 20mm rounds, which have not been confirmed as DU, struck the ship in the bulkhead above the famed "surrender deck" where the Imperial Japanese government had capitulated in 1945. All but one of the rounds bounced off the bulkhead, leaving dents, since their energy was mostly spent. One round penetrated the thin upper metal of the bulkhead and passed through a guest berth on the ship. No casualties resulted, and to the best of the XO's recollection, the round was not recovered and probably fell into the sea.[187, 188]

In summary, the total number of friendly fire exposures could involve numerous soldiers, including those who may have entered the contaminated systems soon after they were disabled by DU munitions. Based on standard manning configurations, we estimate that 113 soldiers were aboard the fifteen Bradleys and six Abrams at the time they were struck by DU munitions (see Table 6).

All of the DU friendly fire incidents reported from the Gulf War involved US systems firing on other US systems. No Coalition troops or equipment were targeted or struck by DU rounds fired from US or UK weapons.

[187] Lead Sheet 14246, Interview of former USS Missouri Executive Officer, January 23, 1998.

[188] "Military Probes Friendly Fire Incidents" Washington, DC: Office of the Assistant Secretary of Defense, Public Affairs: News Release, August 13, 1991.

Tab I - The Camp Doha Explosion/Fires (July 1991)

- **Background.**

In June, 1991, four months after Operation Desert Storm had ended, the US 11th Armored Cavalry Regiment (ACR) deployed from Germany to occupy Camp Doha, near Kuwait City, to serve as a deterrent/rapid response force (Figure 26). The 11th ACR, with about 3,600 personnel, had not taken part in Operation Desert Shield/Desert Storm. As of July 1991, the regiment was the only US ground combat unit remaining in the Gulf Theater.[189] It replaced the 1st Brigade of the US Army's 3rd Armor Division,[190] the last US unit to have engaged in ground combat during Desert Storm.[191] Due to the threat of renewed hostilities, the 11th ACR's combat vehicles were kept "combat loaded" with ammunition, even in garrison, to reduce their response time in case of renewed hostilities with Iraq. An equal amount of ammunition was stored in MILVANS containers or conexes (large 20-foot or 40-foot metal transport containers) stored in the North Compound motor pool complex near the combat vehicle parking ramps.[192]

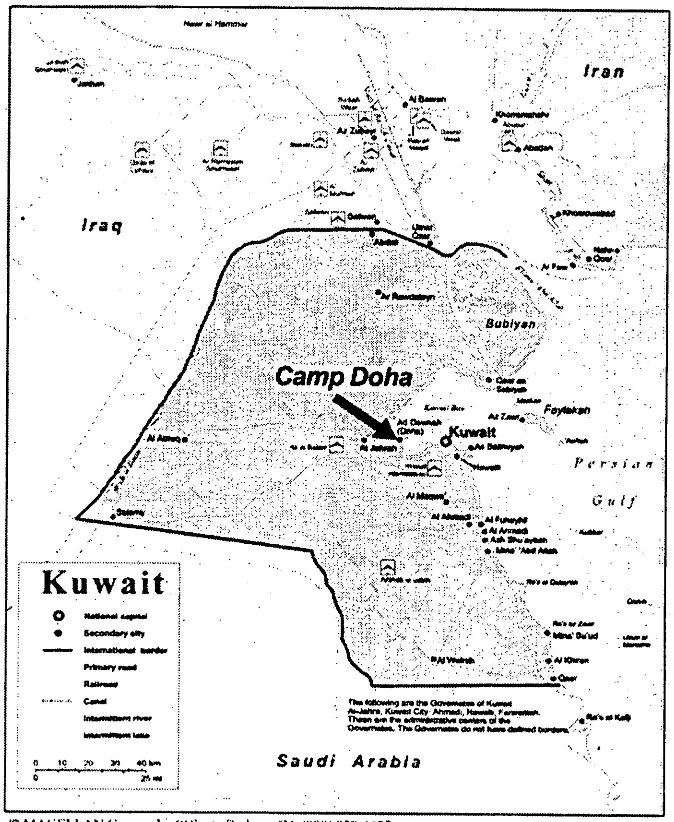

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Figure 26- Camp Doha Location

On the morning of July 11, 1991, two of the 11th ACR's three combat formations, called squadrons, were field-deployed, leaving behind a single squadron (plus support elements) to serve as a guard force.[193] This squadron was parked in Camp Doha's North Compound, a fenced-off area comprising several motor pool pads, each the size of two or three football fields, as well as some administrative buildings and a wash rack (Figure 27).[194] Also located in the area was a compound where approximately 250 British soldiers, mainly from the Royal Anglian

[189] Lead Sheet 15358, Interview of former 11th ACR Commander, March 6, 1998, p. 2.

[190] US Army Safety Center, Army Accident Report 910711001, September 20, 1991, 18 July 1991 interview of Regimental Quartermaster S-4, p. 4.

[191] US Army Safety Center, Army Accident Report 910711001, September 20, 1991, 18 July 1991 interview of Regimental XO, p. 3.

[192] AR 15-6 Report of Investigation, Fire/Explosion at Doha, Kuwait, 11 July 1991: Findings. July 27, 1991, p. 8.

[193] Lead Sheet # 6473, Interview of former Echo Troop, 2/11th ACR NCO, October 20, 1997, p. 1.

[194] AR 15-6 Report of Investigation, Fire/Explosion at Doha, Kuwait, 11 July 1991: Findings. July 27, 1991, p. 1-2.

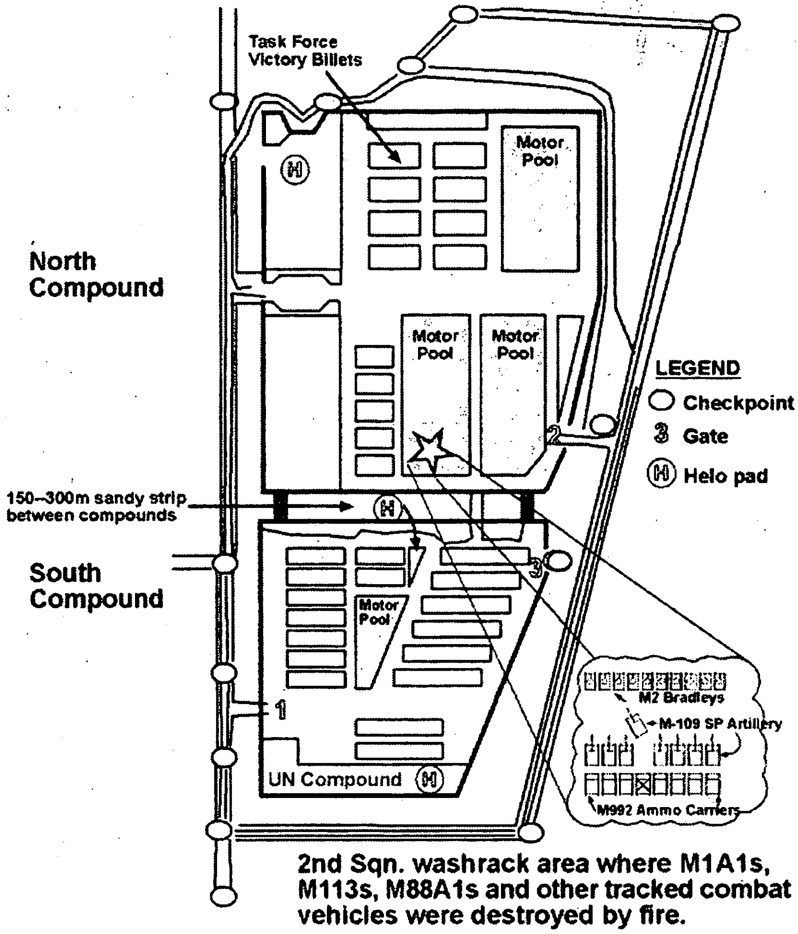

Figure 27 - Camp Doha Diagram

Regiment and Headquarters British Forces Middle East, were present on the morning of the fire.[195]

At approximately 10:20 A.M, a defective heater in a M992 ammunition carrier loaded with 155mm artillery shells caught on fire. Unit members tried unsuccessfully to extinguish the fire before being ordered to evacuate the North Compound. This evacuation was still underway when the burning M992 exploded at 11:00 AM, scattering artillery submunitions (bomblets) over nearby combat-loaded vehicles and ammunition stocks. This set off an hours-long series of blasts and fires that devastated the vehicles and equipment in the North Compound and scattered unexploded ordnance (UXOs) and debris over much of the remainder of the camp.[196] The fires produced billowing black and white clouds of smoke that rose hundreds of feet into the air and drifted to the east-southeast, across portions of both the North and South Compounds, in the direction of Kuwait City.[197]

The fires had died down enough by mid-afternoon to allow a preliminary damage assessment. There were no fatalities; however, 49 US soldiers were injured, two seriously. Most of the injuries were fractures, sprains, contusions, or lacerations suffered when troops scrambled over the 15-foot high perimeter wall to escape the North Compound (Figure 28).[198] In addition, four British troops received minor injuries.

[195] Letter from the Ministry of Defence (UK) to the Countess of Mar, February 2, 1998. p. 6.
[196] "History of Events," Army Accident Report 910711001, Fort Rucker, AL: US Army Safety Center, September 20, 1991, p. 1-3.
[197] Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998. p. 2.
[198] "Medical Aspects of Accident," Army Accident Report 910711001, Fort Rucker, AL: US Army Safety Center, September 20, 1991, p. 2.

Figure 28 - 11th ACR troops evacuate Doha's North Compound, July 11, 1991.

The post-blast destruction was overwhelming. One hundred and two vehicles were damaged or destroyed, including four M1A1 tanks and numerous other combat vehicles. More than two-dozen buildings sustained damage as well.[199] Among the estimated $14 million in munitions that had been damaged or destroyed were 660 M829 120mm DU sabot rounds.[200]

[199] "History of Events," Army Accident Report 910711001, Fort Rucker, AL: US Army Safety Center, September 20, 1991, p. 3-4.
[200] "Estimated Cost of Destroyed Ammunition," Army Accident Report 910711001, Fort Rucker, AL: US Army Safety Center, September 20, 1991, p. 1.

Figure 29 - Aftermath of Doha motor pool fire (view of washrack area) showing armor hulks and UXOs.

- **Initial Recovery Efforts.**

Given Iraq's proximity, still-formidable striking power, and belligerence, rebuilding the 11th ACR's shattered combat potential was a matter of utmost urgency. The Regimental Commander and his staff had to restore basic life support functions (power, running water, sewage, cooking facilities, etc.) and a secure operating area, and then clear the motor pool areas so that serviceable vehicles could be recovered and the unit's combat readiness reconstituted. In planning recovery operations, the unit leadership viewed unexploded ordnance (UXOs) as by far the most significant, widespread, and deadly hazard. The blasts had deposited huge quantities of live ammunition of every description over the motor pool and in the adjacent life support area (figure 29).[201,202] This ordnance was highly unstable, a fact underlined the next day when a

[201]Lead Sheet # 15358, Interview of former 11th ACR Commander, March 6, 1998.

British EOD technician entering the North Compound stepped on a live artillery bomblet, seriously injuring his foot.[203]


Figure 30 - Burned DU rod and sabot

Although concern over UXOs predominated, the 11th ACR leadership was also concerned about possible radiological contamination from depleted uranium rounds that had "cooked off" and burned in the fire.[204,205] Three M1A1 (HA) tanks in the wash rack area (where the fire started) had been gutted by internal explosions of their mostly DU ammunition loads. Each M1A1 is assumed to have been uploaded with 37 M829 sabot rounds with DU penetrators and 3 non-DU HEAT rounds. In addition to the estimated 111 sabot rounds uploaded on the burned tanks, several hundred other sabot rounds were stored in MILVANS trailers or conexes in the 2nd Squadron motor pool. Some of these had exploded in fires that were of such sustained intensity that steel howitzers and other equipment had melted, making it likely that many DU rounds had been damaged by oxidization in the fires.

It is clear from viewing contemporary logs and other data that the 22nd Support Command (SUPCOM), which supported combat units deployed into the theater, was aware of the potential for DU contamination. Entries from the SUPCOM LOC Sequence of Events (subject: Doha Fire) provide evidence of this awareness, as the following citations indicate:

> (CG Card #3-Date-Time Group 11 1200C Jul)
> ENTIRE 2 SQUADRON MOTOR POOL HAS BEEN AFFECTED BY THE FIRE. 35-40 VEHICLES ON FIRE, TO INCLUDE ENTIRE HOWITZER BATTERY. HOW BATTERY HAS 155MM AMMO UPLOADED. DEPLETED URANIUM ROUNDS ARE GOING OFF.

The significance of this message is amplified by a later entry (Card #10) at 2:30 PM (when the fire and explosions had largely subsided) that reads:

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202 Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998. p. 2.
203 Lead Sheet # 6002, Interview of former 146th Ord. Det. (EOD) Commander, September 11, 1997, p. 1
204 Lead Sheet #5720, Interview of former11th ACR Engineer Officer, August 2, 1997.
205 Lead Sheet # 15523, Interview of former 54th Chemical Troop Commander, March 19, 1998.

EOD POC (Explosive Ordnance Disposal Point of Contact) STATES THAT BURNING DEPLETED URANIUM PARTICLES WHEN BREATHED CAN BE HAZARDOUS. 11TH ACR HAS BEEN NOTIFIED TO TREAT THE AREA AS THOUGH IT WERE A CHEMICAL HAZARD AREA; i.e. STAY UPWIND AND WEAR PROTECTIVE MASK IN THE VICINITY.[206]

It is unclear whom, if anyone, passed this information to the 11th ACR. The former 11th ACR Commander was emphatic in stating that no such warning had ever reached him, and, if it had, he would have responded appropriately.[207] The Regimental Engineer, who directed recovery operations, reacted similarly when asked, on March 10, 1998, about the contents of the logs, and advised of a July 12, 1991 entry in the official diary of the 702nd Transportation Battalion (Provisional), which fell under the 22nd Support Command:

> BN dispatches HET, LB, and FB trucks to KKMC to be in positions to support movement of replacement vehicles and ammunition to Doha. Troops are directed to carry protective masks due to possible Alpha particle contamination from depleted uranium rounds, which exploded in the accident area.[208]

The Regimental Engineer pointed out that the 11th ACR's own gas masks had been placed in storage upon their arrival on the base and were not issued or worn at any point during the cleanup—a directive, annotated in the unit's deployment orders, that he attributes to ARCENT. He added that he and other members of the unit leadership were directly involved in leading recovery operations in the North Compound.[209] It is illogical to suggest that they would have knowingly subjected themselves and their troops to a clearly identified hazard

Entry 32 of the SUPCOM log states:

> 1450 hrs (2:50 PM)—ARCENT G-3 called for Chemical Officer to do Downwind Predictions because of DU rounds. Message passed to (a Captain at the Forward Area Support Coordinating Office, or FASCO).[210]

The Chemical Officer referenced in the log is presumably the Nuclear-Biological-Chemical (NBC) Officer on the 11th ACR Commander's Staff. This officer would have been charged with advising the Commander of any NBC threats, as well as recommending appropriate action. As it happened, the former Regimental NBC officer had left on July 1, 1991, and his replacement did not arrive at Doha until the morning of the fire. Nonetheless, there were also two captains and three senior non-commissioned officers (sergeants) performing Staff NBC functions at the time of the fire. Contacted for this report, the senior NBC officer, a major, had

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[206] "Doha Fire, SUPCOM LOC Sequence of Events Log," July 11, 1991.
[207] Lead Sheet # 15358, Interview of former 11th ACR Commander, March 6, 1998, p. 3.
[208] 12 July 1991 entry, 702D Transportation Battalion (Provisional) Battalion Operations Diary, Saudi Arabia (Part 1 of 2); Gulf War Collection, Group Swain Papers, SSG After-action Report, SSG 3rd-051, p. 4-13.
[209] Lead Sheet # 15454, Interview of former 11th ACR Engineer Officer, March 11, 1998, p. 1-2.
[210] "Doha Fire, SUPCOM LOC Sequence of Events Log," July 11, 1991.

no recollection of receiving specific guidance or direction from higher headquarters (ARCENT or the 22nd Support Command) regarding the potential hazard from DU. He emphasized that the unit-level NBC assets were trained, staffed, and equipped to deal with battlefield radiological hazards, rather than DU contamination, for which detection and remediation requirements are substantially different[211]

SUPCOM LOC Entry 42 (at 3:48 PM) states:

> Regiment reports they have no capability to do "Airborne" monitoring. Will check to see if they have AN/PDR-27s. SUPCOM LOC initiating actions to locate "Airborne" capability.[212]

An airborne monitoring capability would have been invaluable in quantifying and documenting the presence or absence of alpha particles in areas downwind of the burned tanks and DU ammunition. However, the 11th ACR's organic NBC assets were not trained or equipped to monitor for airborne DU.

Although the Regimental leadership had a general awareness that DU could pose a radiological hazard, in the crucial days following the fire they lacked clear and authoritative guidance regarding the radiological characteristics of DU, its chemical toxicity, or methods by which these exposure hazards could be prevented or minimized.

SUPCOM was apparently aware of the regulatory requirement to establish a radiation control perimeter in response to the hazard of oxidized DU. SUPCOM LOC Entry 34 at 1456 hrs (2:56) states: "G-3 notified (a Lieutenant Colonel at FASCO) to start an "Alpha" Damage Assessment, and figure out total complacent area to be cordoned off."[213] Due to the UXO hazard, the North Compound was effectively sealed off for three days after the fire, with entry tightly controlled after that date.[214,215,216] The SUPCOM LOC log confirms this with Entry 69, entered in the log on July 11 at 10:00 PM. The entry reads:

> (A Captain at FASCO) reported no movement because of FASCAM (artillery delivered mines) for 72 hrs in the area of vehicles per EOD guidance. This means no early recovery of damaged vehicles and no EOD activity for 72 hrs.[217]

Access to the 2nd Squadron motor pool and wash rack (the area holding the contaminated tanks) was even more restricted than for the North Compound in general.[218] No formal radiation

[211]Lead Sheet # 15517, Interview of former 11th ACR Regimental NBC Officer, March 18, 1998, p. 1-2.
[212]"Doha Fire, SUPCOM LOC Sequence of Events Log," July 11, 1991.
[213]"Doha Fire, SUPCOM LOC Sequence of Events Log," July 11, 1991.
[214]Lead Sheet # 6002, Former 146th Ord. Det (EOD) Commander, September 11, 1997, p. 1.
[215]Lead Sheet # 5728, Former 11th ACR Regimental Chemical Officer, July 10, 1997, p. 1-2.
[216]Lead Sheet # 5724, Former 54th Chemical Troop Commander, July 7, 1997, p. 1.
[217]"Doha Fire, SUPCOM LOC Sequence of Events Log," July 11, 1991.
[218] Lead Sheet # 15523, Interview of former 54th Chemical Troop Commander, March 19, 1998, p. 2.

control line was established, however, until after July 24, when a RADCON team from the US Army's Directorate of Safety Risk Management from the Communications and Electronics Command (CECOM) arrived at Doha.[219]

Initial DU Contamination Assessment and Control Efforts.

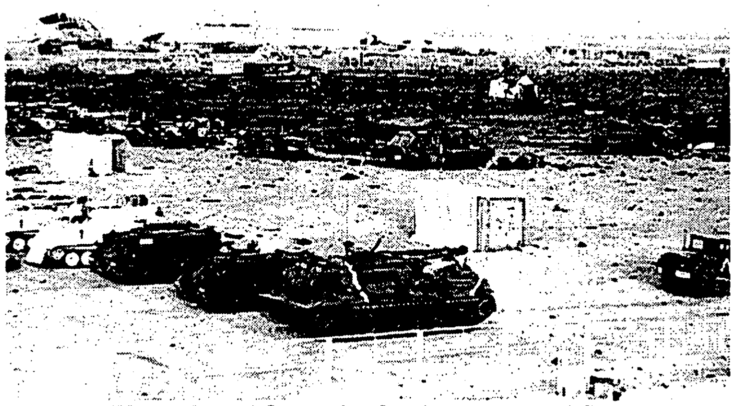
Figure 31 – Aftermath of Doha motor pool fire

Because an accident had occurred involving DU munitions and tanks with DU armor, a radiation control (RADCON) response was required in accordance with the Department of the Army Technical Bulletin (TB) 9-1300-278 and related directives. Two agencies, the US Army Armament Munitions and Chemical Command (AMCCOM), based at Rock Island, IL; and the US Army Communications Electronics Command based at Fort Monmouth, NJ, were notified and began preparing RADCON response teams for deployment to Doha. In the first week after the mishap, however, the 11th ACR had to rely primarily on its own resources to initiate clean up and recovery operations.

On July 12, the day after the blast, the 11th ACR leadership completed a preliminary damage assessment and began formulating plans and establishing priorities for the massive cleanup and recovery operation. The Regiment Commander had three primary assets at his disposal for handling the specialized tasks the cleanup would require. These were:

- The 146th Ordnance Detachment (EOD)
- The 54th Chemical Troop.
- The 58th Combat Engineer Company.

Since these units provided the first response to the accident, and would continue to play a key role for the duration of the clean up, a discussion of their roles and activities is in order.

[219]Lead Sheet # 5997, Interview of CECOM Team Head, July 16,1997, p. 2.

- **Role and Activities of the 146th Ordnance Detachment (EOD)**

The 146th Ordnance Detachment (EOD) had two EOD technicians at Doha on the morning of the blast, and deployed most of its remaining members (approximately 10-12 personnel) from King Khalid Military City (KKMC) and Dhahran, in Saudi Arabia, to Doha over the next two or three days. Their focus was on disarming and removing the huge quantities of unexploded ordnance (UXOs) scattered all over the base by the force of the explosions.

Figure 32 - EOD personnel at Doha

After the initial blast, the North Compound was sealed off for three days because of the threat from delayed-action FASCAM mines that might have armed during the explosions and fire. For two days the EOD team developed a plan of action in coordination with the engineers.[220]

Figure 33 - DU rods collected at Doha

EOD troops were aware of the presence of DU and were familiar with the potential hazard that it posed. More importantly, they were trained and equipped to detect DU contamination. Their initial survey, which was limited due to the quantity of UXOs in the North Compound, found very little DU outside the immediate vicinity of the three destroyed tanks.[221]The standard uniform for UXO clearing was a flak jacket and kevlar helmet, with gloves worn when debris was moved. Because of the extreme heat, only T-shirts were worn under the flak vests. EOD and combat engineer troops (and later, line troops) were not provided with, and did not wear, protective suits, respirators, or dust masks to wear during clearing and cleaning operations.[222]

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220 Lead Sheet # 6002, former 146th Ord. Det. (EOD) Commanding Officer, Oct 6, 1997, p. 1.
221 Lead Sheet # 5732, former 146th Ord Det (EOD) SFC, September 25, 1997, p. 1-2.
222 Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998, p. 2-3.

Most of the DU rounds at Doha had been uploaded on the tanks, all but three of which had survived the fire intact. A fourth tank suffered minor external damage, but its load of ammunition and fuel had not combusted. Other DU rounds were stored in conex containers in the immediate vicinity of the tanks. The conexes held each platoons' field-deployable ammunition stocks: allocations of 7.62mm, .50 cal., and heavier munitions, including DU.

