IV. POTENTIAL HEALTH EFFECTS FROM DU USE IN THE GULF THEATER, 1990-1991

The Gulf War exposed personnel to DU in different ways (see Table 1). US tanks firing DU sabot rounds mistakenly destroyed or damaged occupied and unoccupied US combat vehicles. 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 burned, oxidized, or fragmented DU rounds, which created potential exposures to personnel operating in the vicinity. Other US personnel entered DU-disabled enemy armor or passed near vehicles set on fire by DU rounds.

Promptly evaluating these kinds of exposures usually provides the most meaningful assessment of medical condition, especially if the evaluations measure exposure and dose. Unfortunately, most Gulf War participants were not tested for DU promptly after the operation ended. Testing began in 1993 for some friendly-fire victims wounded with DU. In 1997, this office began a thorough, focused investigation by reviewing hundreds of eyewitness interviews and thousands of pages of official and unofficial documents, records, reports, memos, personal diaries, and photographs to determine the essential facts of each event. Initial results of the investigation revealed that potential exposures could be classified into three levels of possible risk for 13 categories of exposure scenario. (Tab G describes the levels and scenarios in detail.) On January 30, 1998 we asked the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) to produce risk estimates for all 13 identified categories.

USACHPPM's assessments describe the participants' activities, specify the sources of potential DU exposure, and estimate the inhalation, ingestion, and wound contamination dose as appropriate for each category. They also review the current understanding of DU's health effects and describe the possible health risks. In performing its analysis, USACHPPM considered these sources of DU exposure:

- airborne DU from 120mm munitions penetrating Abrams tanks and Bradley Fighting Vehicles;
- residues inside those DU-contaminated vehicles, including both DU-penetrated and burned-out vehicles with onboard munitions, resuspended (stirred up) by personnel entering and working;
- DU on the ground resuspended by vehicle and personnel traffic; and
- DU in smoke from burning vehicles and munitions.
- DU residues inside and outside contaminated vehicles that personnel could ingest or transfer to wounds.

A. Summary of Dose and Risk Assessment Methods

Chemical intakes and radiation doses from DU entering the body cannot be easily measured directly. Bioassay methods, such as measuring uranium in urine or inhaled air, reasonably estimate doses. Except for several servicemembers who unloaded munitions from a tank after a fire had "cooked off" its rounds, DoD did not promptly measure DU intakes or doses. So initial exposure estimates and risk assessments relied on the next best method -- estimating the dose and risk derived from scientific principles and data measured under conditions similar to those in the Gulf War.

USACHPPM assessed Gulf War DU exposures by estimating chemical intakes and radiation doses for very conservative, computer-modeled scenarios representing Gulf War exposure events, such as from the Level I incident involving two DU rounds that penetrated one non-HA Abrams' crew compartment. USACHPPM based its assessments on DU exposure information derived from data collected during a developmental test series in which a purposefully overmatched 120mm DU round penetrated an Abrams "Heavy Armor" (HA) tank's DU armor panels. Lacking test data for two penetrations of DU armor, USACHPPM adjusted the chemical intakes and radiation dose from a single DU round penetrating DU armor to extrapolate values for two penetrating DU rounds. Such a "DU-on-DU" penetration would produce amounts of DU aerosols and spatters of liquefied metal exceeding those that actually occurred during the Gulf War (since none of the DU armor panels on Abrams heavy armor tanks was actually penetrated),[79] and therefore result in higher estimates of crew DU intakes than actually occurred in the Gulf. USACHPPM developed Level II and Level III estimates using test data appropriate for the scenarios under study.[80]

USACHPPM's effort applied DU exposure information to estimate the DU intake and radiation dose by considering:

- the routes of entry into the body for DU;
- DU's behavior inside the body;
- calculation of DU concentration and radiation dose to internal organs; and
- characterization of the health effects.

Tab O discusses the intake and dose assessment process in more detail.

This investigation considered the ways DU could enter the human body. The VA medical follow-up program is evaluating veterans wounded by DU fragments -- a principal route of entry. USACHPPM was not asked to estimate intakes or radiation doses for these individuals. In the remaining Gulf War DU scenarios, the common routes of entry were inhalation, ingestion, and wound contact. Of the three routes, inhalation exposure produced the most concern in each Gulf War scenario evaluated in this report, except for individuals with DU fragments, because few soldiers had wound contact and direct ingestion is normally a minor source. USACHPPM estimated the quantity of material that could enter the body based on the expected air concentrations and surface contamination levels, the exposure duration, and factors for transferring DU from a contaminated surface to the hands and then to the mouth or a wound.

DU entering the body (called intake) through the nose or mouth can be exhaled, remain in the lungs, or be absorbed into the blood from the lungs or gastrointestinal tract. Once absorbed, DU can travel to organs (such as the kidneys or bones), or be excreted in urine or cleared through the gastrointestinal tract. DU is absorbed into the blood over time depending on the DU compound's ability to dissolve in bodily fluids or transfer across the pulmonary and gastrointestinal membranes. For example, soluble DU particles deposited in the lungs usually dissolve and the DU moves into the blood within days or weeks, while the insoluble particles tend to remain in the lungs or lymph nodes for months or years. Once absorbed into the blood stream, DU can be excreted in the urine or move to other organs where it accumulates. While in those organs, DU may cause effects if the uranium concentration or radiation dose is large enough. Bodily processes cause the blood to reabsorb DU from the organs to start the process over.

The body excretes DU through the kidneys in urine at a rate depending on the solubility of the DU material deposited in the body. The more soluble the material, the faster it enters the blood, is processed by the body, and excreted. Insoluble DU deposited in the lungs moves very slowly into the blood, taking about 7,000 days for 99.9 percent to transfer to the blood.[81]

Scientists understand DU's behavior in the body and have developed mathematical models that allow estimates of the amount of DU in various organs and the amount excreted in urine. USACHPPM applied these models describing DU's respiratory tract, gastrointestinal, systemic, and excretion and retention behavior to calculate DU's distribution throughout the body and concentrations in various organs.

USACHPPM assumed all the uranium passing through the kidneys arrives at the same time, producing a very conservative estimate of peak concentration. Estimates of radiation dose, as committed effective dose equivalent (CEDE), required additional calculations to convert organ concentrations into lifetime dose.

USACHPPM used the latest recommendations of the International Commission on Radiological Protection for models of the human respiratory tract for estimating intakes and radiation dose. This model handles all forms of uranium, including the so-called "ceramic" forms produced by oxidizing uranium and exposing it to high temperatures. The ICRP model includes "Type S" materials, which show very little absorption of uranium and may take almost 20 years to completely clear the lungs and enter the blood.[82] DoD's risk assessments properly accounted for the complex behavior of uranium entering the blood and considered the best available science about this behavior. (Tab O fully discusses USACHPPM results.)

Finally, scientists estimated the potential for health effects from the chemical toxicity and radiation exposure. Section III discussed several regulatory limits and guidelines for radiation and chemical toxicity (summarized in Tab O, Section B.6.). These limits and guidelines are, of course, not absolutes: that is, the 0.1 rem limit for the public doesn't mean a dose of 0.09 rem is good and there will be no effects or that a dose 0.101 rem is bad and effects will definitely occur. The limits and guidelines are meant only to provide practical, scientifically accepted limits for risk management and regulation. By comparing estimated doses to these guidelines and considering DU toxicological studies, USACHPPM health experts were able to assess the expected health outcomes from Gulf War DU exposures. All four steps used the accumulated knowledge in handling uranium safely over the past 50 years.

B. Level I Exposures (Friendly Fire)

Level I soldiers were exposed to DU when fragments from penetrating DU rounds embedded in their bodies or when they inhaled DU aerosols generated by the impact of a DU projectile penetrating a target. These soldiers were in or on 6 Abrams tanks and 14 Bradley Fighting Vehicles at the time or immediately after DU rounds struck them. Some soldiers entered vehicles immediately after the attack to assist or rescue fellow soldiers. (Tab G contains details of vehicles struck by DU rounds and the friendly-fire incident summaries in Tab H provide additional details of the Level I soldiers' circumstances. Tab H also presents an account of a 15th Bradley, not included above because it was unoccupied when it was struck.)

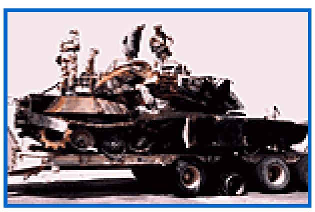

Figure 6. M1A1 tank lost to friendly fire

A depleted uranium strike on an Abrams exterior differs from one on a Bradley. The Abrams Heavy Armor version has thicker armor -- reinforced at the front of the turret by DU panels inserted between regular steel armor -- that resists the striking DU round much more than does the Bradley's thinner, lighter-weight, aluminum-alloy skin. Consequently, DU aerosolization and fragmentation at the Abrams' penetration and exit points and in the interior are greater. By contrast, the Bradley is less vulnerable to interior contamination because DU penetrators typically punch right through the Bradley's relatively thin armor, producing little DU aerosol.[83] During one battle, a DU round penetrated one Bradley and struck a second Bradley standing 20 feet away.[84] The range of likely exposures from a DU strike, therefore, can span a broad spectrum.

Figure 7. Bradley Fighting Vehicle

USACHPPM estimated a worst-case exposure based on data for a single DU sabot round penetrating the Abrams' DU-protected armor, although such DU-on-DU penetrations did not occur during the Gulf War. USACHPPM then adjusted these estimates to account for instances where two rounds penetrated non-DU Abrams armor.

1. Issues with Level I Assessments

Initial assessments, based on sparse test data for DU behavior inside penetrated vehicles, indicate soldiers inside vehicles when they were struck by DU munitions and those rescuing fellow soldiers in stricken vehicles could have received exposures higher than some guidelines in a limited number of cases involving very conservative scenarios. Depending on the time elapsed since DU impact, rescuers may have avoided the high concentrations of airborne DU produced immediately after a DU impact on heavy armor. Bradley occupants and rescuers would likely experience even lower DU exposures because the amount of DU residues produced by striking the Bradley's thin armor is less than when striking heavily armored vehicles.

USACHPPM used the best air concentration data available, contained in Technical Report BRL-TR-3068, Radiological Contamination from Impacted Abrams Heavy Armor (summarized in Tab L, Report # 27), to estimate the range of DU servicemembers may have internalized during the Gulf War. In its August 1998 interim report,[85] USACHPPM estimated DU inhalation intakes and radiation doses for 15 minutes of exposure inside an Abrams crew compartment penetrated by one DU munition. However, several DU rounds hit Abrams tanks and penetrated the non-DU sections of their armor during two friendly-fire incidents. OSAGWI doubled USACHPPM's 1998 estimates of intake and radiation dose for one round to simulate penetration by two rounds. These calculations produced a conservative upper limit estimate of DU intake (52 milligrams total; 43 milligrams insoluble; 9 milligrams soluble) and dose (CEDE of 0.96 rem) for two penetrations -- as occurred in the Gulf War. We reported those values in the 1998 Interim DU Environmental Exposure Report.