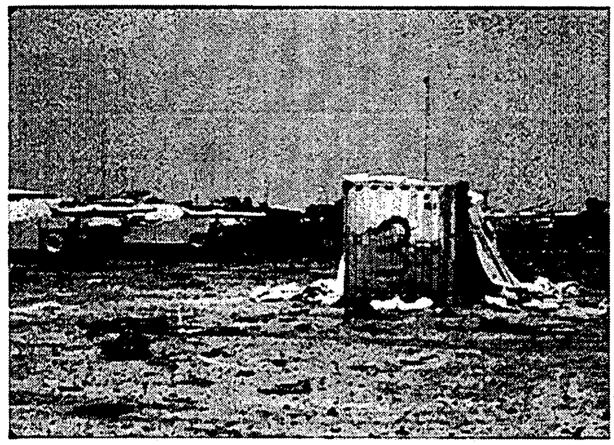
Figure 34 - Surviving Munitions Conex

Post-blast photos show many intact conexes among the burned-out wreckage (figure 34). The commander of the 146th Ordnance Detachment (EOD) stated that stored ammunition is more stable than is generally believed, and is fairly survivable except when directly exposed to fires, extreme heat, or explosions. Even in the conexes that blew up, typically only a few shells would detonate, scattering the other rounds rather than touching off a massive "sympathetic" detonation. This explains the huge quantity of unexploded ordnance (UXOs) littering the motor pool area.[223] Large numbers of the lightweight FASCAM submunitions had been flung into the South Compound, but the heavier rounds, such as TOW anti-tank missiles (and all of the DU penetrators, evidently) remained in the North Compound.

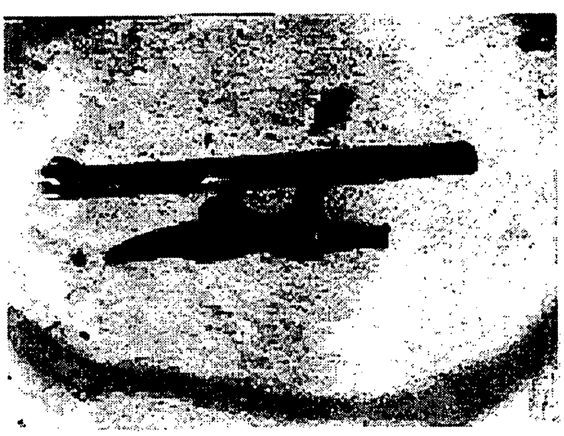
Figure 35 - Marked DU rod and sabot

The cleanup plan for the North Compound involved EOD personnel working together with the 58th Combat Engineering Company to find, mark, render safe, and remove UXOs. The former 146th Ord. Det. (EOD) Commander states that "Engineers didn't pick up any DU unless an EOD guy told them to." EOD marked the DU rounds they found with orange spray paint, painting a circle around the penetrator, and wore leather gloves to pick them up. Exposed DU penetrators were wrapped in heavy plastic and put in wooden boxes or 55-gallon drums. Later, after the AMCCOM Radiation Control team had arrived at Doha, the DU was placed inside one of the destroyed tanks for retrograding and disposal at the Defense Consolidation Facility (DCF), Snelling, SC.[224,225]

[223] Lead Sheet # 6002, former 146th Ord. Det. (EOD) Commanding Officer, Oct 6, 1997, p. 1.
[224] Lead Sheet # 6002, Interview of former 146th Ord. Det. (EOD) Commander, October 6, 1997, p. 2.
[225] Lead Sheet # 6481, Interview of former 146th Ord. Det. (EOD) Sergeant First Class, October 20,1997, p. 2.

Despite the 146th Ord. Det. Commander's statement, it appears that some Engineer troops, including their commander, picked up DU (generally with leather gloves, but in some cases with bare hands) to allow EOD to concentrate on UXOs.[226]

Most if not all of the DU penetrators recovered in the North Compound were picked up within a 120-meter radius of the three destroyed M1A1s. EOD members contacted for this report believed those rounds came from the nearby conexes, rather than the tanks, since the design of the M1A1s' blast panels did not allow most of the intact DU rounds to escape.[227]

EOD members viewed the staggering quantities of UXOs they had to contend with as the most grave and immediate threat at Doha. By its nature, explosive ordnance disposal is an extremely dangerous undertaking, and the sheer magnitude of the task facing the 146th Ord Det. at Doha cannot be overstated. These hazards were tragically underscored on July 23, twelve days after the initial blast and fires. Two senior EOD non-commissioned officers and a 58th CEC soldier died instantly in an accidental UXO blast. The fatal mishap had a significant impact on the remainder of the cleanup effort, and, particularly, on the 146th Ordnance Detachment.

Figure 36 - UXOs in Doha's North Compound

Between the July 11 fire and the July 23 EOD mishap, the 146th Ordnance Detachment had cleared most of the South Compound and periphery of the North Compound, and about 1/3 of the 2nd Squadron motor pool. After July 23, all personnel were prohibited from entering the North Compound, except for a small area at some distance from the 2nd Squadron motor pool where supply operations and other activities were being conducted. This area had survived the blast/fires more or less unscathed, except for UXOs that were soon cleared.[228] Interviews with EOD, Engineer, and other 11th ACR personnel have indicated that no spent (exposed) DU penetrators, fragments, or residues were found in this location.

[226] Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998, p. 2-3; and Lead Sheet # 5721, Interview of former 58th Combat Engineer Company NCO; July 1, 1997.

[227] Lead Sheet # 6002, former 146th Ord. Det. (EOD) Commander, October 6, 1997.

[228] Lead Sheet # 6653, former US Army COR to ECC, October 31, 1997, p. 2-3.

- **Role and Activities of the 54th Chemical Troop**

In the immediate aftermath of the July 11 fires and explosions, the task of monitoring for radiological contamination fell on the 54th Chemical Troop, the 11th ACR's primary asset for responding to nuclear, biological, or chemical (NBC) hazards. On the morning after the blast, the 54th Chemical Troop conducted initial monitoring for alpha, beta, and gamma radiation of the periphery of the North Compound using Fox chemical and radiological detection vehicles and hand-held radiation detectors.[229,230]

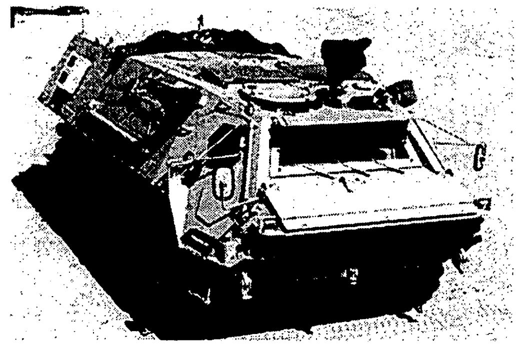

Figure 37 - M93 Fox NBC vehicle

The M-93 Fox vehicle deployed with the 54th Chemical Troop is a sophisticated chemical weapons detector. Built in Germany and widely regarded as the best chemical detection vehicle in service, it has a secondary capability to detect beta and gamma radiation, with a very limited alpha detection capability. The Foxes had two on-board radiation detectors: the German-made ASG-1 and the US AN/VDR-2. The Reconnaissance Platoon of the 54th Chemical Troop operated and maintained six of the vehicles, with a seventh Fox serving as a "floater" or spare. Each Fox had four crewmen.[231]

The initial radiological monitoring effort was conducted on July 12, the day after the fire, by three Fox vehicles. The 54th Troop Commander and other troop personnel have indicated in recent interviews that their monitoring equipment was fully operational and calibrated. The Foxes conducted radiation surveys around the North Compound's perimeter and inside the South Compound.[232,233] The 54th Chemical Troop Commander acknowledged, in a March 1998 meeting with investigators, that while he and his Troop were well-trained to detect battlefield radiation, they had little training or experience with DU and its alpha radiation. However, he had been directed by his superiors to use the Fox vehicles in this role, and so he did.[234] Troop personnel also entered the motor pool area on foot a week after the blast (July 18), using hand-held VDR-2 monitors to check for beta and gamma radiation. These forays produced "negative" readings for radiation.[235]

[229] Lead Sheet #5724, Interview of former 54th Chemical Troop Commander, July 7, 1997, p. 1-2.
[230] Lead Sheet # 5731, Interview of former 54th Chemical Troop Reconnaissance Platoon NCO, July 15, 1997, p. 1.
[231] Lead Sheet #5730, Interview of former 1st Reconnaissance Platoon Leader, 54th Chemical Troop, July 14, 1997, p. 1.
[232] Lead Sheet #5724, Interview of former 54th Chemical Troop Commander, July 7, 1997, p. 1-2.
[233] Lead Sheet # 15492, Interview of former 54th Chemical Troop Reconnaissance Platoon Leader, March 25, 1998, p. 1.
[234] Lead Sheet # 15523, Interview of former 54th Chemical Troop CO, March 19, 1998.
[235] Lead Sheet # 5731, Interview of former 54th Chemical Troop Reconnaissance Platoon NCO, July 15, 1997.

The former Regimental NBC officer and several former 54th Chemical Troop members, including the Platoon Leader of the 54th Reconnaissance Platoon which operated the Fox vehicles, have indicated some doubts about these initial surveys since they lacked the proper equipment to detect the most widespread contaminant: alpha radiation. Alpha radiation could only be detected at extremely close ranges (an inch or less), with a specialized alpha-detection probe held directly above the suspected contamination. On the other hand, DU also emits beta and gamma radiation in sufficient quantity to detect the presence of visible pieces of DU using common beta/gamma survey instruments. In addition, the Foxes were carrying out operations in the South Compound and around the periphery of the motor pool, where the likelihood of detectable levels of DU contamination was very low. These concerns were voiced to the Regimental Commander.[236] Based on this preliminary assessment and a similar input from the first RADCON responder on the scene, the Regimental Commander directed the Foxes to discontinue their monitoring efforts shortly afterwards.[237]

The 54th Chemical Troop (and the NBC Regimental Staff members at Doha) conducted limited operations inside the North Compound due to the huge quantities of UXO, and collateral efforts by EOD and RADCON personnel. While they did not play a major role in detecting or cleaning up DU alpha particle contamination at Doha, they helped pick up visible DU penetrator rods and fragments.[238]

- **Role and Activities of the 58th Combat Engineer Company (CEC)**

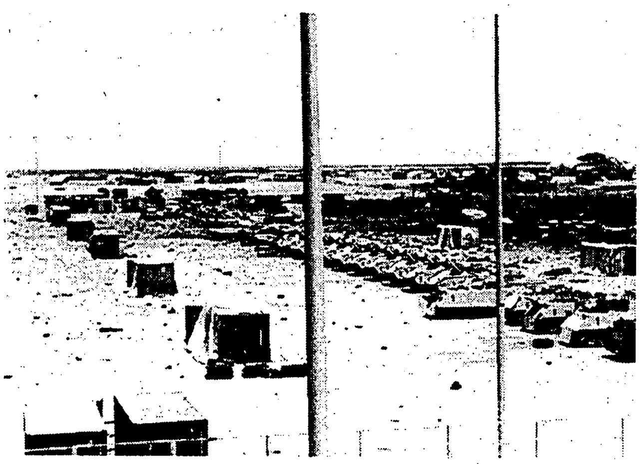

Figure 38 - North Compound

The 58th Combat Engineer Company, the 11th ACR's organic Engineer element, had the primary responsibility for the cleanup and recovery effort. Working closely with the 146th Ord. Det. (EOD), and later with a contract EOD team, the 58th CEC used its bulldozers and graders to clear heavy debris from the North Compound after EOD personnel had cleared away UXOs and exposed DU penetrators. As such, the 58th CEC represented the largest contingent of personnel who operated in the North Compound during cleanup and recovery operations. Former 146th Ord. Det. (EOD) personnel have stated that 58th CEC troops were given safety briefings prior to entering the North Compound warning them to alert EOD technicians when they found UXOs and DU. For obvious reasons, Engineer Troops avoided

[236] Lead Sheet #5728, Interview of former 11th ACR Chemical Officer, July 10, 1997, p. 1; Lead Sheet #5730, Interview of former 54th Chemical Troop Reconnaissance Platoon Leader, July 14, 1997; and Lead Sheet #5731, Interview of former 54th Chemical Troop Reconnaissance Platoon Sergeant, July 15, 1997.
[237] Lead Sheet #5724, Interview of former 54th Chemical Troop CO, July 7, 1997, p. 2.
[238] Lead Sheet # 15523, Interview of former 54th Chemical Troop CO, March 19, 1998, p. 2.

UXOs; however, some have stated that they did not recall being briefed on DU, and therefore picked up exposed DU penetrators, which they did not realize were hazardous material.

- **Impact of the fatal July 23 UXO mishap**

Following the July 23 UXO blast, ARCENT (the 11th ACR's in-theater higher headquarters) immediately halted cleanup activities in the North Compound while they reassessed the situation at Doha. From that point on, the 146th Ord. Det. (EOD) was effectively sidelined, relegated to providing support to the AMCCOM and CECOM personnel who had arrived on July 19 and July 24, respectively, to decontaminate and retrograde (remove) the contaminated M1A1 tanks.[239,240]

Due to the magnitude of the UXO contamination, ARCENT brought in the 512th EOD Control Team and a civilian EOD contract company staffed by ex-military EOD technicians to finish the cleanup of Doha's North Compound (the South Compound had already been cleared by the 146th Ord. Det.). This resulted in a near suspension of activity in the North Compound from July 23 until mid-September.[241,242]

- **Arrival and Activities of Radiation Control Teams**

While the 146th Ord. Det. (EOD), 54th Chemical Troop, and 58th Combat Engineer Company played key roles in the cleanup and recovery operation, the stringent demands of handling and disposing of DU contaminated equipment required the commitment of additional resources. It should be noted that regulatory radiation control measures mandated by Army and NRC regulations had been written for peacetime accidents at stateside military installations. Nonetheless, a RADCON response was required. It came initially from two Radiation Control teams deployed from appropriate agencies in the United States, and later from the Environmental Chemical Corporation, which, as mentioned, conducted the final cleanup of UXO and DU contamination at Doha.

The Industrial Operations Command (formerly Armament Munitions and Chemical Command, or AMCCOM) based at Rock Island, Illinois, maintains the Nuclear Regulatory Commission (NRC) license authorizing storage of Army DU ammunition at Army installations within the United States and US territories.[243] Since the Doha explosion involved DU, the Army directed AMCCOM to assemble and deploy a team to assess the levels of DU contamination in and around the damaged/destroyed tanks.[244]

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239 Lead Sheet # 5739, Interview of former 146th Ord. Det. (EOD) SSG, July 28, 1997.
240 Lead Sheet # 6653, Interview of former 146th Ord. Det. (EOD) Sergeant First Class, October 20, 1997.
241 Lead Sheet # 6481, Interview of former 146th Ord. Det. (EOD) Sergeant First Class, October 20, 1997, p.2.
242 Lead Sheet # 6499, Interview of ECC Contract Team member, October 21, 1997.
243 Guidelines For Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium, Department of the Army TB 9-1300-278 Washington, DC: Headquarters, Department of the Army, July 21, 1996, p. 1-2.
244 Lead Sheets #5698 and #5699, Interviews of AMCCOM members

Several hundred 120mm DU sabot rounds stored in the motor pool area had exploded, leaving behind the DU penetrator rod. Intact, these penetrators, 27 inches long and 1.5 inches thick, weighed 10.7 pounds.[245] The first AMCCOM representative to enter the North Compound on July 18 stated that the motor pool in total contained about 900 DU rounds, of which all but 10-40 had been uploaded in the tanks. He was able to find five spent DU rounds (intact) within 150 meters of the tanks. Although his preliminary assessment was limited, due to the extraordinary quantity of UXOs, his initial reaction was that the area was not nearly as badly contaminated as first believed.[246] He was apparently unaware that several hundred DU sabot rounds were stored in MILVANS and conexes.

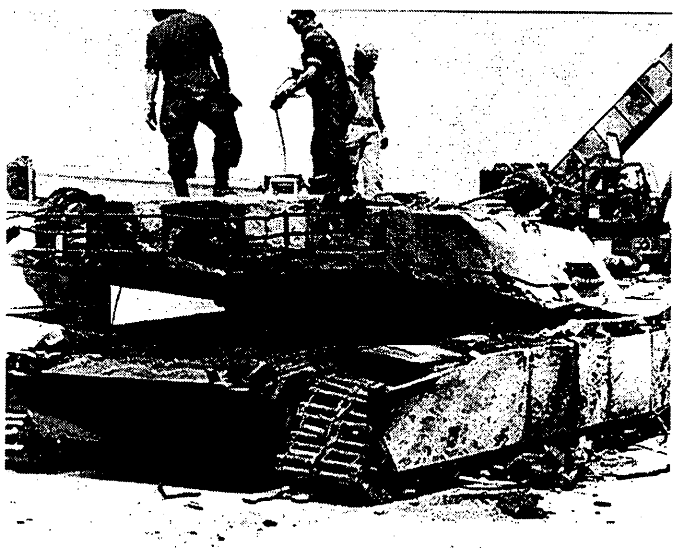
Figure 39 - AMCCOM RADCON Personnel at Doha

The 3-man AMCCOM Radiation Control team arrived at Camp Doha on July 19th. The team's mission was limited to assessing the state of the M1A1 tanks, and then decontaminating the damaged or destroyed tanks to allow their entry into the United States for decontamination or preparation for disposal at a low-level radioactive waste disposal site at Barnwell, SC. Although the team was equipped with a variety of sophisticated radiological detection equipment, it essentially limited its activities to collecting DU penetrators found in and around the tanks, and preparing the tanks for shipment to the port of Dammam, where they would be readied for shipment to the US.[247] Upon its arrival at Doha, the AMCCOM team did a visual inspection of the motor pool, accompanied by members of the 54th Chemical Troop and some EOD personnel. The North Compound had been cordoned off since the blast, with entry strictly controlled and limited almost exclusively to 58th Combat Engineers and 146th Ord. Det. (EOD) personnel involved in UXO clearing operations.[248] Later, after lanes had been cleared through areas of UXO concentrations, small groups of drivers were brought in to move operational equipment out of the motor pool area to a new site some distance away.[249]

245 Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Atlanta, GA: US Army Environmental Policy Institute, Georgia Institute of Technology, June 1995, p. 39.
246 Memorandum for Record, telephone report from SWA Radiation Protection Office, on update of status of Doha accident site, July 18, 1991.
247 Lead Sheet #5698, Interview of former AMCCOM team member August 8, 1997 and Lead Sheet #5699, Interview of AMCCOM Team head, July 25, 1997.
248 Lead Sheet #5699, Interview of AMCCOM Team head, July 25, 1997.
249 Lead Sheet #6473, Interview of former Echo Troop, 2/11th ACR NCO, October 20, 1997, p. 2.

The AMCCOM team found that almost all of the DU rounds in each tank's basic load had remained inside the hull. Most of the penetrators found in the tanks were scorched but intact. Others had melted, fragmented, or oxidized to some degree in the intense heat.[250] These observations were corroborated by the Battle Damage Assessment Team from the US Army Ballistic Research Laboratory, which examined the four destroyed or damaged M1A1s. In a memorandum dated August 5, 1991, the Team stated:

> All four of the M1A1s were damaged/destroyed as a result of fires external to the vehicle. *There were no penetrations anywhere of the exterior armor* (emphasis added). Three of the four M1A1s had their fuel and ammunition destroyed. In these three cases, there was an explosion in the ammunition compartment. The ammunition doors and blowout panels functioned properly, keeping the blast from entering the crew compartment. The fourth M1A1 was damaged on the right suspension only, and except for the gunner's computer and transmission warning lights, was completely operational.[251]

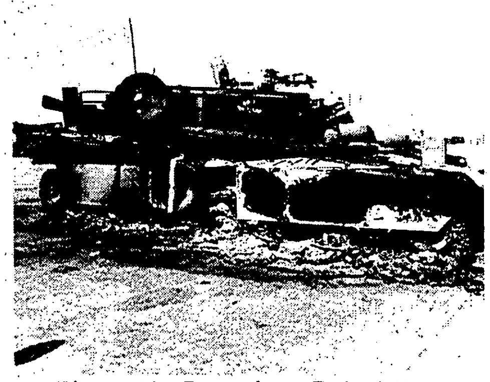
Figure 40 - Burned-out Doha M1A1

The above memo indicates that concerns about the M1A1's DU Heavy Armor panels burning and adding to the DU contamination appear to be misplaced. In order for oxidization to occur, the DU armor panels, sealed between (and shielded by) regular rolled homogenous steel armor, would have required exposure to air as well as to intense, sustained heat. Since the tanks' structural integrity remained intact, the possibility of contamination from burning DU armor is negligible.

A small number of DU rounds were ejected from the burned tanks through their blast panels, designed to allow the escape of the extreme overpressures created during an ammo-compartment explosion. The anecdotal evidence collected, however, suggests that very few rounds were ejected in this manner.[252,253]

After the head of the team ascertained that the 54th Chemical Troop members were familiar with the operation of the hand-held PDR-77s (alpha detectors) the team employed, he led them on a limited survey of the motor pool and its periphery. Again, the danger from UXOs prevented a more comprehensive effort. The AMCCOM members also inspected the burned-out tanks.

[250] Lead Sheets #5699, Interview of AMCCOM Team head, July 25, 1997; and Lead Sheet #5997, Interview of CECOM Team head, July 16, 1997.

[251] Memorandum for Commander, 22 Support Command, APO NY, Subject: "Damage Assessment at Camp Doha," August 5, 1991.

[252] Lead Sheet #6002, Interview of former 146th Ord. Det. (EOD) Commander, October 6, 1997.

[253] Lead Sheet # 6481, former 146th Ord. Det. (EOD) Sergeant First Class, October 20, 1997.

After a team member nearly stepped on a live artillery bomblet, EOD and Engineer troops cleared a lane to facilitate access to the tanks.[254]

Although the AMCCOM mission was limited in scope, they seem to have elevated the issue of DU to new prominence. Prior to the AMCCOM team's arrival, DU penetrators picked up by Engineer or EOD personnel were deposited in an on-base trash pile. The AMCCOM team halted this practice, segregating and retrieving the DU penetrators for proper disposal. Enough DU penetrators were collected to fill at least two 55-gallon drums. These penetrators were dumped inside one of the burned-out M1A1 tanks identified for shipment to the Defense Consolidation Facility at Snelling, SC.[255]

Communication between the AMCCOM (and later, CECOM) RADCON responders and the leadership of the 11th ACR appears to have been spotty at best. The Regimental Engineer Officer recalls that he knew nothing about the arrival of the AMCCOM personnel until they showed up at Doha. He also stated that the 11th ACR Commander had a direct question put to the first RADCON responder: "Is there a radiological hazard (at Doha)?" The response was negative.[256] This response, however, apparently did not address the issue of DU's chemical toxicity. RADCON members apparently had little interface, formal or informal, with the 11th ACR Commander or his staff.[257,258,259]

- **CECOM Team Augments Radiation Control Efforts**

On July 24th, the day after the fatal EOD blast, a team arrived at Doha from the Communications and Electronics Command (CECOM) based at Ft. Monmouth, NJ. The CECOM team was headed by the Project Director for the US Army Radiological Control Team, Headquarters, Department of Army Operations. Using Eberline Field Instruments for the Detection of Low Energy Radiation (FIDLER) and SPA-3 gamma detectors, the team conducted what one member called a "site characterization survey."[260] These surveys located a sizable number of DU fragments and areas of DU contamination, but were hampered by the general "background" gamma radiation fields from the DU in the tanks and ammunition. This was not a grid-by-grid survey, but rather a more general sampling, mostly in and around the motor pool. The CECOM team surveyed all areas cleared by EOD (an estimated two or three acres of the motor pool, which was the size of several football fields).