While reviewing our DU Environmental Exposure Report, the General Accounting Office (GAO) questioned the reliability of the data USACHPPM used in its Level I evaluation. USACHPPM reviewed the data, consulted with the test report authors, and revised its initial estimates. Our review of those assessments revealed serious technical problems with the test data, particularly the air sampler run times, which led us to conclude the data would not support reliable estimates. Consequently, in October 1999, the Special Assistant directed the Army to conduct additional testing to strengthen the validity of the health effects assessments. That program, funded in part by this office, conducted the first test firing in November 2000, and is expected to be completed in Fiscal Year 2002.

2. Refinement of Level I Estimates of DU Intake and Radiation Dose

USACHPPM continued its reassessments to try to obtain reasonable estimates. Its September 2000 report contained those reassessments, which reported inadequacies with the air sampling data, primarily related to sampler run-time. They applied various innovative approaches, including probabilistic (statistical modeling) techniques, to estimate a range of possible DU air concentrations, possible DU intakes, radiation doses, and kidney concentrations.[86] USACHPPM based its assessment on two assumptions for calculating the estimates.

- Assumption 1 (representing an upper bound) used the measured surface contamination levels inside the tank to estimate the sampler run-time from the quantity of airborne DU produced and other factors.
- Assumption 2 (representing a lower bound) used a valid air sampler measurement (the sampler ran as expected) of the air concentration in the driver's compartment.

USACHPPM reported these upper limit estimates by tripling the median values from its analysis of one penetration for Level I to account for two penetrations:

- inhalation: 27–237 milligrams intake, 0.51–4.38 micrograms uranium per gram of kidney tissue kidney concentration, and 0.54–4.8 rem radiation dose (CEDE); and
- ingestion: 36-72 milligrams intake, 0.6-1.2 micrograms of uranium per gram of kidney tissue kidney concentration, and 0.0009-0.0018 rem radiation dose (CEDE).[87]

The Special Assistant expects that these estimates of Level I DU intake and radiation dose will be revised using measurements from the tests he has directed.

3. Assessing Possible Health Effects of Refined Level I DU Intake and Radiation Dose Estimates

Comparing the kidney concentrations and radiation doses from inhalation and ingestion to the guidelines discussed in Section III of the main report reveals that only the 4.38 µg of uranium per gram of kidney tissue obtained for two penetrations exceeds the 3 µg of uranium per gram of kidney tissue MPOC guideline. Furthermore, none of the radiation doses (CEDE) exceeds the 5 rem guideline. These values represent very conservative estimates for Gulf War participants because the penetration of DU armor did not actually occur and the amount of aerosol produced in BFVs should be much less. Furthermore, estimates have been tripled to account for two rounds penetrating into the crew compartment, despite there being only two such friendly-fire incidents involving seven survivors.

Despite the concerns about possible temporary and permanent kidney damage from the estimated Level I exposures, to date the Baltimore VA medical monitoring indicates Gulf War veterans have not shown the adverse kidney effects expected from excessive exposures caused by inhalation, ingestion, embedded fragments, or wound contamination. In the Baltimore VA program, the observations of the veterans with no embedded DU fragments show no unusual uranium concentrations in urine. In soldiers with embedded fragments, the urine uranium concentrations are well above normal -- implying the embedded DU fragments are a constant source of DU to the blood and other bodily organs. The 1995 clinical evaluations found no adverse clinical effects from uranium exposure.[88] Additional studies through 1997 found that veterans with fragments continue to excrete elevated concentrations of uranium.[89] The VA reported committed effective dose equivalents to the whole body of about 0.01 to 0.1 rem per year in those veterans with embedded fragments.[90] If these doses remain constant over 50 years, the veteran with the highest urine concentration would receive a cumulative 50-year dose of 5 rem, which is the annual limit for workers and about equal to USACHPPM's September 2000 estimated dose for Level I veterans who inhaled or ingested DU but retain no fragments in their bodies. While the VA noted some subtle variations in the latest medical examinations (which the VA will continue to monitor), the 1997 examinations did not attribute any adverse medical effects to the veterans' DU exposures, other than those arising from their traumatic injuries.

USACHPPM's results also support DoD and VA's decision to expand the medical follow-up program for Level I veterans. The results of this medical monitoring revealed no medical effects associated with DU exposure and no uranium concentrations in urine above the normal range of dietary intakes, except for veterans who were wounded with DU. Although the GAO has raised questions about USACHPPM's initial health risk assessment, the best indicator of the medical significance of the Gulf War DU exposures is the actual health of the individual soldiers. To date the Baltimore VA program has demonstrated that those in vehicles hit by DU munitions during the Gulf War have experienced no adverse clinical outcomes since their initial traumatic injuries. Section V.C. discusses the Baltimore VA program results.

C. Level II Exposures

Once the crews and other injured personnel had been evacuated from the friendly-fire scene, Battle Damage Assessment Teams (BDAT), Explosive Ordnance Disposal (EOD), Radiation Control (RADCON), and salvage and/or maintenance teams converged on the damaged equipment. They removed munitions, personal weapons, and sensitive or salvageable equipment; surveyed the damage and surrounding area; and prepared damaged vehicles for transport to a salvage depot in Saudi Arabia. At the salvage depot, soldiers from the 144th Service and Supply Company, unaware of the potential DU hazard, often worked inside the wrecked vehicles to salvage or prepare them for burial or shipment to the US. (Tab G, Section B.5., discusses low-level waste disposal practices.)