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[254] Lead Sheets #5724, 5728, 5730, 5732.
[255] Lead Sheet #5699, Interview of AMCCOM Team head, July 25, 1997, p. 3; and Lead Sheet #5720, 11th ACR Engineer Officer, July 16,1997.
[256] Lead Sheet #5720, Interview of former 11th ACR Regimental Engineer, July 7, 1997, p. 2.
[257] Lead Sheet # 15854, Interview of ARCENT Radiation Protection Officer, April 6, 1998, p. 2.
[258] Lead Sheet 15358, Interview of former 11th ACR Commander, March 6, 1998, p. 3.
[259] Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998, p. 3-4.
[260] Lead Sheet #5993, Interview of former CECOM Team Member, August 7, 1997.

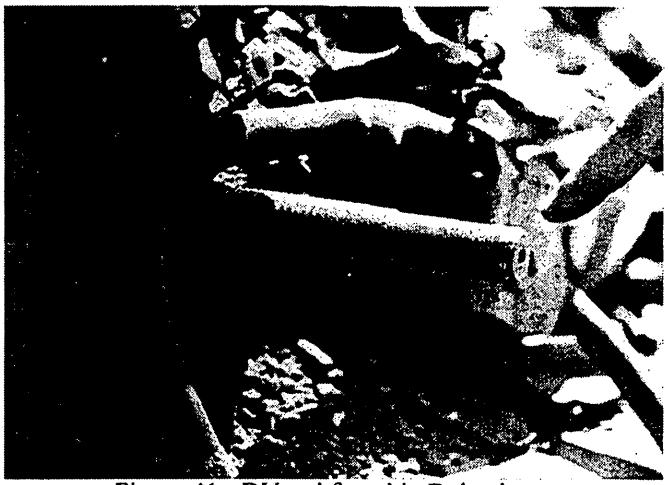

Figure 41 - DU rod found in Doha dump

Three 55-gallon drums containing DU penetrators and a separate pile of burned penetrators were placed into the three contaminated tanks for shipment to the US. Seven M8A1 Chemical Agent Alarm Systems containing Americium-241 were also involved in the fire. One was recovered from the area cleared by EOD. The radioactive source cell was not damaged. One additional M8A1 was recovered from one of the M1A1 tanks removed from the area near the wash rack. The radioactive source cell was penetrated by a fragment from the explosion and burned in the fire. No alpha radiation contamination was detected. This M8A1 was placed in one of the contaminated M1A1 tanks for shipment to the US for disposal. The dumpsite located near the camp (where post-accident debris was discarded) was also surveyed. The survey found one DU penetrator (see Figure 41) which was recovered for disposal.

A July 31, 1991 CECOM report submitted to the to the Commander, Task Force Victory, Forward (which was overseeing the overall Doha recovery effort) reported no radiation hazard to personnel existed outside the exclusion area (the North Compound). It advised that five M8A1s and an unknown number of DU penetrators in solid, melted, and burned states remained in the exclusion are, and recommended that all persons entering that area be made aware of the potential hazard. After arrangements were made for the contaminated tanks to be shipped to the port of Dammam for shipment back to the US on August 6, 1991, the CECOM team departed Doha in early August.[261,262]

As sections of the 2nd Squadron's concrete pad were cleared of UXOs and DU, regular support and combat troops were brought in to do a final cleanup using brooms and other hand tools.[263] While the area with the heaviest concentration of depleted uranium contamination—the three burned M1A1s on the washrack—was cleaned up by RADCON personnel, the surrounding areas could have held residual DU oxides or residues. In addition, several hundred spent DU penetrators had been scattered and in some cases partially burned and oxidized in and around the MILVANS containers holding each platoon's ammunition resupply load.[264] These particles, if

[261] Memorandum for Commander, Task Force Victory (Fwd), Subject: "Camp Doha Accident Survey Update," August 2, 1991, p. 1.

[262] Lead Sheet #5993, Interview of former CECOM Team Member, August 7, 1997; and Lead Sheet #5997, Interview of former CECOM Team Chief, July 16, 1997.

[263] Lead Sheet # 15493, Memorandum for Office of the Special Assistant for Gulf War Illnesses from former 11th ACR Engineer Officer, subject: "Summary of Personal Involvement and Observations Concerning Depleted Uranium at Camp Doha, Kuwait, 11 July -25 August 1991," March 16, 1998, p. 3.

[264] Lead Sheet # 6653, Interview of former US Army Contracting Officer's Representative to ECC, October 31, 1997. p. 2.

resuspended (stirred up) by brooms, could have been inhaled or otherwise internalized by soldiers in the vicinity.

- **Post-M1A1 Retrograde Radiation Control and Cleanup Activity**

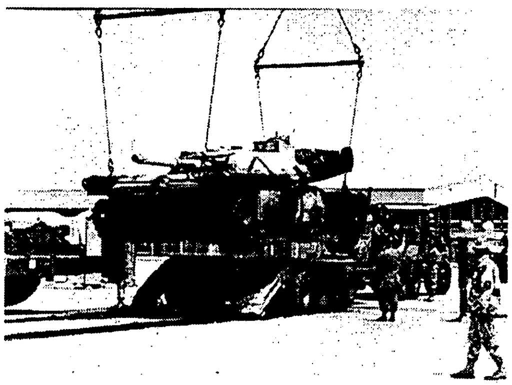
Figure 42 - Removing burned M1A1

Following the removal of the contaminated M1A1 tanks and the departure of the AMCCOM and CECOM teams on August 2, a hiatus in Radiation Control and cleanup activities ensued for several weeks. The only activity that took place in the North Compound during this time frame was in the supply area several hundred meters away from the 2nd Squadron motor pool area, which had been cleared earlier of UXOs thrown into the area by the July 11 explosions. No ammunition was stored in this location, and no DU was found in or near this area.

The 146th Ord. Det. (EOD) was rotated out of the theater in September 1991, after having been virtually sidelined since July 23. A civilian firm, Environmental Chemical Corporation (ECC), was contracted to finish all clean up and recovery activity in the North Compound. Two reserve Army EOD officers managed the contract and overall effort, while a highly trained and experienced Army Sergeant First Class (SFC) provided on-scene oversight, support, and safety monitoring to approximately 14 ECC EOD technicians. In this capacity, the SFC conducted most of the actual radiological survey efforts that were carried out in the second, final phase of the Doha clean up.

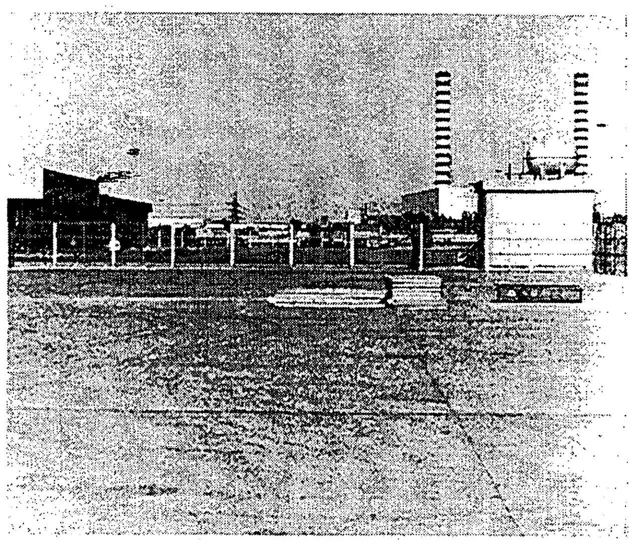
Figure 43 - Doha motor pool pad after cleanup

The ECC team brought their own radiation detection and measurement equipment and performed survey activities in the North Compound. Upon entering the 2nd Squadron motor pool, they found large quantities of DU scattered around the vicinity of the MILVAN containers (used for ammo storage) that had detonated in the fire. Many of these DU penetrators were intact, but others had fragmented or burned down to varying degrees, with some almost completely reduced. Some had been ejected into the open by the "kick-out" effect of individual rounds exploding among the stacked ammunition. Others, burned or unexploded, remained within the shells of the conexes. Using an AN/PDR-56 fitted with the small alpha probe, the SFC measured the DU cores and, after they were picked up, monitored the surface underneath them. Most of the DU penetrators inside and outside the conexes gave off very low radiation readings. The DU penetrators were then double-wrapped in plastic, bubble-wrapped, and placed in 55-gallon drums. Personnel packing the drums with DU penetrators wore surgeon's caps, safety glasses, half face protective masks, coveralls, butyl rubber aprons, rubber surgeon's gloves with cotton inserts, and rubber "booties" over their normal work boots. A total of eight drums were filled with about 250 DU penetrators.

The SFC took readings inside the MILVAN containers, where levels of radiation were somewhat higher. He typically measured 4,500 counts per minute on the surface of the penetrator rods, reported as 9,000 disintegrations per minute (dpm, or the number of radioactive particles that decay per minute) multiplied by a correction factor of two. The levels on the surface of the ground directly beneath the penetrator were typically half the levels on the surface of the penetrator rod, or 2,200-2,300 cpm (corrected to 4,500-4,600 dpm). At the 10,000-dpm level, the military requires personnel to wear an M17A1 protective mask (gas mask) or equivalent respiratory protection. Given the reading of approximately 9,000 dpm, ECC elected to don white surgeon's masks in addition to their other protective gear while working on the motor pool pad. ECC personnel brushed down the containers until the radiation levels had reached natural background levels.

The SFC took readings on the surfaces the four burned-out (and DU-contaminated) M1A1 tanks had occupied. Since those areas had already been cleaned, they produced no readings for radiation.

- **The Final Cleanup**

When the ECC team started work in mid-September 1991, approximately two-thirds of the North compound remained uncleared, and due to the UXO threat, no one was permitted into those areas. It took the ECC team two months to get these areas cleaned up. Once explosive munitions were deemed safe for transport, they were moved to the EOD demo area approximately 750 meters east of the compound to be destroyed. All submunitions that were considered unsafe to transport were destroyed in place. Once the concrete pads had been cleared of ordnance and possible alpha contamination, heavy equipment was used to scrape up remaining debris and transport it to the EOD demolition area. As a precaution, diesel fuel was poured over the scrap metal and ignited to detonate or destroy any small-arms rounds or submunitions that might have been missed. This was done twice.

When the entire North Compound and the sandy strip between the North and South Compounds had been cleared, third-country nationals were hired to perform the final sweeping of the motor pool pads. These individuals were provided with dust masks, gloves, cotton overalls, and other personnel protective equipment, although the levels of radiation detected fell below the Army's criteria for donning M17 or similar gas-mask type respirators. When the motor pool had been swept completely clean, eleven water tankers were brought in to do a final, thorough "hose-down." When this process was complete, the Army EOD Control Team performed a radiological survey to ensure that no residual contamination remained. When none was found, the contractor was certified as having fulfilled all contractual obligations to clean up the North Compound and its periphery.[265]

- **Working Conditions During the Doha Clean up and Recovery Operations.**

No discussion of the Doha cleanup would be complete without describing the extremely severe environmental and working conditions. Summer temperatures typically reached 115 degrees by mid-afternoon. Smoke from oil fires billowed constantly, coating the western surfaces of poles, walls, and parked vehicles with a black film and forcing soldiers to don handkerchiefs over their mouths and noses. Life support facilities, marginal before the fire, were practically wiped out. Since a serious water shortage was in effect, soldiers often wore the same uniforms for days on end. Biting sand flies and other parasites and pests were common. During the initial phase of the clean up, soldiers typically labored in these conditions twelve or more hours a day, often seven days a week.[266]

Department of the Army Technical Bulletin (TB) 9-1300-278, "Guidelines For Safe Response To Handling, Storage, And Transportation Accidents Involving Army Tank Munitions Or Armor Which Contain Depleted Uranium" (dated September 1990) states:

> Anyone passing over (the radiation control line) to the fire area is to wear appropriate protective equipment that may include protective coveralls, gloves, rubberized boots, head covering, and respiratory protection. EOD personnel are to wear the M25 or M17A2 protective mask with the M13A2 filter element and the accompanying head covers (i.e., MOPP Level 4). Personnel assisting in the radiation survey and decontamination operations should wear full-face respirators with high-efficiency dust filters. Tape is to be used to seal the clothing where there are any openings to the body.[267]

Note that these instructions, written for peacetime accidents on stateside military installations, are generally advisory rather than directive in nature. Given the searing heat and physically exhausting duties being performed, wearing the aforementioned ensemble would have resulted in mass heat casualties in very short order. As it was, personnel working around unexploded ordnance (UXOs) were required to wear flak vests and helmets at all times. Most wore gloves

[265] Information in sections on "Post-M1A1 Retrograde Radiation Control and Clean up Activity" and "The Final Clean up" is taken from Lead Sheet # 6653, Interview of former US Army Contracting Officer's Representative to ECC, October 31, 1997, and Lead Sheet # 6499, Interview of ECC Contract EOD Team member, October 21, 1997, p. 1-2.
[266] Lead Sheets #5720, Interview of former 11th ACR Regimental Engineer, July 7, 1997 and Lead Sheet #5739, Interview of 146th Ordnance Detachment (EOD) SSG, July 28, 1997, p. 2.
[267] Guidelines For Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium, Department of the Army TB 9-1300-278 Washington, DC: Headquarters, Department of the Army, September 1990, paragraph 6-2a, page 6-2.

because they were picking up sun-scorched metal fragments and debris with sharp edges.[268] Even the AMCCOM Radiation Control (RADCON) team wore nothing more protective than cotton overalls, work gloves, and dust masks.[269] Under the conditions described, this level of personal protective equipment (PPE) would have provided substantial protection, especially for inhalation, ingestion, and protection from wounds, while allowing important cleanup operations to continue with maximum efficiency under very stressful conditions.

- **Comments on the Radiation Control Efforts**

Seven of the eight AMCCOM and CECOM team members directly involved in the Camp Doha radiological efforts were contacted for this report, including the heads of both teams. The consensus among the team members was that "we did what we were sent over to do," and that the hazard from DU was negligible outside the immediate vicinity of the tanks. Key members of the ECC team and the Army CORs who assisted and oversaw their efforts have expressed similar beliefs to investigators, and feel that they left behind an uncontaminated site when their efforts were completed.

It is noteworthy that all of the AMCCOM, CECOM, ECC, and 146th Ord. Det. (EOD) personnel who would have been most exposed to any DU contamination in the North Compound have reported that they are in good health. It should also be noted that these individuals (with the exception of 146th Ord. Det. members) generally took appropriate precautions and often (but not always) wore half-face respirators, gloves, and similar protective equipment.

In reviewing the overall radiation control response, the following areas raise concerns:

Coordination and support from ARCENT, AMCCOM, CECOM, and Contract personnel.
As log entries and other evidence indicates, ARCENT was aware of the potential hazards posed by Alpha radiation. This information, however, apparently did not reach key leaders and decision-makers at the 11th ACR. The 11th ACR Engineer Officer was unaware that the AMCCOM team was en route until they "showed up" at Camp Doha. There was little formal coordination and interface between RADCON personnel and the 11th ACR leadership, who, if better informed, could have issued better environmental and safety guidance to the troops.[270] Relations between the heads of the AMCCOM and CECOM teams appeared strained, and cooperation between the two teams was limited.[271] 11th ACR commanders and decision-makers felt that they were largely disconnected from the radiation-control information loop, since ARCENT was, in effect, "running the show" after the motor pool fire. The reasons for these disconnects remain undetermined, but the net result is that 11th ACR soldiers were needlessly subjected to potential DU exposures.

[268] Lead Sheets #5720, Interview of former 11th ACR Engineer Officer July 7, 1997; Lead Sheet #5721, Interview of former 58th Combat Engineer Company NCO; July 1, 1997 and Lead Sheet #5732, Interview of former 146th Ord. Det. (EOD) NCO, July 15, 1997.
[269] Lead Sheet #5698, Interview of former AMCCOM team member.
[270] Lead Sheet #5720, Interview of 11th ACR Engineer Officer, July 16, 1997.
[271] Lead Sheets #5698, #5699, #5700, and #5997, Interviews of AMCCOM and CECOM members.

Timeliness of the response. The AMCCOM team arrived a week after the blast; the CECOM team arrived almost two weeks later. During the crucial first few days after the blast, the unit leadership and personnel lacked clear, authoritative guidance regarding DU's potential hazard and how it should be handled. This led to unsound practices, such as soldiers picking up spent DU penetrators with their bare hands, and DU penetrators being dumped in an on-base trash pile.[272]

Limited early scope of the effort. Radiation control efforts focused almost exclusively on the M1A1s until the CECOM team arrived on July 24th. Contamination from the DU rounds in each tank's magazine had largely been confined to the interiors of the vehicles. However, DU rounds stored elsewhere were also exposed to the fire. DU penetrators not trapped in a burning tank are far more likely to remain intact after the "cook-off" of their propellant. During intense heat, however, some penetrators stored outside the tanks may have burned. There was no concerted effort to assess possible DU contamination from rounds stored outside the tanks until the arrival of the ECC team in mid-September.[273]

Lack of documentation and reporting. Paragraph 1-3c of 1-TB 9-1300-278, the existing guidelines for responding to accidents involving DU, states: "Interim or final written reports will be transmitted through the local Radiation Protection Officer (RPO) to the license RPO within 30 days of the accident or incident. If an interim report is submitted, a final report will be submitted as expeditiously as possible." The CECOM team chief indicated that he submitted daily reports to AMCCOM (now called Industrial Operations Command), but says a final report was never submitted.[274] AMCCOM personnel submitted frequent memos and very brief descriptions of their efforts, but no detailed accounts, complete with daily measurements and written reports, were generated. In the absence of such documentation and other supporting material (daily logs and records, etc.), attempts to quantify possible radiological exposures will remain inexact.

The central question remains: How much DU was actually released into the environment? A precise estimate is impossible, but some key variables have been established. The ammunition stored at Camp Doha constituted the 11th ACR's "basic load," or combat requirements. A relatively small number of DU rounds (660) were destroyed or damaged.[275] Of these, about 111 would have been loaded in the three burned-out tanks.[276] Many rounds included in the figure of 660 lost rounds survived the fire without exploding or burning (Figure 44) but had to be removed from the inventory since they had been in a fire.

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[272] Lead Sheet #5720, Interview of 11th ACR Engineer Officer, July 16, 1997.
[273] Lead Sheet #5997, Interview of CECOM Team Chief, July 16, 1997.
[274] Lead Sheet #5678, Interview of CECOM Team Chief, August 13, 1997.
[275] "Estimated Cost of Destroyed Ammunition" Army Accident Report 910711001, Fort Rucker, AL: US Army Safety Center, September 20, 1991.
[276] Assumes the three tanks were uploaded with 37 DU rounds each.

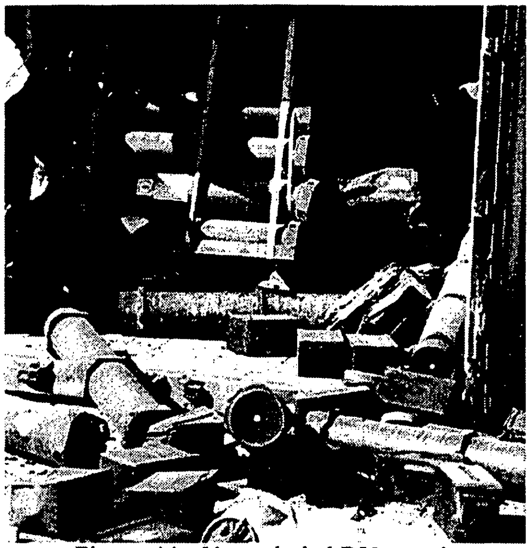

Figure 44 - Unexploded DU rounds

Most of the exposed penetrators recovered at Doha were found intact or nearly intact. Surveys by RADCON teams found no DU contamination outside the North Compound. The heaviest concentration of DU contamination was found in the interiors of the burned tanks. Localized contamination was also found around three of the tanks and several of the burned conexes, however, reports and accounts by RADCON personnel indicated that the levels of radiation here were below even the regulatory guidelines for donning respiratory protection. While several hundred troops could have come into contact with DU rods, fragments, and residual particles in the course of cleaning areas of the 2nd Squadron motor pool, the available evidence suggests that these exposures were well below the threshold levels at which health effects might occur.

Tab J - Accidental Tank Fires

- **December 1990 Accidental Tank Fire**

The first Operation Desert Shield tank fire occurred on December 5, 1990 and involved an M1 tank from A Co. 3-69th Armor, a task force of the 2nd Brigade, 24th Infantry Division. The tank (bumper number A-66) caught fire in an assembly area north of Main Supply Route (MSR) Cadillac and was completely destroyed.[277] The fire, attributed to ongoing transmission problems, started in the engine compartment. Despite the efforts of the crew to extinguish it, fire spread to the ammunition compartment and the ammunition burned and exploded for 12-14 hours. The crew initially moved 1,500 meters away from the tank, but the possible hazard from the DU rounds prompted them to move away another 800 meters.[278] The radiation containment (RAD CON) experts from the US Army's Armament Munitions and Chemical Command (AMCCOM) wrote a report saying there was no significant radiological safety hazard to the crew at any time.[279]

AMCCOM sent a three-person team to Saudi Arabia to assist in the survey, the radiological decontamination, and the preparation of the M1 for shipment back to the US. The tank could not be approached until this AMCCOM team, in concert with EOD, ensured that it was safe.[280] While assisting with the clean up the AMCCOM team, headed by the Chief of the Radiological Waste Disposal Division, trained two military health physicists (a captain and a lieutenant). The team arrived at the site of the tank fire on December 15, 1990. Several high-explosive antitank (HEAT) rounds and belts of small arms ammunition were near the tank. After removing several DU penetrators and getting EOD advice, the team exploded the HEAT and small arms ammunition in place. The 24th Infantry Division safety officer completed a safety investigation and turned the tank over to the AMCCOM team on December 16, 1990.

The initial radiological survey showed no radiological contamination on the ground around the tank and only a small amount on the tank, near the ammunition compartment. Most of the DU rounds had burned and penetrators and pieces of penetrators were thrown up to 60 feet from the tank. All but five of the 37 DU penetrators were recovered in, around, and under the tank. Several of these recovered penetrators were significantly reduced in size and others were fused to the inside of the hull. The recovery team concluded that the fire consumed the unrecovered penetrators, contributing to the contamination found beneath the tank.[281] AMCCOM shipped

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277 AR 15-6 Investigation, Investigating Officer's Statement, S-3, 1st Bn., 64th Armor, undated.