Figure 8. RADCON personnel atop M1A1 tank hulk

EOD and RADCON personnel also played key roles in responding to the post-war Camp Doha motor pool fire, which on July 11, 1991, destroyed three M1A1 tanks loaded with DU rounds and several hundred DU rounds stored nearby. Cleanup efforts in Camp Doha's motor pool area (the North Compound) also exposed several hundred soldiers to residual DU contamination in the vicinity of the burned tanks and ammunition conexes (containers). (Tab I describes the Doha fire and cleanup. Tab G more completely discusses Level II activities and practices.)

DU contaminated a total of 31 US combat vehicles (16 Abrams and 15 Bradleys) in the Gulf during 1990-1991. In addition to the 20 occupied combat vehicles hit by DU friendly fire (6 Abrams and 14 Bradleys), tank-fired DU rounds also struck 1 unoccupied Bradley. US tanks intentionally fired DU rounds into 3 unoccupied, immobilized Abrams to prevent their capture. Tank fires, causing some onboard DU rounds to "cook off," contaminated the final 7 Abrams, including the 3 Doha tanks mentioned previously. Whether contaminated by impacting DU rounds or DU rounds that caught fire and exploded, these 31 vehicles all required essentially the same processing.

USACHPPM evaluated the exposures for Level II categories in two groups, field units and Camp Doha.

1. Field Units

a. Estimates of DU Intake and Radiation Dose

Inhalation and ingestion are the primary exposure pathways for Level II personnel. Entering contaminated equipment may have stirred up DU residues inside that soldiers then could inhale. Persons outside the vehicles could have inhaled DU resuspended from the vehicles' outside surfaces or the surrounding soil; inadvertently ingested DU from their hands or lips; or nicked, scratched, or otherwise injured themselves and thereby contaminated wounds. The inhalation exposure from resuspended DU residues inside or outside vehicles depends on the air concentration of the resuspended DU and the time the person spends in the resuspended DU. The inhalation exposure from smoke depends on DU concentration and the time spent in the smoke. Ingestion mainly comes from touching a DU-contaminated surface and then inadvertently touching the mouth; the amount ingested is usually a small fraction of the amount on the hands.

USACHPPM reviewed data obtained during developmental tests conducted under circumstances similar to the Gulf to estimate:

- DU soil contamination as a function of the distance from a vehicle hit by DU munitions;
- DU airborne concentrations inside a re-entered vehicle struck by DU munitions;
- outside airborne DU concentrations as a function of the distance from a vehicle struck by DU munitions; and
- outside airborne DU concentrations as a function of the distance from a fire in a vehicle loaded with DU munitions.

USACHPPM used data from these tests[91] to develop a range of highly conservative air concentrations and surface DU contamination levels derived from penetrations of the DU armor plate on an Abrams Heavy M1A1 main battle tank, which did not occur in the Gulf War. Tab O provides details of these source terms. USACHPPM concluded that the DU air concentrations and surface contamination levels represented those encountered by Level II personnel.

USACHPPM focused its efforts on inhalation and ingestion during re-entry of DU-contaminated vehicles and activities around and near contaminated vehicles.[92] Recognizing that Level II personnel experienced contamination levels, entry times, and exposure times that varied widely and were known only in general, USACHPPM elected to develop chemical and radiation dose factors based on one hour of exposure in a vehicle. Once established, simply multiplying those factors by the exposure time in each vehicle and number of vehicles entered could produce estimates for Level II intakes and doses.

Table 5 contains the factors for DU intake, kidney concentration, and radiation dose (CEDE, whole body) for one hour of exposure for inhaled and ingested soluble and insoluble DU, and the totals for each route of exposure and for an individual.

Table 5. Estimated Level II DU exposure and dose factors for one hour exposure[93]

spacer	Inhalation			Ingestion			Total
Factor	Soluble	Insoluble	Total	Soluble	Insoluble	Total	--
Intake (mg)	0.002	0.023	0.025	0.01	0.047	0.057	0.082
Kidney concentration (µg DU/g kidney)	0.00042	0.00025	0.00067	0.0006	0.00029	0.00095	0.0016
Radiation dose (CEDE, rem)	-	-	0.0005	-	-	$2x10^{-6}$	0.0005

We can estimate intakes and doses for any Level II scenario by multiplying the factor for one hour by the exposure time in each vehicle and number of vehicles encountered. For example, a BDAT team member who spent three hours in one vehicle would have an intake of 0.075 milligram (3 hours times 0.025 mg per hour) from inhalation and 0.171 milligram (3 times 0.057 mg per hour) from ingestion for a total of 0.246 milligram. That would produce a kidney concentration of 0.002 microgram of DU per gram of kidney tissue (3 times 0.00067 microgram of DU per gram of kidney tissue) from inhalation and 0.0028 microgram of DU per gram of kidney tissue (3 times 0.00095 microgram of DU per gram of kidney tissue) from ingestion for a total of 0.0048 microgram of DU per gram of kidney tissue. This kidney concentration is well below the 3 micrograms of uranium per gram of kidney tissue guideline and indicates chemical effects would not be expected from this DU exposure. The corresponding radiation dose (0.0015 rem CEDE) from inhalation and ingestion (3 times 0.0005 rem) is far below the annual guideline (0.1 rem) for members of the public, indicating that no adverse radiation effects would be expected from this exposure. Readers can apply a similar process to estimate their own intakes and doses based on their own estimates of the number of vehicles they entered and their exposure time.

Based on our interviews with Level II personnel and our analysis of their possible activities, we concluded that it was conservative to assume Level II personnel encountered some or all of the contaminated vehicles: 16 Abrams tanks (6 destroyed by friendly fire, 3 destroyed intentionally, 7 involved in fires) and 15 Bradleys (all involved in friendly fire incidents). Therefore, we also concluded that exposure to all 31 vehicles provided a very conservative estimate of the upper limit for intake, kidney concentration, and radiation dose for Level II personnel. We recognized that one person would not enter all 31 vehicles at the same time or in rapid sequence. Assuming they do produces a higher estimate of peak kidney concentration than would be possible if the exposures occurred over days or weeks because the body would continually remove uranium during the longer exposure period.

Based on interviews with many Gulf War veterans, we developed nominal exposure times ranging from one hour per vehicle for EOD personnel and LARs to three hours per vehicle for Unit Maintenance Personnel, BDAT, and 144th Service and Supply Company personnel and gave them to USACHPPM. Table O-4 in Tab O lists the exposure times for each Level II scenario.

USACHPPM estimated intakes of total DU, soluble DU, and insoluble DU, DU kidney concentration, and radiation dose from inhalation and ingestion for each Level II scenario. They assumed a member from each scenario contacted each of the 31 vehicles for the time established for the scenario. For example, this assumption means a typical BDAT soldier spent 3 hours in each of the 31 tanks. USACHPPM considered contact with all vehicles a very unlikely possibility in the Gulf, so these estimates provide a reasonable upper limit to DU intakes and doses.

b. Assessing Possible Health Effects

USACHPPM's assessments of the chemical and radiation doses (CEDE) for Level II personnel estimated upper limits of DU inhalation intake at 2.3 milligrams, DU ingestion intake at 5.3 milligrams, kidney concentration at 0.15 microgram of DU per gram of kidney tissue, and radiation dose of 0.047 rem. Tab O provides details of USACHPPM's results. The 2.3 milligram inhalation intake includes 0.19 milligram of soluble DU and 2.11 milligrams of insoluble DU.[94] Both the total inhalation intake and its soluble portion are well below the 8 milligram and 40 milligram guidelines for kidney effects from inhaling soluble DU.

The 5.3 milligram ingestion intake includes 0.93 milligram of soluble DU and 4.4 milligrams of insoluble DU. USACHPPM assessed the potential for kidney effects from the combined inhalation and ingestion intakes by comparing the DU kidney concentration with the 3 micrograms of uranium per gram of kidney tissue guideline. They estimated a maximum kidney concentration of 0.06 microgram (µg) of DU per gram of kidney tissue from inhalation and 0.09 microgram (µg) of DU per gram of kidney tissue from ingestion for a total of 0.15 microgram (µg) of DU per gram of kidney tissue. That kidney concentration is far less than the 3 micrograms (µg) of uranium per gram of kidney tissue guideline.[95] Therefore, we conclude that these results are well below the chemical toxicity guidelines and no health effects are expected.

USACHPPM estimated maximum radiation doses (CEDE) of 0.047 rem from inhalation and 0.0002 rem from ingestion for a total maximum radiation dose of 0.047 rem.[96] That radiation dose is less than the 0.1 rem annual guideline for members of the public and far less than the 5 rem annual limit for workers. Therefore, no adverse health effects from radiation would be expected from these radiation doses.

Limited testing on some Level II personnel supports these assessments. After the April 13, 1991, tank fire (see Tab J), urine uranium concentrations for seven soldiers who downloaded ammunition and equipment were all below minimum detection limits when tested on April 15, 1991.[97] Tests starting in 1993 on members of the 144th Service and Supply Company, New Jersey Army National Guard also produced urine uranium concentrations considered normal. (See Section V, "Follow-up.")

These results clearly indicate that the very conservative estimated risks from DU inhalation are less than the guidelines for members of the public. They also provide perspective on the requirements for respiratory protection around contaminated vehicles. A Gulf War-era technical bulletin recommended wearing MOPP 4 (Mission Oriented Protective Posture [MOPP] Level 4) because it was readily available to all soldiers. Most soldiers and civilians were not trained in DU's characteristics and risks and were unaware of this protective guidance.[98] Those familiar with the guidance found the recommended precautions overprotective and hazardous in the desert heat. The estimates reported here indicate that MOPP 4 provides much more protection than necessary. (Tab N discusses DU protective guidance in place during the Gulf War.)

2. Camp Doha Personnel

a. Estimates of DU Intake and Radiation Dose

The July 11, 1991, fire and explosion that engulfed the 2nd Squadron Motor Pool created potential DU inhalation and ingestion exposures in hundreds of Army personnel. Those personnel could have experienced the events associated with the original accident and efforts to gain control, followed by preliminary recovery, assessment of the situation, and eventual cleanup. The complete sequence of events occurred from July 11, 1991, through November 1991. The explosion and fire involved 660 M829 DU sabot rounds that released some DU residues to the air and contaminated grounds and equipment, creating potential exposure pathways for personnel.