278 Memorandum for Commander, XVIII Airborne Corps, Subject: "Law and Order Significant Activities (SIGACTS)," December 9, 1990.

279 Memorandum for Record, Subject: "Trip Report to Saudi Arabia, 3d Company, 69th Armored Battalion, 1st Brigade, 24th Infantry Division, 6-22 December 1990," December 31, 1990.

280 Memorandum for the Commanding General, Subject: "Status of Collateral Investigation Into Destruction of M1 Tank Assigned to 3/69 AR (Bumper #A66)," December 17, 1990.

281 Memorandum for Record, Subject: "Trip Report to Saudi Arabia, 3d Company, 69th Armored Battalion, 1st Brigade, 24th Infantry Division, 6-22 December 1990," December 31, 1990.

this contamination and a small amount of sand in a 55-gallon barrel, along with the contaminated tank, to Barnwell, SC. for burial.[282]

In a July 2, 1997 phone conversation, the head of the AMCCOM RADCON team stated that individuals inside the contaminated tank wore protective masks (High Efficiency Particulate Aerosol [HEPA] respirators). He also indicated that the team placed the recovered DU penetrators inside the tank, which was then sealed shut. Finally, the team washed down the tank exterior to remove any contamination prior to shipment (by Heavy Equipment Transporter [HET]) to the port at Dhahran.[283]

- **February 1991 Tank Fire Due to Large Shaped Charge Penetration**

On the evening of February 26, 1991, a large shaped-charge weapon hit an Abrams tank (bumper number B-23) belonging to B Co., 1-37 Armor, penetrating the rear grill doors. The loader was injured when a second round (probably an antitank weapon) struck the tank while the crew was attempting to evacuate. The D Company Executive Officer's tank picked up the crew. The fire from the penetration caused a catastrophic fire in the hull, destroying all stowed DU ammunition. The recovery team found pieces of a Hellfire missile at the site, but investigators never determined whether a Hellfire actually struck B-23. The inside of B-23's turret had no ballistic damage. The tank was recovered on or about March 7, 1991.[284]

- **April 4, 1991 Accidental Tank Fire**

On April 4, 1991 a tank (bumper number D-66) belonging to D Company, 2-34 Armor (a 1st Infantry Division task force) caught fire during a tactical road march. The crew frantically discharged 13 hand-held fire extinguishers, but the fire persisted, forcing the crew to move away from the vehicle. The tank continued to burn for 50 hours before two rounds of main gun ammunition (stored in the hull ammunition storage compartment) cooked off. D-66 burned for another 22 hours before EOD personnel could gain access. These EOD personnel and other individuals who may have entered the burned tank could have been exposed to DU. No further information is available regarding the final disposition of the tank.[285]

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[282] Information Paper, Subject: "History and Status of Retrograde of M1 Battle Tank From Saudi Arabia," March 4, 1991.
[283] Lead Sheet #5719, Interview of the former head of the AMCCOM radiation control team dispatched in response to the December 5, 1990 tank fire, July 2, 1997, p. 1.
[284] "Analysis of 1-37 Armor's Battle Damage Incident," Aberdeen Proving Ground, MD: Ballistic Research Laboratory, Undated.
[285] Army Accident Report 910404001, Fort Rucker, AL: US Army Safety Center, printed July 14, 1997.

- **April 13, 1991 Accidental Tank Fire**

On April 13, 1991, a tank (bumper number A-31) from the 2nd Brigade of the 1st Armored Division was being towed by another tank (bumper number A-32) when the tank rounds aboard A-31 suddenly blew up. High temperatures combined with the tank exhaust from A-32 (the towing tank) probably caused the service rounds to ignite. No crew was on board A-31 at the time of the explosion. The crew of A-32 quickly scrambled to safety, sustaining minor injuries in their haste to distance themselves from the burning tank.[286]

A three-man AMCCOM radiation containment (RAD CON) team flew by helicopter from King Khalid Military City (KKMC), where they were working with DU-contaminated systems, to the site of the tank fire to assess the damage and provide technical assistance. Upon arrival, they observed the tank crew removing all ammunition from the burned A-31. DU and high explosive (HE) rounds were lying on the ground around the tank. Crewmembers were working on the tank, in the ammunition compartment, and on the ground surrounding the tank. Initial readings indicated possible contamination of the tank and surrounding area. More extensive readings confirmed DU contamination on the ground beside the tank, on the front surface of the tank, on the top of the ammunition compartment, and in the ammunition compartment. The RADCON team asked all crewmembers to vacate the tank so they could be radiologically examined. The hands of several crewmembers were contaminated, and one crewmember's coveralls were also contaminated. All individuals were shown how to decontaminate their skin and clothing. All exposed skin was checked for cuts and lacerations. Individuals with open wounds were directed to wash thoroughly. These wounds were also cleaned with Betadine and bandaged. One individual had radiological contamination in an open wound. The wound was thoroughly scrubbed until all traces of contamination were removed.

All crewmembers were issued surgical gloves and masks. The crewmembers and the RAD CON team radiologically examined all equipment removed from the tank in order to separate out the contaminated items. The RAD CON team explained the procedure for washing clothes contaminated by DU and advised the battalion commander to have all exposed personnel shower and wash their clothing as soon as possible. The tank was then transported to the contaminated equipment yard at KKMC.[287]

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[286] Accident Report 910413017, Fort Rucker, AL: US Army Safety Center, printed July 14, 1997.
[287] Memorandum for SRC, AMCCOM-SWA, Subject "Vehicle Assessment Report Depleted Uranium Contamination," May 14, 1991.

Tab K- DU Notification and Medical Follow-up Program

This Information Paper outlines the program for arranging follow-up medical monitoring and treatment for veterans potentially exposed to depleted uranium (DU) during or following the Gulf War.

Background
On July 8, 1998, the Department of Defense (DoD) and the Department of Veterans Affairs (DVA) will institute a medical follow-up program to evaluate veterans who received the largest DU exposures during the Gulf War. The highest exposures (Level One) occurred during friendly fire incidents in which US combat vehicles were struck by DU munitions fired from US M1A1 tanks. Soldiers riding in or on these vehicles were potentially exposed to DU through fragments embedded in their bodies, inhalation/ingestion of DU particles created upon impact/penetration, and wound contamination. As a result, some soldiers may still retain DU in their bodies. Other soldiers in Level One entered a struck vehicle immediately after it was struck, and could have inhaled or ingested the fine DU particles still suspended in the vehicle's interior. Personnel classified as Level II participants are believed to have received lesser exposures, but still warrant evaluation. These personnel may have been exposed to DU oxides, residues, and fragments while working in or on US vehicles contaminated with DU.

Objectives
Personnel in Levels I and II will be contacted by the Office of the Special Assistant for Gulf War Illnesses for two purposes.

> First, the veterans will be informed about the availability of the DoD and DVA depleted uranium medical screening programs and they will be encouraged to enroll in the program for which they are eligible. Also, they will be informed that a follow-up letter will be sent within a week.

> Second, the veterans will be asked about their experiences in the friendly fire incidents, or other possible exposures. These data will be used to reconstruct the veterans' possible DU exposure levels. These data will also be used to identify additional personnel who were potentially exposed to DU.

The follow-up program is aimed at ensuring that Gulf War veterans with higher-than-normal levels of uranium in their bodies are identified and given appropriate monitoring and evaluation. It is likely that most soldiers will have normal levels of uranium in their bodies. This program will provide reassurance to them. The program requires a 24-hour urine collection and a detailed medical history in addition to the examination Gulf War veterans receive through the Comprehensive Clinical Evaluation Program or the Department of Veterans Affairs Gulf War Registry. The follow-up will be executed in phases.

Implementation

In Phase I, the pilot program, friendly fire victims contacted by the Office of the Special Assistant for Gulf War Illnesses in October 1997 will be re-contacted and urged to obtain a medical follow-up. The Office of the Special Assistant will send the notification letter at Attachment A, informing veterans of their eligibility for the new medical follow-up program. The notification letter will include the DU Fact Sheet shown in Attachment B.

In Phase II, veterans not previously contacted, but believed to have been in or on vehicles at the time they were struck by DU munitions, will be contacted. Also included in this group are senior leadership from each unit which incurred DU-related friendly fire losses. Phase II will begin on July 15, 1998, and will follow a scenario similar to Phase I, with minor modifications. These soldiers will require a more detailed and flexible notification interview, since some of them were not personally exposed, but may have information regarding soldiers who were. The interview will include questions designed to estimate exposures as well as to identify other soldiers who may have been exposed to DU.

In Phase III, beginning on July 29th, the Office of the Special Assistant will contact other personnel who were possibly exposed to DU. This phase will include personnel who entered DU-contaminated vehicles such as personnel serving in the following organizations or functions: 144th Service and Supply Company, Battle Damage Assessment Teams, Logistics Assistance Officers, radiation control teams, and unit maintenance organizations. The Office of the Special Assistant is currently compiling a list of personnel in Phase III. While the medical follow-up protocols and procedures are expected to remain the same for this phase, the information gathering portion of the notification script will be tailored to the specific functions performed by the contacted veterans. By analyzing the medical results from phase I, II, and III veterans, the decision will be made to discontinue notifications, or to add a Phase IV to notify and evaluate veterans with lower exposures.

Some Gulf War veterans have expressed concerns about potential DU exposures, which were at much lower levels than those experienced by the veterans involved in the Level I or Level II categories. For example, some veterans are concerned about potential exposures due to climbing on damaged Iraqi vehicles, or due to being present in the South Compound during the fire at Doha, Kuwait in July 1991. While they are at much lower risk than the veterans in the friendly fire incidents, veterans with these lower exposures may still have questions for their physicians. Veterans in these lower exposure categories will not be identified or contacted by OSAGWI, but they may refer themselves to the DoD or VA for medical advice. If these individuals and/or their physicians believe it is warranted, they will receive a DU medical evaluation.

Attachments

Attachment A	Depleted Uranium Notification Letter
Attachment B	Depleted Uranium Fact Sheet

May 27, 1998

OFFICE OF THE SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

SPECIAL ASSISTANT
FOR
GULF WAR ILLNESSES

[Veteran's name]
[Veteran's address]
[Veteran's address]

Dear [veteran's name]:

Since early 1997, the Office of the Special Assistant for Gulf War Illnesses has been conducting an investigation into the use of depleted uranium (DU) munitions and armor in the Gulf War. As part of that investigation, we recently contacted you about your wartime experiences and DU exposure.

As part of follow-up efforts to ensure that Gulf War veterans who may have had the highest exposure to DU receive appropriate evaluation, the Department of Defense (DoD) and the Department of Veterans Affairs (VA) have instituted a new program to identify, contact, and evaluate the veterans who are believed to have had the greatest risk of coming into contact with DU. This would include veterans who were riding in or on a vehicle that was struck by DU munitions or veterans who entered a struck vehicle immediately after it was hit by DU munitions. Also included are veterans who worked in or on US vehicles contaminated with DU.

Because of your possible exposure to DU, we would encourage you to enroll in this program. The follow-up program is strictly voluntary; however, you are encouraged to participate so that you can be provided with the appropriate medical follow-up should you be found to have a high level of uranium in your body. If you are on active duty, you will be contacted by a DoD representative to schedule an appointment at the closest medical treatment facility. If you are not on active duty, a staff member from the VA will be contacting you to arrange the evaluation at your nearest VA medical center.

We have enclosed a fact sheet describing the potential health effects that may be associated with DU. Please feel free to share this letter and fact sheet with your personal physician, so he or she will know that you may have been exposed to DU. In addition, DoD and VA physicians who perform the CCEP or Gulf War Registry examinations should be able to answer any questions you might have about the impact of DU on your health.

We know that for many veterans the Gulf War is a painful chapter. We are making every effort to ensure that the lessons learned from the war are applied to protect our soldiers. To do this, we need to fully understand the events that occurred in the Gulf, and any health effects that resulted. If you have further information to share with us about your experiences, please contact my office toll-free at 1-800-497-6261 or write to:

Office of the Special Assistant for Gulf War Illnesses
5113 Leesburg Pike, Suite 901
Falls Church, Virginia 22041

The health of Gulf War veterans is of utmost importance to us. The DoD and VA are committed to protecting the health of our Gulf War veterans. As we learn more about the impact of the Gulf War on veterans' health, we will continue to keep you informed.

Sincerely,
[signature]
Bernard Rostker

Enclosure

DEPLETED URANIUM FACT SHEET

What is Uranium?

Uranium is a weakly radioactive element that occurs naturally in the environment. Each of us ingests and inhales natural uranium every day from the natural uranium in our air, water, and soil. The amount varies depending upon the natural levels found in the area you live and the levels found in the areas where the food you eat and the water you drink are produced. Consequently, each of us has some level of uranium in our body, which is eliminated in the urine. In areas where the natural uranium level in the soil or water is high, these levels can be substantially higher.

Enriched uranium (uranium that is more radioactive than natural uranium) is used in nuclear power reactors and very highly enriched uranium is used in some nuclear weapons.

What is Depleted Uranium?

Depleted uranium (sometimes known as DU) is uranium that is 40% less radioactive than natural uranium, while retaining identical chemical properties.

The United States Armed Forces used depleted uranium munitions and armor for the first time during the Gulf War. Depleted uranium's ability to protect our soldiers' lives was clearly demonstrated. Depleted uranium is the most effective material for these uses because of its high density and the metallic properties that allow it to "self-sharpen" as it penetrates armor. In contrast, antitank munitions made from other materials (tungsten compounds) tend to mushroom and become blunt as they penetrate. Armor containing depleted uranium is very effective at blunting antitank weapons.

What are the health effects of Depleted Uranium?

The major health concerns about DU relate to its chemical properties as a heavy metal rather than to its radioactivity, which is very low. As with all chemicals, the hazard depends mainly upon the amount taken into the body. It has been recognized that natural uranium at high doses has caused kidney damage. The greatest potential for medically significant DU exposure occurred with those veterans who were in or on tanks and other armored vehicles when the vehicles were hit by DU munitions and in veterans who worked in or on US vehicles or sites contaminated with DU.

Since 1993, the Department of Veterans Affairs has been monitoring 33 vets who were seriously injured in friendly fire incidents involving depleted uranium. These veterans are being monitored at the Baltimore VA Medical Center. Many of these veterans continue to have medical problems, especially problems relating to the physical injuries they received during friendly fire incidents. About half of this group still have depleted uranium metal fragments in their bodies. Those with higher than normal levels of uranium in their urine since monitoring began in 1993 have embedded DU fragments. These veterans are being followed very carefully and a number of different medical tests are being done to determine if the depleted uranium fragments are causing any health problems.

The veterans being followed who were in friendly fire incidents but who do not have retained depleted uranium fragments, generally speaking, have not shown higher than normal levels of uranium in their urine.

For the 33 veterans in the program, tests for kidney function have all been normal. In addition, the reproductive health of this group appears to be normal in that all babies fathered by these veterans between 1991 and 1997 had no birth defects.

What new program on DU is available?

As part of follow-up efforts to ensure that Gulf War veterans who may have had the highest DU exposures receive appropriate evaluation and follow-up, DoD and VA have instituted a new program to identify, contact, and evaluate these individuals. This would include veterans who were riding in or on a vehicle that was struck by DU munitions or veterans who entered a struck vehicle immediately after it was hit by DU munitions. Also included are personnel who worked in or on US vehicles contaminated with DU.

What does this involve if I agree to participate?

If you are on active duty and not enrolled in the Comprehensive Clinical Evaluation Program (CCEP) or if your CCEP examination is over 1 year old, you will receive the standard CCEP evaluation. If your CCEP evaluation is less than 1 year old, your physician will decide what evaluations are clinically required.

All participants will be asked to fill out a brief questionnaire relating to possible exposure to depleted uranium during the Gulf War. In addition, all participants will be asked to provide a 24-hour urine sample – you will be provided a container in which you will collect all of your urine for one day. This urine sample will be analyzed for the presence of uranium.

If you are no longer on active duty, you may enroll in the Gulf War Registry Examination Program at any VA Medical Center. You will be asked to fill out a brief DU questionnaire and provide a 24-hour urine sample for uranium and get a medical examination if you have not already had one or wish to be re-examined.

What does a negative-urine mean?

It is good news. It means that the level of uranium in your body now is no higher than would be expected from normal intake from natural sources (food, water, and air). It does not mean you were never exposed to DU. It simply means that you have a normal level of uranium in your body now.

Tab L- Research Report Summaries

This tab provides a summary of some of the major research efforts regarding the military use of depleted uranium. While this listing is not intended to be all-inclusive, it does provide a sense of the depth and breadth of research conducted to date. The studies listed below are summarized on the pages to follow.

Study Number	Description
1	Hanson, Wayne C. Ecological Considerations of Depleted Uranium Munitions, LA-5559. Los Alamos, NM: Los Alamos Scientific Laboratory, June 1974.
2	Environmental Assessment - Depleted Uranium (DU) Armor Penetrating Munitions for the GAU-8 Automatic Cannon, Development and Operational Test and Evaluation, AF/SGPA, April 1975.
3	Elder, J.C., M.I. Tillery, and H.J. Ettinger. Hazard Classification Test of GAU-8 Ammunition by Bonfire Cookoff with Limited Air Sampling, LA-6210-MS, Informal Report. Los Alamos, NM: Los Alamos Scientific Laboratory of the University of California, February 1976.
4	Prado, Captain Karl L. External Radiation Hazard Evaluation of GAU-8 API Munitions, TR 78-106. Brooks Air Force Base, TX: USAF Occupational and Environmental Health Laboratory, 1978.
5	Bartlett, W.T., R.L. Gilchrist, G.W.R. Endres, and J.L. Baer. Radiation Characterization, and Exposure Rate Measurements From Cartridge, 105-mm, APFSDS-T, XM774, PNL-2947. Richland, WA: Battelle Pacific Northwest Laboratory, November 1979.
6	Gilchrist, R.L., J.A. Glissmyer, and J. Mishima. Characterization of Airborne Uranium From Test Firings of XM774 Ammunition, PNL-2944. Richland, WA, Battelle Pacific Northwest Laboratory, November 1979.
7	Davitt, Richard P. A Comparison of the Advantages and Disadvantages of Depleted Uranium and Tungsten Alloy As Penetrator Materials, Tank Ammo Section Report No. 107. Dover, NJ: US Army Armament Research and Development Command, June 1980.
8	Ensminger, Daniel A. and S.A. Bucci. Procedures to Calculate Radiological and Toxicological Exposures From Airborne Release of Depleted Uranium, TR-3135-1. Reading, MA: The Analytic Sciences Corporation, October 1980.
9	Elder, J.C. and M.C. Tinkle. Oxidation of Depleted Uranium Penetrators and Aerosol Dispersal at High Temperatures, LA-8610-MS. Los Alamos, NM: Los Alamos Scientific Laboratory of the University of California, December 1980.

10 Chambers, Dennis R., Richard A. Markland, Michael K Clary, and Roy L. Bowman. Aerosolization Characteristics of Hard Impact Testing of Depleted Uranium Penetrators, Technical Report ARBRL-TR-02435. Aberdeen Proving Ground, MD: US Army Armament Research and Development Command, Ballistic Research Laboratory, October 1982.

11 Hooker, C.D., D.E. Hadlock, J. Mishima, and R.L. Gilchrist. Hazard Classification Test of the Cartridge, 120 mm, APFSDS-T, XM829, PNL-4459. Richland, WA: Battelle Pacific Northwest Laboratory, November 1983.

12 Mishima, J., M.A. Parkhurst, R.L. Scherpels, and D.E. Hadlock. Potential Behavior of Depleted Uranium Penetrators under Shipping and Bulk Storage Accident Conditions, PNL-5415. Richland, WA: Battelle Pacific Northwest Laboratory, March 1985.

13 Wilsey, Edward F. and Ernest W. Boore, Draft Report: Radiation Measurement of an M1A1 Tank Loaded with 120-MM M829 Ammunition. Aberdeen Proving Ground, MD: US Army Ballistic Research Laboratory, July 1985.

14 Magness, C. Reed. Environmental Overview for Depleted Uranium, CRDC-TR-85030. Aberdeen Proving Ground, MD: Chemical Research & Development Center, October 1985.

15 Scherpelz, R.I, J. Mishima, L.A. Sigalla, and D.E. Hadlock. Computer Codes for Calculating Doses Resulting From Accidents involving Munitions Containing Depleted Uranium, PNL-5723. Richland, WA: Battelle Pacific Northwest Laboratory, March 1986.

16 Haggard, D.L., C.D. Hooker, M.A. Parkhurst, L.A. Sigalla, W.M. Herrington, J. Mishima, R.I. Scherpelz, and D.E. Hadlock. Hazard Classification Test of the 120-MM, APFSDS-T, M829 Cartridge: Metal Shipping Container, PNL-5928. Richland, WA: Battelle Pacific Northwest Laboratory, July 1986.

17 Hooker, C.D. and D.E. Hadlock. Radiological Assessment Classification Test of the 120-MM, APFSDS-T, M829 Cartridge: Metal Shipping Container, PNL-5927. Richland, WA: Battelle Pacific Northwest Laboratory, July 1986.

18 Life Cycle Environmental Assessment For the Cartridge, 120MM: APFSDS-T, XM829. Picatinny Arsenal, NJ: US Army Armament Research, Development and Engineering Center, Close Combat Armament Center, December 12, 1988.

19 Parkhurst, M.A. and K.L. Sodat. Radiological Assessment of the 105-MM, APFSDS-T, XM900E1 Cartridge, PNL-6896. Richland, WA: Battelle Pacific Northwest Laboratory, May 1989.

20 Wilsey, Edward F. and E.W. Bloore. M774 Cartridges Impacting Armor-Bustle Targets: Depleted Uranium Airborne and Fallout Material, BRL-MR-3760. Aberdeen Proving Ground, MD: Ballistic Research Laboratory, May 1989.

21 Erikson, R.L., C.J. Hostetler, J.R. Divine, and K.R. Price. Environmental Behavior of Uranium Derived From Depleted Uranium Alloy Penetrators, PNL-5927. Richland, WA: Battelle Pacific Northwest Laboratory, June 1989.

22 Fliszar, Richard W., Edward F. Wilsey, and Ernest W. Bloore. Radiological Contamination from Impacted Abrams Heavy Armor, Technical Report BRL-TR-3068. Aberdeen Proving Ground, MD: Ballistic Research Laboratory, December 1989.

23 Hadlock, D.E. and M.A. Parkhurst. Radiological Assessment of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7228. Richland, WA: Battelle Pacific Northwest Laboratory, March 1990.

24 M.A. Parkhurst, J. Mishima, D.E. Hadlock, and S.J. Jette. Hazard Classification and Airborne Dispersion Characteristics of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7232. Richland, WA: Battelle Pacific Northwest Laboratory, April 1990.

25 Kinetic Energy Penetrator Long Term Strategy Study (Abridged), Final Report. Picatinny Arsenal, NJ: US Army Production Base Modernization Activity, July 24, 1990.