The Pacific Northwest National Laboratory (PNNL) had conducted many DU tests during the past two decades and developed safety and health guidelines for DU munitions, so USACHPPM requested PNNL to review and analyze data from burn tests of DU munitions to assess the possible chemical and radiation exposures to Camp Doha personnel. PNNL approached this task by determining the pathways, assessing the intake of DU oxides in smoke, assessing recovery personnel's inhalation of DU oxides, determining these workers' activities, converting the amount of DU oxides inhaled or ingested into radiation doses, and reporting their findings. Possible pathways included inhaling DU oxides from smoke generated by the fire, inhaling DU oxides resuspended from contaminated surfaces, and ingesting DU oxides from contaminated surfaces.[99]

Since detailed environmental studies of the Camp Doha situation were not done during and immediately after the incident, PNNL reviewed the available developmental test data and information, interviewed several participants, identified data gaps, and prepared reasonable estimates for many of the parameters required for calculating estimated doses. PNNL first estimated the mass of DU involved in and released during the fire, the distribution of DU oxides in the North Compound, the air concentrations of resuspended DU and workers' activities. PNNL developed activities and assessed doses for eight worker categories involved in the characterization and cleanup activities in the North Compound.

b. Assessing Possible Health Effects

PNNL used its estimates of air concentration, surface contamination, periods of recovery activity, and workers' activity described above to estimate chemical doses as DU concentrations in the kidneys and radiation doses for representative personnel in each job category (Table 6).

Details of the evaluation process for the eight worker categories are provided in Tab O. Their estimated kidney concentrations ranged from 0.003 to 0.095 microgram of DU per gram of tissue (µg DU/g tissue) and their estimated radiation dose ranged from 0.001 to 0.065 rem (the latter for contract cleanup workers).[100] These estimated kidney concentrations are well below the 3 µg uranium/g tissue guideline. The estimated radiation doses are all below the annual guideline (0.1 rem) for members of the general public -- even for the contractors who performed the bulk of the cleanup,[101] who had the highest estimated dose. Adverse health effects are not associated with these doses.

Table 6. Estimated chemical and radiation doses (CEDE) received by personnel during recovery work activities at Camp Doha[102]

Job categories		Maximum concentration of uranium in the kidney µg-U/g kidney	Internal doses received, rem, CEDE
EOD Personnel -- 146th Ord. Det		0.063	0.0052 rem

Engineers - 58th Combat Engineer Company	Average	0.005	00.0072 rem
	High	0.02	0.014 rem
54th Chemical Troop		0.015	0.0010 rem
Regimental NBC Staff		0.03	0.0027 rem
2nd Squadron Personnel		0.0033	0.0024 rem
AMCCOM		0.052	0.0055 rem
CECOM		0.05	0.0047 rem
ECC Contractors		0.095	0.065 rem

D. Level III Exposures

Level III represents individuals who received relatively fleeting DU exposures from climbing on or entering US or enemy combat vehicles to assess damage, remove equipment, or collect souvenirs and persons 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 motor pool accident. Besides the Level II personnel involved in cleaning up the North Compound, hundreds of additional personnel may have received short-term exposure to the smoke from burning DU munitions stored in the tanks or conexes. The smoke drifting over the soldiers evacuated to the southern tip of the camp probably contained small quantities of DU particles. (Tab G discusses Level III activities and practices more completely.) Level III personnel may have received exposures from inhalation, ingestion, or wound contamination. They experienced essentially the same scenarios and routes of entry as Level II personnel, except that exposure times were shorter because Level III personnel generally did not remain in vehicles as long as Level II personnel.

To simplify the Level III assessments, USACHPPM classified Level III participants into two separate groups, field units and Camp Doha personnel. Field unit personnel may have been exposed to damaged or burning combat equipment throughout the theater of operations. Camp Doha personnel comprised those involved with the accident, but not the recovery and cleanup, who may have had fleeting encounters with the smoke and fumes from the fire.

1. Field Units

a. Estimates of DU Intake and Radiation Dose

As with Level II, USACHPPM estimated inhalation and ingestion intakes by first evaluating the amounts of DU contamination and DU air concentrations from resuspended DU residues inside vehicles, and DU air concentrations from burning vehicles loaded with DU munitions using data from relevant test scenarios. It calculated the DU air concentrations, contamination on inside surfaces, and contamination in the outside soil for four Gulf War scenarios:

- exposure to smoke from a burning, fully loaded Abrams tank;
- entry into a fully loaded Abrams tank after a fire;
- entry into contaminated, DU-damaged or -destroyed vehicles; and
- exposure to airborne DU downwind of a vehicle perforated by a DU round.

Air concentrations and surface contamination levels provide the bases for estimating the exposures to personnel in the Level III categories. USACHPPM recognized that Level III personnel experienced a wide range of possible exposure scenarios involving different types of vehicles, extent of vehicle damage, and amount of time exposed. Therefore, as for Level II, USACHPPM developed chemical and radiation dose factors based on one hour of exposure to a vehicle or fire. Tab O discusses the evaluation process and provides these factors for Level III field units.

We cannot assess the possible health effects from these exposure scenarios for an individual soldier without knowing the details of his or her possible exposures. Information on the number of vehicles entered, the time spent in the vehicles, or the extent of damage to a vehicle is not determined easily. Yet soldiers would like to know something about their possible health effects from DU contacts. We have chosen to provide estimates of intake, kidney concentration, and radiation dose from multiple exposures that soldiers can use to estimate their own situation. Table 7 lists those values for 1, 10, and 100 exposures. The exposure time represents a combination of vehicles contacted and the time spent. That is, 10 could be obtained from exposure to 10 vehicles for 1 hour each, 5 vehicles for 2 hours each, 1 vehicle for 10 hours, 20 vehicles for 30 minutes (one-half hour), or any other combination that produces 10.