26 Jette, S.J., J. Mishima, and D.E. Haddock. Aerosolization of M829A1 and XM900E1 Rounds Fired Against Hard Targets, PNL-7452. Richland, WA: Battelle Pacific Northwest Laboratory, August 1990.

27 Munson, L.H., J. Mishima, M.A. Parkhurst, and M.H. Smith. Radiological Hazards Following a Tank Hit with Large - Caliber DU Munitions, Draft Letter Report. Richland, WA: Battelle Pacific Northwest Laboratory, October 9, 1990.

28 Memorandum for SMCAR-CCH-V from SMCAR, Radiological Hazards in the Immediate Areas of a Tank Fire and/or Battle Damaged Tank Involving Depleted Uranium, Letter Report, Picatinny Arsenal, NJ, December 4, 1990.

29 Mishima, J., D.E. Hadlock, and M.A. Parkhurst. Radiological Assessment of the 105-MM, APFSDS-T, XM900E1 Cartridge by Analogy to Previous Test Results, PNL-7764. Richland, WA: Battelle Pacific Northwest Laboratory, July 1991.

30 Parkhurst, M.A. Radiological Assessment of M1 and M60A3 Tanks uploaded with M900 Cartridges. PNL-7767. Richland, WA: Battelle Pacific Northwest National Laboratory, July 1991.

31 Life Cycle Environmental Assessment for the Cartridge, 105MM: APFSDS-T, XM900E1. Picatinny Arsenal, NJ: US Army Armament Research, Development and Engineering Center, Close Combat Armament Center, August 21, 1991.

32 Life Cycle Environmental Assessment For the Cartridge, 120MM: APFSDS-T, XM829A2. Picatinny Arsenal, NJ: US Army Production Base Modernization Activity, February 2, 1994.

33 Parkhurst, M.A. and R.I. Scherpelz. Dosimetry of Large Caliber Cartridges: Updated Dose Rate Calculations, PNL-8983. Richland, WA: Battelle Pacific Northwest Laboratory, Reissued, June 1994.

34 Parkhurst, M.A., G.W.R. Endres, and L.H. Munson. Evaluation of Depleted Uranium Contamination in Gun Tubes, PNL-10352. Richland, WA: Battelle Pacific Northwest Laboratory, January 1995.

35 Parkhurst, M.A., J.R. Johnson, J. Mishima, and J.L. Pierce. Evaluation of DU Aerosol Data: Its Adequacy for Inhalation Modeling, PNL-10903. Richland, WA: Battelle Pacific Northwest Laboratory, December 1995.

Report Number 1

Hanson, Wayne C. Ecological Considerations of Depleted Uranium Munitions, LA-5559. Los Alamos, NM: Los Alamos Scientific Laboratory, June 1974.

This report concluded that the major ecological hazard from expended DU munitions would be chemical toxicity rather than radiation. Because DU munitions are composed of alloys, the mobility of the DU is substantially decreased compared to uranium. However, the report stated that the chemical toxicity of expended DU to terrestrial ecosystems could not be ignored and must be seriously considered.

Report Number 2

Environmental Assessment, Depleted Uranium (DU) Armor Penetrating Munitions for the GAU-8 Automatic Cannon, Development and Operational Test and Evaluation, AF/SGPA, April 1975.

This was the Environmental Assessment for the US Air Force's GAU-8 Program. It covered the manufacturing, transportation, storage, use and disposal of GAU-8 ammunition and resulted in a finding of no significant environmental impact.

Report Number 3

Elder, J.C., M.I. Tillery, and H.J. Ettinger. Hazard Classification Test of GAU-8 Ammunition by Bonfire Cookoff with Limited Air Sampling, LA-6210-MS, Informal Report. Los Alamos, NM: Los Alamos Scientific Laboratory of the University of California, February 1976.

On August 26, 1975, the Los Alamos Lab (under contract to the US Air Force Armament Laboratory, Eglin AFB, FL) tested the GAU-8 ammunition to establish its hazard classification. The new armor-piercing version of the GAU-8 (30-mm) contained a DU core. In addition to "fragment pattern scoring" (the usual objective of a bonfire cookoff test), testers sampled the air to evaluate the potential for airborne DU. One hundred and eighty live GAU-8 rounds were set off in the bonfire cook-off. The test plan did not include the measurement of aerosol size characteristics and mass concentrations.

Analysis of the air sampling data concluded nothing beyond the obvious fact that DU aerosol was released. All but one of the 180 rounds remained within 400 feet of the bonfire. The exception was a shell base. The DU penetrators lost a good deal of mass in the bonfire—about 30% of the penetrators lost visually detectable amounts of DU. The remaining rounds escaped the high temperatures that normally turn DU into aerosol and ash. As the report notes, "Almost total dispersion of several penetrators to aerosol and ash illustrated the probable fate of any penetrator remaining in a high temperature region." In other words, in fires, the potential for DU aerosol dispersion is greater than in other scenarios.

Report Number 4

Prado, Captain Karl L. External Radiation Hazard Evaluation of GAU-8 API Munitions, TR 78-106. Brooks Air Force Base, TX: USAF Occupational and Environmental Health Laboratory, 1978.

The study concluded that the standards for protection against radiation (10CFR20.105) were met during typical field conditions, provided that: "(1) occupancy of any area 100 cm from any accessible surface of stored CNU-309/E containers by non-occupationally exposed personnel does not exceed a total of 1,000 hours per year, and that (2) the PGU-14/B cartridge is in a case when handled (If the cartridge is handled directly, the total contact time with the projectile surface should not exceed 180 hours per calendar quarter)."

Report Number 5

Bartlett, W.T., R.L. Gilchrist, G.W.R. Endres, and J.L. Baer. Radiation Characterization, and Exposure Rate Measurements From Cartridge, 105-mm, APFSDS-T, XM774, PNL-2947. Richland, WA: Battelle-Pacific Northwest Laboratory, November 1979.

This was one of three studies recommended by the Joint Technical Coordinating Group for Munitions Effectiveness Working Group on Depleted Uranium Munitions in their initial 1974 environmental assessment of DU. This study focused on the health physics problems associated with the assembly, storage, and use of the 105 mm, APFSDS-T, XM774 ammunition. The conclusion of the report was that the "radiation levels associated with the XM774 ammunition are extremely low. The photon emissions measured did not exceed a maximum whole-body or critical organ exposure of 0.26 mR/hr. Even if personnel were exposed for long periods to the highest levels of radiation measured, it is doubtful that their exposure would reach 25% of the maximum permissible occupational dose listed in Title 10 of the Code of Federal Regulations, Part 20."

Report Number 6

Gilchrist, R.L., J.A. Glissmyer, and J. Mishima. Characterization of Airborne Uranium From Test Firings of XM774 Ammunition, PNL-2944. Richland, WA, Battelle Pacific Northwest Laboratory, November 1979.

This was the last of three studies recommended by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) in the late 1970s. The purpose of this particular test was to gather data necessary to evaluate the potential human health exposure to airborne DU. (The other two studies were: "Radiological and Toxicological Assessment of an External Heat (Burn) Test of the 105 mm Cartridge, APFSDS-T, XM774" and "Radiation Dose Rate Measurements Associated with the Use and Storage of XM774 Ammunition.") Data collected during this test included the following:

1. Size distribution of airborne DU
2. Quantity of airborne DU
3. Dispersion of airborne DU from the target vicinity
4. Amount of DU deposited on the ground

5. Solubility of airborne DU compounds in lung fluid
6. Oxide forms of airborne and fallout DU

The study included extensive assessment of total and respirable DU levels above the targets and at downwind locations, fallout and fragment deposition around the target, and high-speed movies of the smoke generated by the penetrator impact to estimate the cloud volume. Although technical problems were encountered during the test with filter overload, etc., the following conclusions were drawn:

1. Each test firing generated approximately 2.4 kg of airborne DU.
2. Approximately 75% of the airborne DU was U_3O_8 and 25% was UO_2.
3. Immediately after the test, about 50% of the airborne DU was respirable, and about 43% of that amount was soluble in simulated lung fluid within seven days. After seven days the remaining DU was essentially insoluble.
4. Particles in the respirable range were predominantly U_3O_8. Iron and traces of tungsten, aluminum and silicon compounds were found in the airborne particles.
5. The report stated that "Measurement of airborne DU in the target vicinity (within 20 ft) after a test firing showed that personnel involved in routinely changing targets could be exposed to concentrations exceeding recommended maximums. This may have resulted in part from mechanical resuspension of DU from the soil or other surfaces."

Numerous problems were encountered during the sampling for total particulates, which contributed to the conclusion that the average fraction of the penetrator being aerosolized was 70%. These problems included:

- the particulate samplers became clogged and the flow rates dropped to zero which required that the sampling time be estimated,
- the number of fallout trays near the target was inadequate to determine the amount of DU deposited on the ground, and
- the cloud volumes could not be fully evaluated because of inadequate films of the cloud.

Despite the technical problems encountered during the test, 70% is frequently cited as the average level of penetrator aerosolized during hard impact.

Report Number 7

Davitt, Richard P. A Comparison of the Advantages and Disadvantages of Depleted Uranium and Tungsten Alloy As Penetrator Materials, Tank Ammo Section Report No. 107. Dover, NJ: US Army Armament Research and Development Command, June 1980.

This report provides an excellent history of the logic behind the Army's decision to use DU as a kinetic energy, armored-piercing munition. The final selection of DU over Tungsten was based on a combination of reasons, including the lower initial cost of the penetrator itself and its overall improved performance. DU and Tungsten were rated even for "producibility." Tungsten had the advantage for safety, environmental concerns, and deployment.

Report Number 8

Ensminger, Daniel A. and S.A. Bucci. Procedures to Calculate Radiological and Toxicological Exposures From Airborne Release of Depleted Uranium, TR-3135-1. Reading, MA: The Analytic Sciences Corporation, October 1980.

This report provided a description of the models for assessing radiological and toxicological exposures from airborne dispersions of DU under given release conditions—particularly APFSDS-T (Armor-Piercing, Fin-Stabilized, Discarding Sabot-Tracered) XM774 and M735A1 rounds.

Report Number 9

Elder, J.C. and M.C. Tinkle. Oxidation of Depleted Uranium Penetrators and Aerosol Dispersal at High Temperatures, LA-8610-MS. Los Alamos, NM: Los Alamos Scientific Laboratory of the University of California, December 1980.

This was an early test to evaluate the consequences of exposing DU penetrators to a variety of thermal conditions ranging from 500°C to 1,000°C in different atmospheres for 2 to 4 hours. The general conclusions of these tests were:

1. DU aerosols with respirable-sized particles are produced when penetrators are exposed to temperatures above 500°C for one-half hour or more.
2. When the penetrators were exposed to sustained fires; forced drafts and temperature cycling enhanced the production of oxide and aerosol.
3. Since the penetrators are not in themselves flammable, complete oxidation required adequate fuel and a fire of more than 4 hours.

Report Number 10

Chambers, Dennis R., Richard A. Markland, Michael K Clary, and Roy L. Bowman. Aerosolization Characteristics of Hard Impact Testing of Depleted Uranium Penetrators, Technical Report ARBRL-TR-02435. Aberdeen Proving Ground, MD: US Army Armament Research and Development Command, Ballistic Research Laboratory, October 1982.

This is the early documentation required by the NRC to support indoor, confined testing of 105 and 120mm kinetic energy DU rounds. NRC initially approved the test firing of 10 rounds to verify the integrity of the test facility; then it approved the firing of 20 DU penetrators to characterize the aerosol generated by a penetrator impact with an armor target. The study contradicted a previous study by Battelle for the XM774, which indicated that up to 70% of the DU penetrator was aerosolized upon impact. During this study, approximately 3% of the penetrator was aerosolized 2-3 minutes after impact, and accounting for error, it was highly unlikely that more than 10% was aerosolized. The test data was consistent with previous test data for small caliber ammunition. For the aerosolized particulates, the mass mean diameter was 1.6 microns and approximately 70% was less than 7 microns, which is considered the upper range of respirable particulates for DU. The study raised many questions concerning the nature of aerosols generated by hard impact testing of DU penetrators.

Report Number 11

Hooker, C.D., D.E. Hadlock, J. Mishima, and R.L. Gilchrist. Hazard Classification Test of the Cartridge, 120 mm, APFSDS-T, XM829, PNL-4459. Richland, WA: Battelle Pacific Northwest Laboratory, November 1983.

The purpose of this test was to determine the behavior of the XM829 cartridge when subjected to (1) detonation of an adjacent XM829 cartridge, and (2) a sustained hot fire. The test concluded that detonating a XM829 cartridge in one container would not cause the immediate detonation of XM829 cartridges in adjacent cartridges. But if a fire starts and continues to burn, adjacent cartridges may ignite, scattering debris up to 40 feet. A mass analysis for the two tests conducted under this project indicated that at least 80% of the cartridge's mass was recovered in the 1982 test and 100% was recovered in the 1983 test. No DU contamination was detected in samples from the sand taken from ground zero. An analysis of the filters from 7 high volume air samplers also indicated that the airborne level of DU remained at natural background levels. The report noted that "great care was taken during this time to prevent the residue from being scattered by winds and that under different conditions these values could vary." An analysis of the respirator canisters also revealed no measurable levels of DU.

Report Number 12

Mishima, J., M.A. Parkhurst, R.L. Scherpels, and D.E. Hadlock. Potential Behavior of Depleted Uranium Penetrators under Shipping and Bulk Storage Accident Conditions, PNL-5415. Richland, WA: Battelle Pacific Northwest Laboratory, March 1985.

The purpose of this test was to characterize the particle size, morphology, and lung solubility of DU oxide samples from 120 mm M829 DU rounds exposed to an external heat test and to conduct a literature search on "uranium oxidation rates, the characteristics of oxides generated during the fire, the airborne release as a result of the fire, and the radiological/toxicological hazards from inhaled uranium oxides."

The test results indicated that a maximum of 0.6% by weight of the DU oxide generated was in the respirable range (i.e., less than 10 μm Aerodynamic Equivalent Diameter) and that the respirable fraction of the oxide was insoluble (i.e., 96.5% had not dissolved within 60 days). The study concluded that DU oxides formed during burning should be classified as insoluble (Class Y-dissolution half-times in the lung of more that 100 days).

Report Number 13

Wilsey, Edward F. and Ernest W. Boore. Draft Report: Radiation Measurement of an M1A1 Tank Loaded with 120-MM M829 Ammunition. Aberdeen Proving Ground, MD: US Army Ballistic Research Laboratory, undated.

This work was supported by the Project Manager, M1A1 Abrams Tank System, US Army Tank and Automotive Command. The tank was loaded with forty M829 120mm rounds to evaluate crew radiation exposure levels. "Preliminary results of the radiation exposures to M1A1 tank crews were well within the Nuclear Regulatory Guidelines for the general population and there was no undue radiation hazard when the tank was fully loaded with M829 rounds."

Report Number 14

Magness, C. Reed. Environmental Overview for Depleted Uranium, CRDC-TR-85030, Aberdeen Proving Ground, MD, Chemical Research & Development Center, October 1985.

This is an excellent environmental overview of DU—its relation to natural uranium, its applications (both commercial and military), and its long-term effects on man and the environment. The Army conducted this study to fulfill the relevant background information for Army documentation requirements as detailed in Army Regulation (AR) 200-2.

Report Number 15

Scherpelz, R.I., J. Mishima, L.A. Sigalla, and D.E. Hadlock. Computer Codes for Calculating Doses Resulting From Accidents involving Munitions Containing Depleted Uranium, PNL-5723. Richland, WA: Battelle Pacific Northwest Laboratory, March 1986.

The report described the Army's computer modeling to determine whether or not an exclusion zone should be imposed around an accident site, where a boundary should be located, and whether the potential effects farther downwind would be significant or trivial based the characteristics of the incident, the actual munitions involved, and the packaging of the munitions.

Report Number 16

Haggard, D.L., C.D. Hooker, M.A. Parkhurst, L.A. Sigalla, W.M. Herrington, J. Mishima, R.I. Scherpelz, and D.E. Hadlock. Hazard Classification Test of the 120-MM, APFSDS-T, M829 Cartridge: Metal Shipping Container, PNL-5928. Richland, WA: Battelle Pacific Northwest Laboratory, July 1986.

This was a follow-up test to the Hazard Classification Test summarized in PNL 4459 (Report Number 11 above), which was conducted with a wooden shipping container. This follow-up test was conducted to evaluate a new PA-116 metal shipping container. The results:

1. Igniting a round in a metal shipping container by way of an external source did not cause the detonation of the entire package contents.
2. Ignition of one round surrounded by other rounds did not cause sympathetic detonation of the other rounds.
3. Igniting the cartridges' propellant with a sustained fire caused individual rounds to explode. These explosions caused perceptible blast pressure pulses up to 20 feet away.
4. The individual explosions blew cartridge and shipping container fragments into the air. The penetrators were recovered within 20 feet of the fire. Most of the fragments fell within 200 feet. Two fragments were recovered between 300 to 600 feet from the fire.
5. Four of the 12 penetrators from the fire test showed evidence of oxidation. One penetrator core had oxidized almost completely to oxide powder.

The test also revealed these radiological aspects:

1. About 9.5% of the total DU in the 12 cores was converted to oxide during the fire.
2. The oxide was predominantly U_3O_8.
3. The fraction of generated oxide that was aerodynamically small enough to be suspended in air and carried by the wind was 0.002 to 0.006 (0.2% to 0.6%).
4. The fraction of generated oxide that was small enough to be inhaled was about 0.0007 (0.07%).
5. The solubility of the DU oxide in simulated lung fluid indicated that 96% was essentially insoluble. Four percent was dissolved in the fluid within 10 days.
6. During the test, winds were relatively calm. "Air monitors (detection limit of 1μg DU) set up to intercept downwind DU aerosol detected no DU on their filters and tended to confirm that there was no significant airborne DU oxide."

The study concluded that, "the minute quantity of oxide that was of respirable size and the calm winds limited the downwind disposal and posed no biological hazard to cleanup crews or others in the area."

Report Number 17

Hooker, C.D. and D.E. Hadlock. Radiological Assessment Classification Test of the 120-MM, APFSDS-T, M829 Cartridge: Metal Shipping Container, PNL-5927. Richland, WA: Battelle Pacific Northwest Laboratory, July 1986.

This was the follow-up study to a 1983 study evaluating potential health problems when the M829 cartridge is shipped and stored in wooden containers. This follow-up assessment was necessary to evaluate radiation levels when the M829 cartridge is packaged in a metallic container. Results of the study indicate the following:

1. The components of the M829 effectively shield out the predominant nonpenetrating radiation emitted from the bare penetrator; the 1 MeV photons resulting from the decay of the ^{234m}Pa can penetrate both the components of the projectile and the metal container.
2. The radiation levels emanating from the assembled M829 cartridge are no different from the 1983 study, and the slightly higher radiation measurements at the surface of the package are a function of the reduced distance between the penetrator and the outer package surfaces.
3. The radiation levels associated with the M829 ammunition do not present a significant potential hazard to personnel handling and storing the ammunition.
4. The radiation levels at the surface of the single shipping container, measured with field-use-exposure-rate instruments, do not exceed 0.5 mR/hr, and all other criteria given in 49 CFR 173.421 and 173.424 are satisfied by the M829 shipping package. The package therefore qualifies for shipment as "excepted from specification package, shipping paper and certification, marking and labeling requirements." The inner or outer package must, however, bear the word "Radioactive."
5. The ammunition prepared for shipment must be certified as acceptable for transportation by having a notice enclosed in or on the package, included with the packing list, or

otherwise forwarded with the package. This notice must include the name of the co-signer and the statement, "This package conforms to the conditions and limitations specified in 49 CFR 173.424 for articles manufactured from depleted uranium, UN 2909."

Report Number 18
Life Cycle Environmental Assessment For the Cartridge, 120MM: APFSDS-T, XM829. Picatinny Arsenal, NJ: US Army Armament Research, Development and Engineering Center, Close Combat Armament Center, December 12, 1988.

This was the initial Environmental Assessment (EA) for the M829 armor piercing round. The M829 replaced the XM827 (the American analog of the German DM 13), which was the initial APFSDS-T round. The program included the development and testing of four rounds: Target Practice (M831), High Explosive (M830), Armor Piercing (XM827), and Target Practice (M865). The EA incorporates all of the previous supporting studies on the M829 round (e.g., the radiological and hazard classification of the metal and wooden shipping containers). The conclusion of the EA was a "Finding of No Significant Impact" for the design, production, test and evaluation, deployment, and demilitarization of the M829.

Report Number 19
Parkhurst, M.A. and K.L. Sodat. Radiological Assessment of the 105-MM, APFSDS-T, XM900E1 Cartridge, PNL-6896. Richland, WA: Battelle Pacific Northwest Laboratory, May 1989.

In this study the XM900E1 round was packaged in the PA-117 steel container. The conclusions of the report are as follows:

1. The components of the XM900E1 effectively shield out the predominant non-penetrating radiation emitted from the bare penetrator and significantly reduce the majority of the penetrating radiation. The 1MeV photons resulting from the decay of ^{234m}Pa can penetrate both the components of the projectile and the metal canister but are somewhat reduced.
2. Radiation levels associated with the XM900E1 ammunition do not present a significant potential hazard to personnel handling and storing the ammunition.
3. Radiation levels at the surface of the single shipping package, measured with field-exposure-rate instruments, do not exceed 0.5 mR/hr and all other criteria specified by the US Department of Transportation (DOT) in 49 CFR 173.21 and 49 CFR 173.424 are satisfied by the XM900E1 shipping package."

Report Number 20

Wilsey, Edward F. and E.W. Bloore. M774 Cartridges Impacting Armor-Bustle Targets: Depleted Uranium Airborne and Fallout Material, BRL-MR-3760. Aberdeen Proving Ground, MD: Ballistic Research Laboratory, May 1989.

This study was one of several conducted on the M774 ammunition (105mm). It addresses only one objective—the documentation of the amount of DU aerosol and fallout around and downwind of the armor-bustle target. "Very little of the depleted uranium of the M774 penetrator left the immediate target area as an aerosol." The highest value—regardless of the wind conditions—was so low that over 1,400 such tests would have to be fired in a week before tolerance limits would begin to be reached. While the threshold limit value was exceeded when the cloud passed over the samplers, the time-weighted-average exposure for a 40-hour workweek was only 0.07% of the occupational Threshold Limit Value.

Report Number 21

Erikson, R.L., C.J. Hostetler, J.R. Divine, and K.R. Price. Environmental Behavior of Uranium Derived From Depleted Uranium Alloy Penetrators, PNL-2761. Richland, WA: Battelle Pacific Northwest Laboratory, June 1989.

This report covers some of the factors affecting the conversion of DU metal to oxide, the subsequent influences on the leaching and mobility of uranium through surface water and groundwater pathways, and the absorption of uranium by growing plants. Although the report is not directly related to the Gulf War, it demonstrates the Army's efforts to understand the environmental fate of uranium.

Report Number 22

Fliszar, Richard W., Edward F. Wilsey, and Ernest W. Bloore. Radiological Contamination from Impacted Abrams Heavy Armor, Technical Report BRL-TR-3068. Aberdeen Proving Ground, MD: Ballistic Research Laboratory, December 1989.

The objective of this test was to evaluate DU aerosol levels generated inside and outside a heavy armor Abrams tank (i.e., DU armor) impacted by various types of rounds. The test also evaluated particle size distributions of DU puffs generated by the impact near the point of impact and within 100 meters from the tank, resuspension levels within 100 meters of the tank, and DU contamination in air from a burning M1A1 tank with heavy armor after being hit.

The following types of rounds were used in the seven tests:

1. 120 mm APFSDS, KE - tungsten
2. 120 mm, Heat - MP
3. 100 mm AP-C steel rod
4. Anti-tank Mine
5. 120 mm APFSDS, KE - DU (Test 5A)
6. 120 mm APFSDS, KE - tungsten (Test 5B)
7. Hellfire equivalent

In evaluating the data from the test, it is important to recognize the difference between the aerosols typically generated as puffs from impact and aerosols generated from a fire plume involving DU penetrators. Numerous tests have demonstrated that "DU penetrators when burned in a fire for hazard classification, have formed highly insoluble DU oxides, at least in the respirable size range."

The following permissible exposure levels of uranium in the air and soil were extracted from Table 5 of the report:

Medium	Condition	Less than -	Source
Air	Non-occupational, Soluble U-238	3×10^{-12} µCi/ml (or 192 µg/day)	10CFR20, App B Table 2, Column 1
	Occupational, Soluble U-238	7×10^{-12} µCi/ml	Same, Table 1, Column 1
Soil	Unrestricted	35 pCi/gram 97 µg/gram	Federal Register, 46, 205, pp. 5261 to 5263, (1981)
Vehicles	Removable contamination for uncontrolled use	Alpha: 450dpm/100 cm^2 Beta: 550dpm/100cm^2	(AMC) DARCOM 385-1.1-78

Based on the test data, exposures from passing clouds are insignificant beyond 100 meters. The maximum estimated intake at distances greater than 100 meters was 0.82 micrograms of DU. The study noted that it would only take four minutes to reach the airborne limit for the general public, but the passing cloud from each test was present for only a few seconds at a given location. Within 100 meters, but outside the cloud path, air sample results were also insignificant. This included air samplers within 5 to 10 meters of the target. Air sample results in the cloud path varied with the highest level being recorded at a distance of 10 meters from the target (280 micrograms—an acute exposure). There was little additional intake after the puff passed by. Air sampling results for test #6 (a Hellfire equivalent caused a fire that consumed the vehicle) were still within the intake limit even though the air samplers were also exposed to the plume of the fire.

Cascade impactor data for puff of smoke generated at impact revealed that the particles within the cloud were primarily respirable particles (ranging from 76% at the point of impact to 85% just outside the cloud path and 79% along the cloud path). Results of the resuspension air samplers at a distance of 10 to 100 meters from the target revealed that at least for this test, resuspension was not a problem. The highest level recorded was 1.7×10^{-14} microcuries/ml which was well within the limit for airborne uranium.

A personal sampler was worn in the breathing zone by a member of the initial reentry team to evaluate resuspension at the test pad and while climbing inside the crew compartment. All of the resuspension results were within acceptable limits except in Test 6B. For Test 6B, reentry occurred following the fire and the Test 6B sample was collected primarily from inside the crew compartment. The report indicated that a penetrator might have been ejected from one of the storage compartments into the crew compartment and then completely oxidized during the test. Even so, the report cited that the airborne concentration was just above the limit for soluble U-238 and that the limit for insoluble U-238 (5×10^{-12} microcuries/ml) was probably appropriate. Based on the insoluble U-238 criteria, all resuspension data would be within acceptable limits.

Test data for representative welding operations lasting approximately 20 minutes revealed that exposure levels were above the unrestrictive release limits of 3×10^{-12}microcuries/ml of uranium. However, they were never above restricted area limits of 7×10^{-11} microcuries/ml. Local exhaust ventilation was not used for these welding operations and the welding was performed both outside and inside the target, both indoors and outdoors. The report stated that "Even if airborne levels of DU had been above the restricted limit during welding, the welder probably would not have been overexposed. The exposure would be time-weighted to the actual amount of time the welder was working. The usual patchwork took about 20 minutes." However, the welder would still need to wear a respirator under the ALARA guidelines and to protect against other welding hazards such as iron oxide fumes.

For all of the tests, the highest fallout levels occurred on the test pad within 5 to 7 meters of the target. However it was noted that heavy armor material was blown out 76 meters (250 feet) or more from the target after several tests.

Interior air sampling was also taken during the three last impact tests when breakthrough into the crew compartment occurred. Data, though limited, was collected on the first two of those impact events. Data for the last impact was lost because the vehicle caught fire destroying all of the air samplers. During the two impact events in which the penetrators entered through the turret into the main crew area, the air samplers located in the Commander, Gunner and Loader crew positions all shut down during the initial minute following impact. This is probably attributable to either ballistic shock from the impact itself, and/or disruption by the short-lived electromagnetic field, which occurs during armor impact. All of the air samplers placed within the vehicle were small battery powered samplers.

In conducting an assessment of the data it was conservatively assumed that the samplers that shut off did so within the first second after impact. Based on that assumption and knowing the flow rate of the respective samplers, an estimate of intake by an individual was calculated with reference to an inhalation rate of 30 liters per minute (lpm). The maximum mass of DU on a filter in the first breakthrough impact was 3.7 mg DU total dust at the Gunner's position. This equated to a projected intake of 26 mg DU total dust for that second in time. In the second breakthrough impact event, the maximum mass of DU measured on a filter was 4.6 mg DU total dust at the Driver's position. This sampler, however, continued to run until turned off during re-entry activities, about 16 minutes after impact. Based on the sampler flow rate and an inhalation rate of 30 lpm, a projected intake to the driver over that 16-minute period would have been 28 mg DU total dust.

Although the filter for the driver collected 4.6 mg of DU over the 16-minute period, the highest filter reading in the main crew compartment during the event was 2.4 mg, presumably collected in a matter of moments before the sampler shut off. This fact suggests that appreciably higher concentrations of DU might have been collected in the main crew compartment, as opposed to that in the driver compartment, had the sampler not shut off.

Based on the circumstances surrounding each of the two impact breakthroughs for which samples inside the vehicle were collected, significantly higher results would have been predicted for the first impact breakthrough. In the first the turret armor impacted had already been hit on two prior occasions, that may have added to the DU residue inside the tank that was resuspended in the crew compartment at impact. In addition, a DU kinetic energy (KE) round was fired into the armor package during this breakthrough event. In contrast, the round fired for the second event was a non-DU KE round, and the DU turret armor package impacted was impacted for the first time. This discrepancy may be explained by the fact that in the first breakthrough event the vehicle's NBC exhaust air filtration exhaust system was running and the Loader's hatch opened upon impact. In the second breakthrough event, the NBC system was off, and none of the vehicle's hatches opened when impact occurred.

Report Number 23
Hadlock, D.E. and M.A. Parkhurst. Radiological Assessment of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7228. Richland, WA: Battelle Pacific Northwest Laboratory, March 1990.

The purpose of the study was to assess the health issues associated with the handling, storage and shipment of 25mm, APFSDS-T, XM919 ammunition for the US Army Bradley M3A1 and the US Marine LAV-25. The DU cartridges for the M919 ammunition are packaged in the Army plastic (M-621) and metal (PA-125) shipping containers and the Marine metal (CNU-405) shipping container. The study evaluated radiation levels for shipping containers in storage configurations within and outside the fighting vehicles. The results are as follows:

1. The radiation levels associated with the M919 are low and do not present a significant hazard to personnel handling and storing the ammunition.
2. The radiation levels in the Bradley M3A1 and the LAV-25 are also low. Potential doses to personnel in these vehicles will depend on the length of occupancy in the vehicle and the configuration of the stored munitions.
3. The components of the M919 effectively shield out the predominant non-penetrating radiation emitted from the bare penetrator and significantly reduce the majority of the penetrating photon energy. The one MeV photons resulting from the decay of ^{234m}Pa can penetrate both the components of the projectile and the plastic M-621 and metal shipping containers but are somewhat reduced.

4. Radiation levels at the surface of the single shipping container and the pallet of 27 shipping containers, measured with field-exposure-rate instruments, do not exceed 2.5 mR/h. The exposure rate is well within the US Department of Transportation's (DOT) special exemption of 2.5 mR/h limit for DU munitions. Therefore, if the Army obtains approval from the Military Traffic Management Command (MTMC), the XM919 shipping container may be shipped under DOT exemption DOT-E96-49. Otherwise, the containers must be shipped under the provisions of 49 CFR 173.425 entitled "Transport Requirements for Low Specific Activity (LSA)."

Report Number 24

Parkhurst, M.A., J. Mishima, D.E. Hadlock, and S.J. Jette. Hazard Classification and Airborne Dispersion Characteristics of the 25-MM, APFSDS-T XM919 Cartridge, PNL-7232. Richland, WA: Battelle Pacific Northwest Laboratory, April 1990.

Although the 25mm, APFSDS-T M919 cartridge was not used during Desert Shield/Desert Storm, a summary of the Hazard Classification testing is included to demonstrate consistency with previous Hazard Classification tests performed on cartridges used in the Gulf War.

The Hazard Classification Tests performed on the XM919 included the Stack Test which evaluates propagation of detonation and the External Fire Stack Test which evaluates the explosive and fragmentation nature of the cartridge resulting from setting fire to boxes of cartridges. In addition, the M919 was tested against hard armor targets and against wood and masonry to determine the extent and nature of Du aerosols created.

The results of the M919 tests are as follows:

- There was no propagation of initiation demonstrated from the Stack Test. The effects of initiation of the donor cartridge were limited to the donor container. There was no propagation of initiation to the other shipping containers.
- The results of the External Fire Stack Test indicated there was no mass detonation of the cartridges. The cartridges exploded progressively and the effects were limited to the immediate test area.
- Many of the penetrators that remained in the fire showed some signs of oxidation. Approximately 35% of the total DU used in the External Fire Stack Test was oxidized. Between 0.1% and 0.2% of the oxide was within the respirable range. The lung solubility analysis of the DU oxide determined that 92.6% was insoluble and 6.8% was slightly soluble.
- There was no indication that any measurable DU became airborne as a result of the External Fire Stack Test.

- The fraction of DU made airborne from the hard target impact testing was less than 10%. Less than 0.1% of the initial DU penetrator weight was within the respirable size range. About 17% of the oxide present in the smallest size fraction was soluble while the remaining 83% was insoluble.

Report Number 25

Kinetic Energy Penetrator Long Term Strategy Study (Abridged), Final Report. Picatinny Arsenal, NJ: US Army Production Base Modernization Activity, July 24, 1990.

This report addressed battlefield DU exposures relative to peacetime occupational limits. Civilian battlefield exposures are not thought to be significant. "All combat-related internal and external radiation risks were in the range of 10^{-7} to 10^{-5}. The most significant external radiation exposure occurs during the loading and unloading of ammunition lockers, with a lifetime increased cancer risk to the extremities as high as 3×10^{-4} resulting from a worst case, 20-year exposure. Even minimal safety precautions would reduce this risk to levels well below those tolerated in most occupational environments."

The report also addressed the following theoretical exposures;

1. Tank Crew Radiation Exposure Maximum Exposure. Assuming ¼ of a day, seven days/week, 52 weeks/year + .25 rem/year, and a half-filled DU kinetic penetrator ammunition rack, this level is well below the occupational limit of 5 rems/year.
2. Soldier Taking Refuge. Assuming a scenario of a tank hit by a DU penetrator, a soldier taking refuge would receive a maximum exposure of 23 mrem—equivalent to a lifetime increased cancer risk of less than 5×10^{-6}, which is three orders of magnitude less that the lifetime increased cancer risk calculated in the same manner resulting from all background radiation exposures.
3. Major Tank Battle. Assuming a two-month duration, the lifetime increased cancer risk for military personnel would be 1.5×10^{-7}. Downwind of such a battleground, the public would experience a lifetime cancer risk increase of about 3×10^{-5}.

The report also addressed the need for further evaluation of battlefield conditions. "Exposures to military personnel may be greater that those allowed in peacetime, and could be locally significant on the battlefield. Cleanup of penetrators and fragments, as well as impact site decontamination may be required." "Public relations efforts are indicated, and may not be effective due to the public's perception of radioactivity." The Overview also indicated that further studies were needed on DU combat impacts for post-combat briefings and actions.

Report Number 26
Jette, S.J., J. Mishima, and D.E. Haddock. Aerosolization of M829A1 and XM900E1 Rounds Fired Against Hard Targets, PNL-7452. Richland, WA: Battelle Pacific Northwest Laboratory, August 1990.

The purpose of this study was to characterize particulate levels after hard impact with both complete and partial penetration of the armor. Tests were performed with both the M829A1 and XM900E1 rounds, as well as two non-DU rounds (the M865 and DM13). The purpose of the non-DU round firings was to evaluate DU resuspension during hard impact tests. The sample results were questioned when the percent aerosolized was initially estimated to be only 0.2% to 0.5% for the M829A1 and 0.02% to 0.04% for the XM900E1. These values were approximately two orders of magnitude below expected values. A value of 70% has frequently been cited in the popular press based on one of the initial studies performed by Battelle for the XM774. This study stated that it was highly unlikely that more than 10% was aerosolized upon impact. In keeping with other studies indicating that a high percentage of the respirable dust from hard-impact testing was soluble in the lungs, this study's evaluation of the respirable dust fraction indicated that 57 to 76% was class "Y" material and 24 to 43% was class "D" material. (Class "D" materials have dissolution half-times less that 10 days; class "W" materials have dissolution half-times of 10 to 100 days; and class "Y" materials have dissolution half-times greater than 100 days.) The resuspension tests indicated that most of the resuspended dust was non-respirable—which is consistent with the theory that most of the respirable dust was removed by the filtering system in the enclosure.

Report Number 27
Munson, L.H., J. Mishima, M.A. Parkhurst, and M.H. Smith. Radiological Hazards Following a Tank Hit with Large - Caliber DU Munitions, Draft Letter Report. Richland, WA: Battelle Pacific Northwest Laboratory, October 9, 1990.

At the beginning of the Gulf War crisis, Battelle's Pacific Northwest Laboratory was tasked to predict potential radiation hazards to personnel entering a site where a tank has been hit by DU. Their prediction was based on a DU penetrator for a 105-mm, APFSDS-T kinetic energy round striking an armored vehicle and penetrating one side of the vehicle. No live fire testing was performed under this tasking. Their estimates were based on previous tests and their "best educated estimates" of exposures for the following scenario: The vehicle contains no DU munitions or DU armor. The event occurs in a desert-like climate, which exhibits high daytime temperatures and low nighttime temperatures and large fluctuations in relative humidity between inland to coastal areas and from day to night. There are winds associated with the changes in surface temperature. Personnel are in the immediate area for inspections and observation within days after the event. Clean up and recovery activities occur within a few weeks to a few months.

The report stated that the "impact of a DU penetrator with an armored vehicle would be expected to result in aerosolization of 12% to 37% of the penetrator, smearing of DU metal around and through the penetration, and scattering of metal fragments both inside and outside the vehicle. The aerosolized DU would most likely be oxidized uranium and form particulate material which, depending upon its size, could deposit around the immediate area and preferentially downwind. The material smeared around and through the vehicle penetration would be both DU metal and DU oxide."

The report indicated that exposures to casual passers-by and cleanup personnel would be very low. "Occupational dose limits for external exposure are 5000 mrem/year to the whole body, 50,000 mrem/year to the skin, and 75,000 mrem/year to the hands and feet (extremities). Since the most likely organ to be exposed during contact with penetrator fragments is the skin, it would require over 800 hours of direct contact to bare skin to reach the current occupational limit for skin exposure." Because such direct and long exposure is quite unlikely, the report indicated the radiological hazard from external exposure to DU fragments was very low for causal passers-by and cleanup personnel.

The report stated that the "principal hazard from exposure to DU material is inhalation and lung deposition of particulate uranium. Alpha particle emissions to the lungs from inhaled DU constitute the main health concern from the inhalation of the mostly insoluble DU. Occupational exposure limits for the inhalation of ^{238}U are 7 x 10^{-11} microcuries/ml for soluble forms of uranium and 1 x 10^{-10} microcuries/ml for insoluble uranium compounds. These exposure limits are based on continual intake of ^{238}U for 13 weeks at 40 hour/week. In terms of mass the limit is an average of 0.2 mg/m^3 of ^{238}U aerosols in a 40-h work week."

The report noted that 44% to 70% of the DU material aerosolized would be equal to or less than the 3.3 micrometer Aerodynamic Equivalent Diameter (AED) which is the approximate size that would be inhaled into the deep lung. Characterization of the DU penetrators oxidized in various Hazard Classification testing indicated that 0.2% to 0.6% of the oxide was less than 10 micrometer AED—which is considered as respirable (inhaled into the nasal passages).

The report stated that any hazards from the presence of DU are relatively insignificant as compared to the other battlefield considerations and should not be considered during life saving and rescue activities.

During the recovery operations, the report expressed concerns that the large fragments could pose a potential hazard from external radiation and their surfaces could be a source of uranium oxide contamination as they erode. The report also expressed concern that aerosolized DU which had been deposited in and around the vehicle and on the soil in the immediate area could be resuspended by wind and during cleanup and recovery operations.

The following precautions during general clean up and recovery efforts are quoted from the report:

1. Restrict an area approximately 30 meters in radius from the vehicle to minimize unnecessary exposure to personnel and resuspension of DU material.
2. Perform a radiological survey of the restricted area using a thin window GM portable detector or a micro-R meter.

3. DU metal penetrator fragments detected during the survey should be placed in plastic bags, sealed in a container, and stored as appropriate for disposal.
4. DU oxidized penetrator fragments, identified as a black powder, should be placed in plastic bags and sealed in a container for removal. A small amount of sand around and under the oxidized material may also be contaminated and need to be removed. If piles of oxidized DU are not removed at the time of the survey, it is prudent to fix them in place when detected by covering them with an inverted can or similar mechanism to minimize potential movement.
5. The openings to the interior of the impacted armored vehicle should be closed. The DU penetrator opening and the immediate area around it should also be covered to provide containment and minimize spallation and removal of impacted material. It is assumed that the vehicle will be moved to another location for decontamination and disposition.
6. Intrusion into the restricted area during periods of high winds should be discouraged to minimize potential resuspension of radioactive material.
7. Precautions necessary for entry into the restricted area should depend on the purpose of the entry.

The report also provided general guidance on routine monitoring and decontamination procedures.

1. Radiation dosimeters should not be necessary for survey, vehicle closure, clean up, or recovery activities.
2. Entry for radiological survey of the vehicle's exterior should require no special protective clothing—provided walking over piles of DU oxide is avoided and actions to disturb the soil are minimized.
3. Entry into the interior of the vehicle for any reason should require a single layer of protective clothing, shoe covering, coveralls, gloves, particulate filter respirator and head covering.
4. Entry for pickup of DU fragments and piles of oxide outside the vehicle should require a single layer of protective clothing, shoe covering, coveralls, gloves, particulate respirator, and head covering
5. Entry to close an opening in the target vehicle should require only gloves for hand protection.
6. After the penetrator fragments and piles of oxide are picked up and the vehicle is closed, entry to remove the vehicle should require no protective clothing.

The transmittal Memorandum recommended that all openings should be sealed and only external surfaces decontaminated in the field. Decontamination of the interior should only be performed in a facility set up for that purpose. The memorandum also recommended limiting intrusion into the cleanup/recovery area during periods of high winds because of the potential for contamination resuspension.

In summary, the report concluded that there is little potential for radiological hazard to personnel entering the site following the impact of a DU penetrator with a tank or other armored vehicle. (The prediction did not assume a DU round impacting an Abrams Heavy Armored vehicle with DU armor.) The report did recommend the use of respiratory protection to minimize the inhalation hazard and decontamination of the body of any fatalities before they are released.

Report Number 28

Memorandum for SMCAR-CCH-V from SMCAR, Radiological Hazards in the Immediate Areas of a Tank Fire and/or Battle Damaged Tank Involving Depleted Uranium, Letter Report, Picatinny Arsenal, NJ, December 4, 1990.

As noted in Report #27, Battelle's Pacific Northwest Laboratory was tasked to predict potential radiation hazards to personnel entering a site where a tank has been hit by DU. Their prediction was based on a DU penetrator (105mm, APFSDS-T kinetic energy round) striking an armored vehicle and penetrating one side of the vehicle. The report did not evaluate a DU munition impacting an armored vehicle containing DU armor or DU munitions. The December 8, 1990 report comments on the Battelle Letter Report (Report Number 27) and expands the prediction to address DU munitions impacting an armored vehicle containing DU munitions and/or DU armor. Although no live fire testing was performed for this report, the conclusions and recommendations were drawn from BRL Technical Report BRL-TR3068, Radiological Contamination from Impacted Abrams Heavy Armor (Report Number 22 above).

The memo attempted to expand on the guidance included in TB 9-1300-278, "Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions Which Contain Depleted Uranium, which was the guideline for responding to peacetime accidents. The memo cited the following points:

- Intrusion into the cleanup/recovery area during periods of high winds should be discouraged due to the potential for unnecessary exposure to DU resuspended by that wind, or by the disturbances caused by people or equipment.
- Other than for decontaminating the outside of the vehicle and covering any openings, as provided in the TB, decontamination of the interior of the tank needs to be performed at a facility set up for such a purpose.
- Removal of deceased personnel from tanks will require radiation safety coordination to determine whether or not the clothing and /or body is radioactively contaminated. If so, decontamination will need to be conducted prior to further disposition of the deceased.
- The procedures in the referenced TB were written for a scenario in where an isolated tank accident involving DU occurred during peacetime conditions. Those same procedures still apply if the scenario were an arena of battle damaged tanks scattered about the surrounding area. In order to properly conduct a recovery/cleanup following the termination of a conflict, one would

begin at the perimeter of that overall area, and gradually work your way in, clean up the immediate area, decontaminate the exterior of that tank, and remove it, before proceeding into the next sector. In other words, don't cross-contaminate or re-contaminate things.

The report also addressed potential problems caused by the sand in Gulf Region and the implication for the Army's standard radiation detection equipment. The report concluded that FIDLERS (field instrument for the detection of low energy radiation) would be more appropriate because of their larger probe areas. The report also provided supplemental procedures to TB 9-1300-278 by reiterating the radiation survey precautions cited in the Battelle Letter Report (Report #27).

Report Number 29
Mishima, J., D.E. Hadlock, and M.A. Parkhurst. Radiological Assessment of the 105-MM, APFSDS-T, XM900E1 Cartridge by Analogy to Previous Test Results, PNL-7764. Richland, WA: Battelle Pacific Northwest Laboratory, July 1991.