Table 7. Estimated Level III DU exposures

Scenario	Exposures (vehicle-hours)	Inhalation [103]			Ingestion [104]			Total		
		Intake (mg)	Kidney concentration (µg DU / g kidney)	Radiation dose (CEDE) (rem)	Intake (mg)	Kidney concentration (µg DU / g kidney)	Radiation dose (CEDE) (rem)	Intake (mg)	Kidney concentration (µg DU / g kidney)	Radiation dose (CEDE) (rem)
Smoke from a burning tank	1	0.0028	0.00007	0.00007	-	-	-	0.0028	0.00007	0.00007
	10	0.028	0.0007	0.0007	-	-	-	0.028	0.0007	0.0007
	100	0.28	0.007	0.007	-	-	-	0.28	0.007	0.007
Entry of a burned tank	1	0.025	0.00067	0.0004	0.057	0.0009	2×10^{-6}	0.082	0.0016	0.0004
	10	0.25	0.0067	0.004	0.57	0.009	2×10^{-5}	0.82	0.016	0.004
	100	2.5	0.067	0.04	5.7	0.09	2×10^{-4}	8.2	0.16	0.04
Enter DU-damaged or destroyed Iraqi vehicle	1	0.0057	0.00026	0.0001	0.057	0.0009	2×10^{-6}	0.063	0.0012	0.0001
	10	0.057	0.0026	0.001	0.57	0.009	2×10^{-5}	0.63	0.012	0.001
	100	0.57	0.026	0.01	5.7	0.09	2×10^{-4}	6.3	0.12	0.01
Downwind of DU penetrated vehicle	1	0.0044	0.0002	0.00001	-	-	-	0.0044	0.0002	0.00001
	10	0.044	0.002	0.0001	-	-	-	0.044	0.002	0.0001
	100	0.44	0.02	0.001	-	-	-	0.44	0.02	0.001

b. Assessing Possible Health Effects

As shown in Table 7, the maximum total intake of 8.2 milligrams due to 100 hours of exposure inside a DU-damaged tank leads to a DU kidney concentration (0.16 µg uranium per gram kidney tissue) far less than the 3 µg/g guideline, and a radiation dose much less (0.04 rem) than the 0.1 rem in a year limit for members of the public.

Recognizing that Level III personnel may have experienced more than one of the four test scenarios, USACHPPM developed a hypothetical, composite scenario that soldiers can use as an example for estimating their own experiences. The scenario involves a cavalry scout who contacted DU in the field:

- taking 20 minutes to pass one burning Abrams Heavy Armor tank;
- entering 7 enemy vehicles hit by DU and spending 7 minutes in each vehicle without contaminating his hands;
- entering one enemy vehicle for one hour, contaminating his uncovered hands, which he then did not wash for two days; and
- taking 10 minutes to pass at a distance of 80 meters through the smoke of 3 burning enemy tanks struck by DU.

As shown in Table 8, the four scenarios produce a total DU intake of 0.065 mg that leads to a kidney concentration (0.0012 µg DU/g tissue) far less than the 3 µg uranium/g tissue guideline, and a radiation dose (0.00016 rem) far less than the 0.1 rem in a year limit for members of the public. The intakes do not represent amounts that would produce chemical or radiation effects.

Table 8. Estimated DU intakes for a Level III scenario -- a soldier's combined exposure to several events[105]

Scenario	Exposure Route	Total DU Intake (mg)	DU in Kidney (µg DU/ g tissue)	Radiation Dose (rem)
1. Scout exposed to smoke from burning Abrams tanks	Inhalation	0.00093	0.00002	0.00002
2. Scout enters contaminated equipment	Inhalation	0.0047	0.00021	0.00008
3. Scout enters contaminated equipment and contaminates his hands	Ingestion	0.057	0.0009	2×10^{-6}
4. Scout exposed to smoke from DU-perforated enemy equipment	Inhalation	0.0022	0.0001	5×10^{-5}
Total	---	0.065	0.0012	0.00016

2. Camp Doha Personnel

a. Estimates of DU Intake and Radiation Dose

DU munitions in the burning tanks and conexes in the North Compound produced airborne DU concentrations in the smoke and fumes that passed to the southeast over the United Nations compound. The several hundred personnel who assembled there could have inhaled DU from the smoke. Pacific Northwest National Laboratory estimated possible air concentrations and doses from two sources -- the area around the burning conexes and the area near the washrack with the three burning tanks.[106] (Tab O discusses the airborne DU produced during the fire in detail.) PNNL calculated values for both an elevated-[107] and a ground-level release.[108]

b. Assessing Possible Health Effects

PNNL estimated that the highest exposures any person could have experienced occurred one kilometer downwind of an elevated release and produced a maximum kidney concentration of 2.8×10^{-7} µg DU/g tissue and a maximum radiation dose (CEDE) of 3.0 x 10^{-6} rem.[109] These results are far less than the kidney concentrations and radiation doses associated with adverse health effects.

E. Other Reports Investigated

Our previously published report on DU noted several exposure scenarios we could not evaluate at the time, mainly because the available information about these often isolated or unique events was largely anecdotal. We subsequently investigated each of these scenarios, with the results of these investigations discussed below. (Tab G describes these accounts in more detail.)

1. Welders

Several veterans have reported welding DU armor panels onto the front turret armor of M1A1 tanks during refit operations to make them more impervious to enemy fire. The program managers, a senior metallurgist, and other personnel involved in the refitting have disputed these claims, saying the panels in question were regular steel armor. The metallurgist said that DU would never be welded to steel.[110] Consequently, we closed the investigation of DU welding unless new information surfaces. We believe DU was not involved.

2. Ammunition 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.[111] Other soldiers and officers, including explosive ordnance disposal personnel and the commander of the unit to which the ammunition truck belonged, have indicated the truck was hauling artillery ammunition.[112] The preponderance of evidence, laid out in Tab G, indicates DU was not involved.