Due to administrative restrictions at the test ranges, this study was conducted by analogy to similar test rounds. The conclusions are that "neither propagation of initiation nor mass explosion have occurred with similar large-caliber ammunition, and it is extremely unlikely that either would occur with the M900/PA117" metal shipping container. In a stack fire, the likely extremes with the M900 cartridge are that either all projectiles would be ejected from the fire and show no evidence of oxidation or that all would remain in the fire and totally oxidize. The reality is that some would be ejected from the fire and some would be oxidized. The study cited similar tests for the M735 cartridge, which had maximum fragmentation distances up to 100 feet for the penetrator and 375 feet for the fragments.

Report Number 30
Parkhurst, M.A. Radiological Assessment of M1 and M60A3 Tanks uploaded with M900 Cartridges. PNL-7767. Richland, WA: Battelle Pacific Northwest National Laboratory, July 1991.

The purpose of the study was to assess the dose rate to which M1 and M60A3 crews would be exposed with the deployment of the 105mm M900 cartridge. The tests were conducted using worst case stowage configurations and placement of the bustle compartment near the driver. All cartridge locations were filled with M900 cartridges, rather than the mix of armor-piercing (M900) and high explosive (HE) cartridges. This is not a likely stowage situation. The dose to a crewmembers was calculated to approximate the actual radiation fields with HE stowed appropriately and taking the place of the excess DU cartridges. The results of the study are quoted as follows:

- Based on this unusual configuration, dose rates peaked in the M1 at 0.5 mR/h under the turret bustle and above the driver's head and in the

M60A3 at 1.5 mR/h in the vertical, exposed cartridge storage rack, as measured by portable radiation detection instrumentation. These levels are within the permissible levels of radiation in unrestricted areas. Using thermoluminescent dosimeters to measure specific points within the vehicle, researchers determined that the M1 commander, gunner, and loader received an average dose rate of about 0.01 mrad/h of penetrating radiation. The driver received an average dose of about 0.2 mrad/h with the bustle above him.

- Dose rates to the M60A3 crew were slightly higher than the dose rates for the M1 crew. The commander and gunner received about 0.05 mrad/h of penetrating radiation. The loader, who had well-shielded cartridges behind him, but a stack of unshielded DU cartridges in front of him, received an average of about 0.2 mrad/h. The driver, who had cartridges on three sides, received an average of 0.28 mrad/h.
- Assuming a crew occupied a fully loaded vehicle for 700-900 hours, none of the crew would be likely to exceed the 250 mrad/year administrative badging limit. Even with DU in all the 105mm ammunition slots, the only person approaching the limit would be the M60A3 driver, and this would only occur if the bustle were over his head during his entire time within the vehicle.
- The study revealed that the drivers of both vehicles had the highest potential exposure. The M1 driver received his entire DU dose from the bustle of cartridges over head. (Note: Most of the time, the gun rather than the bustle is over his head). His dose, measured with the hatch open, maximized the radiation field. Without the bustle, the exposure to the M1 driver is negligible. On the other hand, the driver of the M60A3 gets only a small portion of his exposure from the bustle storage. Most of his exposure comes from storage in the hull.
- The study estimated that dose rates for more ordinary configurations are less than 0.05 mrad/h for the M1 driver and about 0.1 mrad/h for the M60A3 driver.

Report Number 31

Life Cycle Environmental Assessment for the Cartridge, 105MM: APFSDS-T, XM900E1. Picatinny Arsenal, NJ: US Army Armament Research, Development and Engineering Center, Close Combat Armament Center, August 21, 1991.

This Environmental Assessment was developed to address environmental concerns when the service round for the M68 cannon on the M60A3 and M1 tanks (the M833 APFSDS-T) was replaced by the new XM900E1 APFSDS-T round, which has significantly greater armor-piercing capabilities. The Assessment included previous studies of the radiological hazards, etc. conducted on the XM900E1. The Assessment's conclusion was that only the testing modes for armor penetration and accuracy and final disposal of the penetrators presented any significant potential for environmental impact; the report outlined mitigating measures to reduce the impact of testing. From a health and safety standpoint, the XM900E1 presents no greater risk than the existing M833. The XM900E1 program is not expected to have a significant environmental impact on air quality, water quality, ecology (flora and fauna), or health and safety to personnel associated with normal maintenance and life cycle operations.

Report Number 32

Life Cycle Environmental Assessment for the Cartridge, 120MM: APFSDS-T, XM829A2. Picatinny Arsenal, NJ: US Army Production Base Modernization Activity, February 2, 1994.

This is an environmental assessment (EA) of the third generation M829 round (M829A2). It builds on the EA for the previous M829 and M829A1 rounds (see Report Number 18) and concludes with a "Finding of No Significant Impact." This assessment excludes combat uses and fires or other severe and unlikely accidents and the testing modes for armor penetration and accuracy. The EA recognized that the resuspension of DU, environmental transport, and various health and safety issues as areas of concern requiring further evaluation. Consequently, the Army Environmental Policy Institute has been tasked to evaluate the risks associated with depleted uranium left on the battlefields during Desert Storm. In addition, studies on the health effects of DU fragments in soldiers have been funded. The Army is also developing special DU training courses for personnel engaged in fielding, firing, and retrieval operations.

Report Number 33

Parkhurst, M.A. and R.I. Scherpelz. Dosimetry of Large Caliber Cartridges: Updated Dose Rate Calculations, PNL-8983. Richland, WA: Battelle Pacific Northwest Laboratory, June 1994.

This report provides revised exposure levels for all of the previous radiological assessments performed by Pacific Northwest Laboratory (PNL) that used the lithium fluoride thermoluminescent dosimeter (TLD). PNL developed a new, more accurate algorithm for interpreting the response of the TLD used in the radiological assessment of various DU cartridges. As a result, PNL re-evaluated the previously reported exposure values for the following cartridges:

1. 120 mm M829 cartridges
2. 105 mm M333 cartridges
3. 120 mm M829A1 cartridges
4. 120 mm M829A2 cartridges
5. 105 mm M900 cartridges
6. M60A3 and M1 Tanks loaded with M900 cartridges.

The report also provides a comparison of the original versus recalculated values. "In all cases, the recalculated dose rates were significantly lower than the originally reported dose rates. Studies of dose rates in the tanks showed that crews in tanks loaded with DU rounds would pose no danger of exceeding administrative badging limits of 250 mrem/year and it was also unlikely that the more restrictive population limits of 100 mrem/year would be exceeded by personnel in the tanks." In other words, radiation exposure levels associated with uploaded DU munitions in the applicable tanks are within acceptable criteria, even for the general population.

All of the previously reported radiological assessment reports need to be corrected to reflect the results of the recalculations.

Report Number 34
Parkhurst, M.A., G.W.R. Endres, and L.H. Munson. Evaluation of Depleted Uranium Contamination in Gun Tubes, PNL-10352. Richland, WA: Battelle Pacific Northwest Laboratory, January 1995.

Routine radiation monitoring identified radiological contamination in gun tubes that fire developmental and production DU rounds. This report addresses the issues of how much DU is present in tubes that have fired DU, how this relates to unrestricted release standards, how cleaning techniques reduce the DU levels, and how the levels relate to personnel radiation protection.

Testing revealed that numerous tubes had detectable levels of DU in the gun barrels and some were above the unrestricted release limits, but none were high enough to pose a health risk. Firing non-DU training rounds is also effective in reducing the contamination in the tubes, but the practice is not recommended. The removable contamination makes up only a small percentage of the DU contamination that is generated in the firing process. The fixed contamination that is left behind after normal barrel field cleaning procedures was found in a number of instances to be above uncontrolled release limits. Presently, unless more satisfactorily decontaminated by other cleaning means, those barrels would have to be processed as radioactive waste at the time of turn in by the field of the barrel for disposal. Further studies were required to fully assess the problem. Induced flareback was also achieved during firing to determine if tank personnel were exposed in the turret, but no problems were identified for crew personnel.

Report Number 35
Parkhurst, M.A., J.R. Johnson, J. Mishima, and J.L. Pierce. Evaluation of DU Aerosol Data: Its Adequacy for Inhalation Modeling, PNL-10903. Richland, WA: Battelle Pacific Northwest Laboratory, December 1995.

As the name of the report implies, the purpose of this study was to evaluate the existing research data on the characteristics of DU aerosols generated under various conditions. The report is an excellent summary of the studies conducted to date, including many summarized in this report. Project summaries were included for over 20 studies conducted by Battelle Pacific Northwest Laboratory and over 20 additional studies conducted by other researchers. The evaluation focused on chemical composition, particle size, and solubility in lung fluid.

Although several areas such as resuspension and particle size distribution were cited as needing further research, the overall quality of the data was deemed as being adequate to make conservative estimates of dispersion and health effects. The report is an excellent summary of the studies conducted to date.

Tab M- Characterizing DU Aerosols

The actual level of aerosols generated during the various impact tests has varied widely. One of the first hard impact tests conducted on DU ammunition was reported in *Characterization of Airborne Uranium from Test Firings of XM-744(sic) Ammunition*, 1979.[288] This report concluded that as much as 70% of the 105mm penetrator would turn into aerosol upon impact. Although this 70% has been frequently cited, it is flawed and misleading—mainly because it was "back-calculated" from cloud data and represented a worst-case scenario (i.e., an impact against a hard target, which was not penetrated). The 1982 report from the Ballistic Research Laboratory entitled *Aerosolization Characteristics of Hard Impact Testing of Depleted Uranium Penetrators* contradicted the results of the 1979 test. In this test, about 3% was aerosolized 2-3 minutes after impact. Allowing for error, it is highly unlikely that more than 10% of the penetrator was aerosolized in the 1982 test. The 1982 test found that 70% of the aerosolized particles were less than 7 microns—i.e., respirable particles.[289]

Hard impact testing in 1990 of the M829A1 120mm cartridge and the XM900E1 105-mm cartridge produced somewhat contradictory numbers. This study characterized particulate levels after hard impact with both complete and partial penetration of the armor. The tests were performed with both the M829A1 and XM900E1 rounds, as well as two non-DU rounds, the M865 and DM13. (The purpose of the non-DU round firings was to evaluate DU resuspension during hard impact tests.) The sample results were questioned when only about 0.2% to 0.5% of the DU was aerosolized for the M829A1 and 0.02% to 0.04% for the XM900E1. (These values were approximately two orders of magnitude below expected values.) After comparing Real-Time Aerosol Monitor (RAM) data with RAM data from a previous test, researchers eventually estimated that the percent aerosolized was closer to 18%—substantially less than the 70% previously cited by Battelle in the 1979 test. The respirable aerosol fraction [less than 10 μm AED (Aerodynamic Equivalent Diameter)] was 91% to 96% for the M829A1 and 61% to 89% for the XM900E1. Evaluation of the respirable dust fraction indicated that 57% to 76% was class "Y" material and 24% to 43% was class "D" material, in keeping with other studies which indicated that a high percentage of the respirable dust from hard impact testing was soluble in the lungs. (Note: Class "D" materials have dissolution half-times less that 10 days, class "W" materials have dissolution half-times of 10 to 100 days and class "Y" materials have dissolution half-times greater than 100 days.)[290] The resuspension tests indicated that most of the resuspended dust was non-respirable, which is consistent with the theory that most of the respirable dust was removed by the filtering system in the enclosure. The aforementioned tests are but a few of the tests performed on DU munitions in an attempt to characterize aerosol formation and assess potential exposures. As a result of recommendations made in the 1995

[288] J.A. Glissmeyer, J Mishima, and R.L. Gilchrist, Characterization of Airborne Uranium from Test Firings of XM-744(sic) Ammunition, PNL-2944, Richland WA: Battelle Pacific Northwest Laboratory, 1979.

[289] Dennis R. Chambers, Richard A. Markland, Michael K Clary, Roy L. Bowman, Aerosolization Characteristics of Hard Impact Testing of Depleted Uranium Penetrators, Technical Report ARBRL-TR-023435, Aberdeen Proving Ground, MD: Ballistic Research Laboratory, October 1982, p. 46.

[290] S.J. Jette, J. Mishima, and D.E. Haddlock, Aerosolization of M829A1 and XM900E1 Rounds Fired Against Hard Targets, PNL-7452, Richland, WA: Battelle Pacific Northwest Laboratory, August 1990, p. 4.1.

Health and Environmental Consequences of Depleted Uranium Use in the US Army: Technical Report, Battelle's Pacific Northwest Laboratory conducted an evaluation of existing test data for predicting aerosol exposures. Their report (entitled *Evaluation of DU Aerosol Data: Its Adequacy for Inhalation Modeling*) identified some of the technical problems with estimating exposure under various combat scenarios. The following is a brief discussion of DU aerosol generation scenarios present in the report:[291]

- Fires. During a munitions "cookoff," the burning propellant does not consume oxygen since the propellant supplies its own oxygen. Little if any oxidation of the DU metal occurs because combustion is so rapid. Studies have shown that few of the particles generated during a fire are small enough to be caught up in the thermal currents unless there are violent explosions. The solubility of the oxides formed during a fire are low. Most of the particles produced in a tank fire end up deposited on the interior walls of the tanks, but openings (hatches, holes created by explosions, etc.) could let particles out into the surrounding atmosphere.
- Vehicles Punctured by Projectiles. As noted in other studies, the level of oxides formed during impact is largely a function of the "hardness" of the target. The heavier the armor, the more oxides that will be formed as the DU penetrator expends its kinetic energy "burning" through the armor. During the Gulf War, there were numerous DU hits on lightly armored vehicles, which typically left round, golf-ball-sized entrance and exit holes. Because lightly armored vehicles offered little resistance, unless the round struck the engine or similar obstructions, DU aerosolization was limited in these cases. Conversely, harder targets (like Abrams M1A1 Heavy Armor tanks involved in friendly fire incidents) tend to produce higher levels of DU aerosolization. Aerosolization is enhanced if the penetrator splits into fragments and those fragments remain inside the vehicle. Aerosol levels inside the vehicle also depend on such factors as the number of open hatches and other ruptures or openings. Eventually, particles from inside the tank are either deposited on the inside surfaces of the tank or released to the atmosphere through any opening. As particles are deposited on the interior surfaces, the particle size, distribution, and mass change.
- Entry of Contaminated Vehicles. For Battle Damage Assessment Team (BDAT) personnel, recovery personnel, or souvenir hunters entering the damaged vehicles, the primary concern is resuspension of DU dust. Resuspension depends on the air turbulence inside the vehicle and other conditions (e.g., oily surface walls minimize resuspension). Physical activity inside the vehicle (like lifting or moving equipment or personnel) would obviously increase the level of resuspension. For emergency rescue personnel who enter the tank shortly after impact, the aerosols generated at impact would be the primary concern. These impact aerosol levels should be higher

[291] M.A. Parkhurst, J. R. Johnson, J. Mishima, J.L. Pierce, Evaluation of DU Aerosol Data: Its Adequacy for Inhalation Modeling, PNL-10903, Richland, WA: Battelle Pacific Northwest National Laboratory, December 1995, p. 2.4-2.6.

than the resuspension levels generated after the aerosols in the tank have had time to settle or to be vented through open hatches, etc.

- Inspection and Repair Activities on Contaminated Vehicles. Entry into contaminated vehicles for inspection and repair activities can cause significant DU resuspension. And some of the actual repair activities—like cutting and welding—have the potential to raise resuspension levels even higher. Cleaning operations can also cause resuspension.
- Routine Combat Activities. The report, *Evaluation of DU Aerosol Data: Its Adequacy for Inhalation Modeling,* also indicated potential exposures from DU penetrators that did not penetrate the target or were deflected. The penetrator would be hot enough to generate aerosols, so oxides would continue to be formed for a while once the penetrator was buried in the soil. The report also cited potential exposure to troops near the target at impact, or troops exposed to resuspension from subsequent activities on, in, or near the target.

Two recent tests conducted after the Battelle Summary report raise some questions concerning the nature and extent of respirable particulates generated during fires and hard impact testing. In June 1995, the Army fired 120 mm and 25 mm DU munitions against Soviet armored equipment. Although technical and procedural difficulties seriously affected the data and limited the conclusions that could be drawn from the test, several key findings were cited in the Draft report. They were:

- DU aerosols, containing particles of respirable sizes, are generated inside armored vehicles by DU penetrator impact. The concentration of airborne DU aerosol decreases with time, but measurable concentrations of respirable particles remain suspended hours later.
- Measurable quantities of DU oxide particles that settle on surfaces can be resuspended during routine personnel re-entry activities, and that the resuspended aerosols contain particles of respirable sizes.[292]

The second test was the 1994 burn test of a Bradley Fighting Vehicle (BFV) equipped with TOW anti-tank missiles and 1,125 M919 25mm cartridges. This was the first time that a vehicle with a full combat load of DU munitions was actually used in a burn test. Most of the previous data for fires were generated from stack testing wooden or metal shipping crates. The BFV was completely engulfed by the fire and burned vigorously for about an hour. The fire subsided after an hour, but continued to emit a plume over the next five hours with smoldering hot spots into the next day.[293] Of the 1,125 DU penetrators, 625 were accounted for, including nine live rounds found within a few meters of the test pad. Although 500 rounds were unaccounted for, the report indicated that a large percentage was trapped within the melted remains and a significant amount

[292] Draft Depleted Uranium (DU) Hard Impact Aerosolization Test Summary Report (Source Term and Resuspension Estimates), EAI Report A010/96/001D1, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, October 1996.
[293] M.A. Parkhurst, M.H. Smith, and J Mishima, Bradley Fighting Vehicle Burn Test. Final Draft Report, Richland, WA: Battelle Pacific Northwest Laboratory, October 1997, p. 6.1.

of the DU oxide was mixed within the ash and settled inside and around the hull of the vehicle. Six piles of DU oxide were detected on the vehicle surface after the fire. Analysis of the DU oxide indicated that approximately 33% of the oxide particulates were respirable. However, only trace amounts of DU oxide were detected on the air monitoring filters at various distances during the 29 hours of air sampling.[294] Although the higher percentage of respirable particulates (33%) measured in the piles of DU oxide after the fire is an important consideration for assessing resuspension potential during recovery, however, further research is needed to determine whether the higher values of respirable particulates were unique to this test or if results are truly valid for vehicle fires involving DU munitions.

[294] M.A. Parkhurst, M.H. Smith, and J Mishima, Bradley Fighting Vehicle Burn Test. Final Draft Report, Richland, WA: Battelle Pacific Northwest Laboratory, October 1997, p. 6.1-6.5.

Tab N – Summary of Health Estimates

Health risk assessments for 13 identified exposure events are being prepared that describe the activities of the participants, specify the sources of potential DU exposure, and estimate the dose from inhalation, ingestion and wound contamination, as appropriate for each exposure category. The US Army Center for Health Promotion and Preventive Medicine (CHPPM) is conducting these exposure assessments. These assessments will incorporate information from a RAND Corporation review of the current understanding of health effects associated with DU. These will be described in plain language by CHPPM. Most of the health risk-related studies are currently in progress.

This tab summarizes the exposure assessment information prepared by CHPPM for the Level I participants inside combat vehicles as they were struck by DU. Activities of these participants are described, hazards assessed, and exposure assessment (chemical and radiological) and dose response information is reviewed, along with a summary of the risk characterization reflecting the current body of knowledge.

LEVEL I

Level I soldiers, injured or not, were in or around combat vehicles at the time they were struck by DU sabots, or immediately afterward. Besides the embedded fragments from wounds, these individuals may have inhaled DU aerosols generated by fires or by the impact of the DU projectile penetrating the target. The following discussion briefly summarizes the activities of Level I participants and provides pertinent details such as types of vehicles involved and the circumstances under which they were mistakenly targeted by US tank crews. For a more in-depth discussion of the incidents described, please see TAB H.

Level I participants are separated into two categories: soldiers who were in or on combat vehicles at the time they were struck by DU rounds; and soldiers who entered those vehicles immediately afterwards to rescue wounded comrades. The former group is currently believed to have incurred the highest risk from embedded DU fragments and/or inhalation of the DU aerosols resulting from penetrator impact.

1. Occupants of Vehicles When Struck

a) Summary of Activities

Armor crewmen and the "dismounted" infantry transported in M2/M3 Bradley Fighting Vehicles supplied the offensive striking power for Operation Desert Storm. The highly mechanized US armored and mechanized infantry units counted on the speed, mobility, and firepower of their Bradleys and Abrams to maintain a rapid rate of advance while engaging and neutralizing enemy formations who tried to block Coalition troops from achieving their objectives.

b) Hazard Identification:

The activities of Level I vehicle occupants indicate that the combinations of personnel location, form of contamination, and route of exposure shown in Table 8 were possible. Additional details of the scenarios and assessments will be contained in the CHPPM risk assessment paper when published. Members of this group were potentially exposed through all possible routes of entry, including wounds.

Table 8 - Potential Hazards to Occupants of Struck Vehicles.

Location	DU Form	Route of Exposure
Inside Vehicle	Metal Fragment	Wound
	Soluble and Insoluble oxides	Inhalation
		Ingestion
		Wound Contamination

Occupants of the vehicles were subjected to wounds from flying fragments, inhalation of airborne soluble and insoluble DU aerosols, ingestion of soluble and insoluble DU residues by hand-to-mouth transfer, and contamination of wounds by contact with contaminated clothing and vehicle interiors.

c) Dose Assessment

Soldiers in or on vehicles struck by DU munitions were possibly exposed through four routes: direct wounding, inhalation, ingestion, and contamination of wounds. Individuals with direct wounds who retained fragments of DU are currently being evaluated in the DU Follow-up Program. The remaining participants in this category could have been exposed to inhalation, ingestion, and wound contamination whether DU penetrated the crew compartment or not.

Many variables must be considered when estimating the dose received by these individuals. A basic approach, however, involves consideration of test data produced under conditions similar to the scenarios being evaluated. For Level I participants, USACHPPM reviewed over 80 published reports. The characteristics of DU oxide particles, such as chemical composition, particle size, isotopic composition, equilibrium of progeny, and solubility in lung fluid, were identified and considered. These show:

- That fires produce DU oxides that are mostly insoluble;
- That DU impacts on armor produce oxides that are somewhat more soluble; and
- That monitoring data from tests may be used when conditions of the test are the same as the conditions of the case being evaluated.

CHPPM's preliminary review of the test data allowed estimates of the airborne DU inside heavy armor M1A1 tanks to be determined for three scenarios: 1) the upper bound (worst case) (maximum air sample observed) exposure when one DU penetrator enters the crew compartment of a heavy armor M1A1, 2) the most likely (average air sample observed) exposure when one DU penetrator enters the crew compartment of a heavy armor M1A1, and 3) the average (most likely) exposure when one DU penetrator strikes a heavy armor M1A1 but does not enter the crew compartment.[295] Using the test data for DU penetrators impacting on DU armor is considered to be a conservative approach because no penetrations of DU armor were noted for the friendly fire incidents during the Gulf War. However, in several cases, non-DU armor was penetrated by more than one DU round. Since Bradley Fighting Vehicles have much lighter armor than Abrams tanks, penetrations by DU normally produce less aerosol. However, there is not enough data at this point to provide a reliable estimate for Bradley penetrations. Therefore, the data for single and multiple penetrations of an Abrams Heavy Armor tank are considered to represent a worst case.

A review of the test data shows that concentrations of DU in the air under the two scenarios for the DU penetrator entering the crew compartment, with an estimated stay time of 15 minutes and standard breathing rates, yield an estimated maximum intake of 26 milligrams (mg) of DU and an average intake of 12 mg from a single DU penetrator hit. When the DU penetrator did not penetrate the crew compartment the intake was 0.042 mg or 42 micrograms (μg) or almost a thousand times less than when the penetrator enters the crew compartment.

The medical significance of these exposures is discussed below under dose response and risk characterization. It is important to realize that these estimated intakes of 26 mg, 12 mg, and 0.042 mg are for total DU oxide. If the intakes are then converted to radiation doses using the Lung Dose Evaluation Program (LUDEP), a lung dosimetry computer modeling program, CHPPM's estimate of the radiation doses were 0.48 rem (maximum), and 0.23 rem (average) when the penetrator entered the crew compartment; and 0.0005 rem when there was no entry of the crew compartment. For two hits, the intakes were doubled to 52 mg, 24 mg, and 0.084 mg, respectively, which produced radiation doses of 0.96 rem, 0.46 rem, and 0.001 rem.

To evaluate the heavy metal dose, the total DU oxide was divided between soluble and insoluble components. Based on the results of the solubility analysis of the DU oxide (83% insoluble and 17% Class D soluble), CHPPM's estimate of the intake values for a single DU penetrator hit were 22 mg insoluble/4 mg soluble, 10 mg insoluble/2 mg soluble, and 0.035 mg insoluble/0.007 mg soluble for the three cases.[296]

For the ingestion route of exposure for individuals who were in the vehicle when a single DU penetrator entered the crew compartment, intake by hand-to-mouth transfer was estimated to be 16 milligrams of DU based on measured surface contamination levels, estimates of the hand to mouth transfer factors, and the assumption that 83% of the intake was of the insoluble "Y class"

[295] Fliszar, Richard W., Edward F. Wilsey, and Ernest W. Bloore. Radiological Contamination from Impacted Abrams Heavy Armor, Technical Report BRL-TR-3068, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1989.

[296] Memorandum for the Office of the Special Assistant Secretary for Gulf War Illnesses, Subject: Program Summary, USACHPPM Assistance with OSAGWI's Depleted Uranium (DU) Environmental Exposure Report, August 3, 1998.

and 17% of the intake was of the soluble "D class". This intake results in an estimated radiation dose equivalent of 0.000002 rem. For two hits, the intake and associated radiation dose are 32 mg and 0.000004 rem.

Estimates of the intakes from DU contamination of wounds are continuing. This is primarily caused by the gaps in the available data on transfer of contamination from surfaces to wounds. Estimates of the intakes from this route are expected to be included in a follow-up version of this report.

d) Dose Response

The medical effects literature on depleted uranium was reviewed by RAND and will be discussed in their forthcoming report. Their preliminary review indicates that for the level of radiation exposure from depleted uranium in the Gulf War cancer and genetic effects are the main concern. Scientific studies have shown that these effects occur with a total incidence of 7.3×10^{-4} per rem.[297]

e) Risk Characterization

1) Radiation risk.

The exposure for Level I individuals (excluding those with embedded DU fragments) inside an Abrams M1A1 tank when a DU penetrator enters the crew compartment, is conservatively estimated to be 0.48 rem for a 15 minute exposure from a singe DU penetrator or 0.96 rem from two DU penetrators. Using the dose response factor of 7.3×10^{-4} per rem, the combined risk for all fatal cancers, non-fatal cancers, and genetic effects is 0.0007 (which is determined by multiplying 7.3×10^{-4} medical effects per rem by 0.96 rem = .0007). This should be considered an upper limit for the worst case involving two DU penetrators. This estimate is preliminary and will be refined as more data become available.

For comparison, the average radiation exposure to a member of the US population from background radiation is 0.3 rem per year.[298] So this maximum estimated exposure of 0.96 rem is about the same as living in the United States for about three years and is less than one-fifth of the annual limit for workers of 5 rems.

When the crew compartment was not penetrated, the estimated dose (0.001 rem) is much smaller; the same as the radiation exposure from one day of background radiation.

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[297] Memorandum for the Office of the Special Assistant Secretary for Gulf War Illnesses, Subject: Program Summary, USACHPPM Assistance with OSAGWI's Depleted Uranium (DU) Environmental Exposure Report, August 3, 1998.

[298] Exposure of the Population of the United States and Canada from Natural Background Radiation, Report No. 94, NCRP (National Council on Radiation Protection and Measurements), Bethesda, MD, 1987.

Another way to describe the effects on health is by calculating a person's increased probability of experiencing the effects (dying from cancer, contracting other cancer, or producing genetic effects in future generations). For the maximum case above, the probability is 0.0007. This means that the exposed person would experience an increased chance of 1 in 1,427 of experiencing the effect.[299] For comparison, the chance of dying from **all** causes of cancer during his or her lifetime is 23% (1 in 4.3); or about 300 times higher than the highest estimated risk from DU. Therefore, assuming the cancer risks were cumulative, the lifetime cancer risk for personnel inside the tanks at impact would increase from 23% to 23.07%. This is for the worst case example of two DU munitions penetrating a DU armored tank creating maximum aerosolization of the DU penetrator. The quantity of DU aerosols generated by impact on non-heavy armor tanks and lightly armored Bradley Fighting Vehicles would be less. Therefore, the increased lifetime cancer risk of 1 chance in 1,427 would also be worst case when compared to the actual exposures in the friendly fire incidents encountered in the Gulf War.

2) Chemical risk.

The chemical exposure for Level I individuals inside an Abrams M1A1 tank when two DU penetrators entered the crew compartment is conservatively estimated to be 52 mg intake of DU particles for a 15 minute exposure. The 52 mg intake contains about 9 mg of soluble DU based on test data indicating that up to about 17% of the airborne DU produced from impacts is soluble (ICRP Class D). For individuals who were in the vehicle when the DU penetrator did not enter the crew compartment, intakes of soluble DU are calculated to be much less, in the microgram range (14 μg).[300]

A comparison of the risks from radiation with the possible kidney effects of soluble uranium illustrates that heavy metal toxicity effects predominate over the radiological concerns.

3) Additional Comment

The risk estimates discussed above are for soldiers who could have inhaled soluble and insoluble DU produced when a heavy armor M1A1 is struck in its DU armor by two 120 mm DU penetrators. This scenario is believed to produce the highest exposure for a single event. That belief is based on the following considerations:

- There were no penetrations of the DU armor during any of the friendly fire incidents. Most of the damage to Abrams occurred by strikes in the rear of the vehicle which did not penetrate the crew compartment;

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[299] Memorandum for the Office of the Special Assistant Secretary for Gulf War Illnesses, Subject: Program Summary, USACHPPM Assistance with OSAGWI's Depleted Uranium (DU) Environmental Exposure Report, August 3, 1998.

[300] Memorandum for the Office of the Special Assistant Secretary for Gulf War Illnesses, Subject: Program Summary, USACHPPM Assistance with OSAGWI's Depleted Uranium (DU) Environmental Exposure Report, August 3, 1998.

- Impacts on Bradleys are believed to produce far smaller concentrations of airborne DU because their armor is much thinner than that of the Abrams, and is constructed of an aluminum composite;
- Data on airborne concentrations produced by DU penetrations of Bradley vehicles to include particle size distribution, elemental composition, and solubility of DU residues in simulated lung fluid;
- Refined assessments of the resuspension of DU residues inside and outside Abrams and Bradley vehicles to include particle size distribution, elemental composition, surface contamination levels (internal and external to the vehicle) and solubility of DU residues in simulated lung fluid;
- Adherence of airborne DU particulate materials to oily surfaces; and
- Adherence of airborne DU particulate materials to inorganic and organic compounds produced from target penetration and combustion.

Additional work is required to refine the following parameters as well as others that may be identified as the analysis proceeds:

- Data on airborne concentrations and particle size distribution of DU inside and outside armored vehicles;
- Data on airborne concentrations produced by DU penetrations of Bradley vehicles;
- Refined assessments of the resuspension of DU residues inside and outside Abrams and Bradley vehicles;
- Assessment of the Abrams NBC system and fire suppression system on the airborne DU concentrations;
- Additional data and refined assessments of the transfer of contamination by hands to the mouth, and from contaminated surfaces to wounds;
- Assessment of the Bradley's fire suppression system on the characteristics of DU airborne concentrations to include particle size distribution, elemental composition, and solubility of DU residues in simulated lung fluid;
- Assessment of the Abrams EC/NBC (Environmental Control/Nuclear Biological and Chemical) system and fire suppression system on the characteristics of DU airborne concentrations to include particle size distribution, elemental composition, and solubility of DU residues in simulated lung fluid.

Tab O - Guidance for Protecting Troops

The test and evaluation programs that paved the way for the fielding of DU munitions and armor acknowledged their potential for creating battlefield DU contamination. The Department of Defense (DoD) and the Services recognized the need to protect troops who might have to operate in such environments. Unfortunately, most of the guidance issued before and during the war was oriented toward peacetime accidents on US military installations, rather than addressing the very different demands of wartime/contingency operations. A number of memorandums and advisories containing simple, field expedient precautions and advice were sent to the theater, but often failed to reach units and troops who had to respond to accidents and events involving DU contamination.

The storage, handling and distribution of DU munitions and armor are governed by stringent guidelines based on Nuclear Regulatory Commission (NRC) licensing requirements. The Army used this guidance as the basis for developing procedures to respond to accidents such as tank fires or ammunition explosions where DU could be released into the environment. As such, the regulatory guidance was extremely restrictive, and in some respects poorly suited for operational deployments. Unfortunately, alternative guidance addressing battlefield requirements, and offering effective, field-expedient protective measures, was not widely disseminated during Operations Desert Shield/Desert Storm. Instead, the available, peacetime guidance was applied. The primary source of this guidance was TB 9-1300-278, which, as will be explained, mandated procedures that in a wartime context were often disproportionate to the actual hazard, or impractical.

1. Technical Bulletin 9-1300-278

Technical Bulletin (TB) 9-1300-278, *Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium,* was the Army's operative guidance for responding to incidents resulting in the localized release of DU. Dated November 20, 1987, it was revised in September 1990—in time for the Gulf War—and again in July 1996.

TB 9-1300-278 outlines procedures for responding to, and controlling the hazards resulting from, accidents and incidents involving DU. In addition to addressing the radiological and chemical toxicity hazard and contamination control, the guidelines also cover explosive and fire hazards, which are usually present as well. The TB was written to satisfy NRC licensing requirements. The NRC's requirements relate to protection of workers and the public from radiation during peacetime operations. Contamination levels are derived from "NRC Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material." These guidelines set limits for returning formerly contaminated facilities (buildings, shops, etc.) to unrestricted use by members of the public. Similar limits have been adopted by the Department of Energy, in its Radiological Control Manual,[301] and by other agencies

The Technical Bulletin instructs crews, explosive ordnance disposal (EOD), and radiation protection and firefighter personnel on how to deal with tank fires involving DU munitions and armor in peacetime. The guidelines are intended to provide maximum safety while protecting life and property. Examples of the guidelines (with OSAGWI comments in italics) include:

- Personnel should remain upwind, if possible, and a safety perimeter of at least 1,200 feet should be established and maintained around the involved vehicles and munitions to control access. *These are standard initial actions for any incident involving explosion hazards, regardless of whether or not DU is involved.*
- The ground around the tank should be surveyed and decontaminated as needed. Any openings in the tank (hatches or penetrations) should be sealed to prevent the spread of DU contaminants inside the hull. No attempt should be made to decontaminate the interior of the tank at the site of the accident. After the tank is removed, the surface underneath it should be surveyed and decontaminated. *These guidelines are intended to control and contain the contamination with minimal exposure and to make sure surrounding surfaces are returned to their pre-accident state as a matter of prudence.*
- Only EOD personnel should enter the tank to ensure that no explosive hazard is present. *EOD personnel are the only ones qualified to handle explosive hazards, e.g. rounds remaining from on-board ammunition stores.*
- EOD should be dressed in protective coveralls, gloves, rubberized boots and protective mask (i.e. Mission Oriented Protective Posture [MOPP] Level 4), with all exposed openings taped. *EOD troops, like all US troops in the Gulf Theater, deployed with MOPP 4 gear, making it the logical choice for personal protection. EOD troops, who were trained to operate in a DU-contaminated environment, generally chose not to follow these guidelines.*

These and other AMCCOM guidelines serve several purposes:

- Satisfy NRC license requirements.
- Protect the public from radiological exposure in keeping with ALARA.
- Make sure any incident is properly assessed, controlled, and cleaned up
- Protection of soldiers from radiological exposure in keeping with ALARA.

Many personnel whose missions required them to operate around DU-contamination, including at least one in-Theater Health Physicist with an active radiation control role, were not aware of the specific contents of TB 9-1300-278, or even of its existence.[302] In addition, a 1993 General Accounting Office (GAO) report found that TB 9-1300-278 was not widely available in

[301] Radiological Control Manual, Department of Energy, DOE/EH-0256T Revision 1, US Department of Energy, Washington, DC, April 1994, p.2-12.
[302] Lead Sheet # 15854, Interview of former Army Health Physicist, April 6, 1998, p. 2.

late 1990 or 1991.[303] However, according to a former US Army major serving with the US Army Armament, Munitions, and Chemical Command (AMCCOM) at King Khalid Military City (KKMC) the manual was available at the time of the December 1990, tank fire in Saudi Arabia.[304] In any event, the guidelines contained in TB 9-1300-278 were largely unknown outside a few specialized teams (RADCON responders, Battle Damage Assessment Teams) deployed to the Gulf.

The DoD has acknowledged that pre-war DU awareness training was inadequate. Abrams crewmen received a brief block of training on the peacetime, regulatory requirements for handling DU munitions. More extensive training was provided to Nuclear-Biological-Chemical (NBC) response personnel assigned to most units, as well as EOD, RADCON, and safety personnel.[305] In general, this information was not shared outside these units or agencies. The lack of DU awareness was identified as a deficiency, as evidenced by a May 24, 1991, Memorandum from AMCCOM to TRADOC (Training and Doctrine Command) recommending that DU safety training be given to all armor and infantry soldiers and officers who required it.[306]

2. Other Warnings and Advisories

Before, during, and after the ground campaign, AMCCOM and other agencies issued warnings and advisories regarding specific measures to minimize exposures to DU. Too often, this information failed to reach commanders, officers, NCOs, and soldiers at the unit level. Many veterans have reported that they were completely unaware of DU, its properties, and safeguards and precautions to take against DU exposure.

Examples of supplemental guidance issued in support of the Gulf deployment include:

- A February 1991 message to Army Central Command (ARCENT) described proper procedures for the segregation and safe handling of tanks posing a radiological hazard after their DU armor or munitions were involved in a fire. These precautions were primarily designed to satisfy stringent NRC requirements for handling and disposal of DU-contaminated materials by civilian workers and facilities in a peacetime environment. Each unit was responsible for segregating equipment presenting a radiological risk. Contaminated equipment was to be inspected, encapsulated, and tagged prior to shipment back to the US to satisfy the requirements of peacetime radioactive material control. Access

[303] Operation Desert Storm - Army Not Adequately Prepared to Deal With Depleted Uranium Contamination, GAO/NSIAD-93-90. Washington, DC: United States General Accounting Office, Report to the Chairman, Subcommittee on Regulation, Business Opportunities, and Energy, Committee on Small Business, House of Representatives, January 1993, p. 35.
[304] Lead Sheet # 5680, Interview of US Army Major who was AMCCOM Operations Officer at KKMC during the Gulf War, August 1, 1997.
[305] Operation Desert Storm - Army Not Adequately Prepared to Deal With Depleted Uranium Contamination, GAO/NSIAD-93-90. Washington, DC: United States General Accounting Office, Report to the Chairman, Subcommittee on Regulation, Business Opportunities, and Energy, Committee on Small Business, House of Representatives, January 1993, p. 34.
[306] Memorandum from AMCCOM to TRADOC, Subject: Depleted Uranium (DU) Contamination, May 24, 1991.

to the contaminated equipment was to be limited to contain the spread of contamination beyond the damaged tank.[307]

- A March 3, 1991 memorandum to theater recommended that clothing and gloves worn inside contaminated systems be left inside the system upon exiting, and that hands be washed. It also advised against eating or smoking inside a contaminated system to decrease the probability of ingesting DU.[308] Later that month, a message was sent to the Gulf advising that "any system struck by a DU penetrator can be assumed to be contaminated with DU."[309]

- As late as April 7, 1991, the AMCCOM team at KKMC requested advice from its higher headquarters on examination and monitoring requirements for crewmembers of vehicles hit by DU penetrators.[310] This advice came in the form of an April 11, 1991, memorandum, which states that the local Radiation Protection Officer (RPO) or medical authority has the responsibility to determine if, and when, a medical exam or bioassay is required. This same memorandum states that "in the event that a vehicle is hit by a DU penetrator the likelihood that a crew member would receive an excessive dose of radiation is minimal." It goes on to say that, in the case of a tank fire or DU penetration, the crews would be expected to have abandoned the vehicles before receiving an excessive dose.[311]

These messages were aimed at ensuring adherence to the ALARA principle to minimize potential exposures. Some guidance given to selected groups was less restrictive. The Battle Damage Assessment Team (BDAT), tasked with evaluating destroyed US combat vehicles, were instructed to wear anti-contamination suits (cotton overgarments) and dust masks.[312] This protective posture was the same as that used by range personnel at Aberdeen Test Center, where several of the BDAT members worked prior to the war. This locally developed guidance applies to range workers who work with hard target impact testing, and has been validated by years of medical surveillance on the range workers, to include annual lung scans.[313]

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[307] Message from CDRTACOM in Warren, MI. to J4, ARCENT HQ, Subject: "Field Processing of Tanks Contaminated With Depleted Uranium (DU)," February 1991.
[308] Memorandum from AMCCOM (Army Munitions and Chemical Command), Subject: Tanks and Armored Vehicles Contaminated With Depleted Uranium (DU), March 3, 1991.
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[312] Lead Sheet #15330, Interview of a Major in the Battle Damage Assessment Team, March 5, 1998, p. 2.
[313] Lead Sheet #16157, Interview of the Chief of the Safety Division, Army Test and Evaluation Command, April 22, 1998.

3. Apparent Contradictions between Guidance and Wartime Practices.

A comparison of the guidelines outlined in TB 9-1300-278 and actual practices followed during the Gulf War invites criticisms that the Services disregarded regulatory guidance put in place to protect human health and ensure the proper handling of battlefield contamination. While the perception is understandable, the reality is more complex.

Shortcomings in pre-war training and awareness of DU were not effectively remedied by supplemental guidance—mainly warning messages and advisories—that in many cases did not reach tactical units. At the same time, a review of the operative guidance in force at the time of the Gulf War indicates that much of this guidance was in fact excessive and impractical in an operational setting. In particular, the emphasis on donning the MOPP 4 chemical warfare ensemble before working in or near DU-contaminated equipment deserves examination.

MOPP 4 is explicitly associated in most soldiers' minds with protection from Nuclear- Biological -Chemical hazards. "Nuclear" in this sense means fall-out from tactical nuclear detonations, which produce high-order concentrations of primarily gamma radiation, as opposed to DU, which produces mainly alpha particles which are too weak to penetrate the outer layer of skin.

Biological and chemical agents can take the form of gases, vapors, or liquids, necessitating the features found in MOPP 4 gear, i.e.: gas mask with protective hood, charcoal-filled overgarments, and rubber "booties" and gloves. DU, on the other hand, poses a credible hazard only when its oxides, residues, or fragments are internalized in the body via inhalation, ingestion, imbedding, or wound contamination, in sufficient quantity.

Exposure hazards, no matter how slight, require suitable protection under ALARA. The level of protection afforded by MOPP 4 was excessive, in the view of many experts. However, it was mandated largely because every soldier deployed to the Gulf had MOPP 4 gear and knew how to use it. Hence it was a viable, field-expedient means by which to prevent exposures. In addition, suitable alternatives such as dust masks were often unavailable through normal supply channels.

Another potential inconsistency was the precautions taken by the Radiation Control (RADCON) personnel deployed to the Gulf. Unlike ordinary troops, these personnel were specifically trained and equipped to respond to DU contamination. However, they often elected to work on contaminated systems without such TB 9-1300-278-recommended protection as respirators or dust masks. The reason for this is simple: In their professional judgement, the radiological and chemical toxicity hazard was too low, in these instances, to warrant the wear of respirators or dust masks. This subjective judgement may seem at odds with existing guidance, but the reader should be reminded that guidance is just that—and the RADCON experts felt that they had the experience and expertise to determine the appropriate level of protection.

In short, the operative guidance available at the time of the Gulf War, based on peacetime regulatory requirements, set protection levels that proved to be disproportionate to the actual hazard. Unfortunately, formal guidance that would have satisfied regulatory requirements while more definitively addressing actual requirements had not been developed. Although supplemental guidance was developed and sent to the theater, it was not widely disseminated outside the very small community (mainly RADCON experts) with a specific DU-related mission. Among tactical units, awareness of DU's characteristics and its potential hazard remained very low, in general. In consequence, many personnel were needlessly exposed to DU during clean up and recovery actions, or other activities.

The deficiencies in Gulf War guidance have been recognized by the Army, which has taken steps to remedy the situation. A meeting was conducted in April 1998 to discuss organizational roles and responsibilities relative to low level radioactive hazards in operational settings. An Integration Process Team (IPT) was formed to review low-level radiation as well as nuclear, biological, and chemical hazards, and associated environmental issues. At the soldier level, the Army has developed a new common training task "Respond to Depleted Uranium /Low-Level Radioactive Materials (DULLRAM) Hazards".

The DULLRAM training task, due to commence in FY99, should produce a dramatic, sustained improvement in troop awareness of DU. It addresses two primary concerns associated with earlier guidance:1) It protects health while recognizing the utility of field-expedient protective measures, and 2) While Gulf War-era guidance was not widely available or circulated outside of the small, specialized units with a radiation control or health physics role, the DULLRAM lesson plan will be universal. Every soldier will receive this training during their initial Army training, with refresher or periodic training held over the course of their military service.

Regarding the first point, the training task offers practical, field-expedient measures to protect soldiers from exposures without imposing excessive personal protection requirements. In contrast to earlier guidance, it advises soldiers to only use protective masks if working in an area where there is heavy smoke from burning vehicles or the dust plume from the impact has not settled.

The DULLRAM is a simple, uniform, and effective lesson plan that explains:

- Identified possible hazards (conditions under which DU contamination might be encountered)
- Assumed field expedient respiratory protection (cravat/handkerchief) or donning a protective mask (gas mask) as appropriate
- Warning others of the DU hazard
- Protection from contact with DU
- Reporting suspected DU contamination to supervisors/superiors.[314]

[314] US Army Common Task 031-503-1017, "Respond to Depleted Uranium/Low Level Radioactive Materials (DULLRAM) Hazards", July 1998.

The DULLRAM task lesson plan and training requirement will impress on ordinary soldiers, as well as supervisors and leaders, the importance of recognizing DU contamination as a battlefield hazard, and responding appropriately.

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