3. A-10 Crash

An A-10 aircraft crashed and burned while trying to land at King Khalid Military City (KKMC) in northern Saudi Arabia on February 27, 1991. The commander on the scene reported that fire personnel quickly extinguished the fire[113] -- a fact substantiated by the photographs we obtained. An ammunition specialist estimated the crash clean-up recovered fewer than 20 "spent" DU cartridges; the rest of the rounds remained intact on the aircraft.[114] Because KKMC was the primary recovery field (i.e., the closest airstrip for damaged aircraft to land), personnel quickly cleared the runway for other in-flight emergencies. There is no record of anyone performing a radiological survey or of how the designated personnel disposed of the remaining DU ammunition when they ultimately disposed of the A-10. Given the limited fire damage to the aircraft, it is doubtful the fire heavily oxidized the DU penetrators.

4. Misfired DU Rounds on A-10 Aircraft

30mm DU rounds periodically misfired or jammed in the A-10's GAU-8 cannon during the war. Although the mishap was uncommon, one veteran reported five to seven incidents. Ground crews had to clear and remove these "hangfires" from the gun barrel, potentially exposing the ground crews to airborne DU. If maintenance personnel could not dislodge the jammed rounds, they replaced the cannon barrel; in some cases, they replaced the entire gun.[115,116] Since the A-10 fires the 30mm DU round only in combat, peacetime maintenance procedures do not apply. To date, investigators have not evaluated the procedure to fix an A-10 cannon jammed with a DU round, but they believe the procedure would not produce a significant exposure. Although basic peacetime occupational radiation safety practice would suggest protective equipment (e.g., gloves, dust mask) and work practices to minimize exposure during such a procedure, personnel did not use protective equipment or follow these safe practices during the Gulf War.[117]

F. Summary of Health Assessments

This revised report updates estimates for Level I participants and provides generic assessments for Level II and Level III personnel. Table 9 summarizes the upper limit estimates for all levels. As discussed above, the Level II estimates assume each individual was exposed to all 31 DU-contaminated vehicles for the exposure times shown in Table O-4. Level III estimates assume exposures of 100 vehicle-hours, such as from one-hour exposures in 100 vehicles.

Table 9. Estimated upper limit for intakes, kidney concentration, and radiation dose (CEDE)

2	Intake (mg)	Exceeds Health Guide	Kidney Concentration (µg/g tissue)	Exceeds Health Guide	Radiation Dose CEDE, (rem)	Exceeds Health Guide
Level I						
Soldiers in or on a US vehicle when a DU munition penetrated it.	[1]237	Yes	[1]4.38	Yes	[1]4.8	No
Soldiers who entered US vehicles to rescue occupants immediately after friendly-fire DU impacts.	[1]237	Yes	[1]4.38	Yes	[1]4.8	No
Level II						
Explosive Ordnance Disposal (EOD)	2.5	No	0.05	No	0.016	No
Unit maintenance personnel	7.6	No	0.15	No	0.047	No
Logistics Assistance Representatives (LARs)	2.5	No	0.05	No	0.016	No
Battle Damage Assessment Team (BDAT)	7.6	No	0.15	No	0.047	No
144th Service and Supply Co.	2.5	No	0.05	No	0.016	No
Radiation Control (RADCON) team.	3.8	No	0.075	No	0.023	No

Cleanup at Camp Doha's North Compound.	[2]NR	-	0.095	No	0.065	No
Level III						
Personnel exposed to smoke at Camp Doha.	[2]NR	-	2.8×10^{-7}	No	3.0×10^{-6}	No
Personnel exposed to smoke from burning Abrams tanks.	0.28	No	0.007	No	0.007	No
Personnel who entered DU-contaminated equipment.	8.2	[3]No	0.012	No	0.01	No
Personnel exposed to smoke from Iraq's DU-impacted equipment.	0.44	No	0.02	No	0.001	No

Notes: 1. Status means exceeds health guideline or not.
2. NR -- not separately reported by PNNL.
3. The total DU intake for 100 vehicle-hours appears to exceed the 8 mg inhalation guideline; however that guideline pertains to soluble uranium, which in this estimate is about 1.1 milligrams. The remainder is insoluble uranium.

Critical re-evaluations of the Level I assessments revealed that the test data support estimates of upper and lower limits of the Level I intakes and corresponding chemical and radiation doses. However, they also provide additional evidence of the problems with those data and strengthen the need for better data. Consequently, we are sponsoring a test program that will develop reliable, peer-reviewed data on DU aerosol behavior to support a definitive assessment of the Level I doses and evaluations of future exposure scenarios. Aside from this test program, Baltimore VA Medical Follow-up Program results provide the most relevant information about Level I participants' health and medical condition.[118] The VA has reported that while these veterans have definite medical afflictions resulting from their wartime injuries, they exhibit none of the known clinical manifestations seen in other (civilian) overexposed groups from uranium's chemical or radiological toxicity.[119]

USACHPPM based Level II and Level III exposure estimates on test data from weapons tests, which were not subject to the air sampler problems that caused the GAO to question their 1998 Level I estimates. The estimates of DU intake, chemical dose, and radiation dose calculated for Level II and III participants indicate those veterans experienced air concentrations well below the short-term exposure limit established by the American Conference of Governmental Industrial Hygienists. These estimates are far below any relevant Federal or industrial guideline for chemical or radiation exposure. Therefore, we can conclude harmful medical effects from DU exposure for Level II or III personnel are not expected.[120]

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