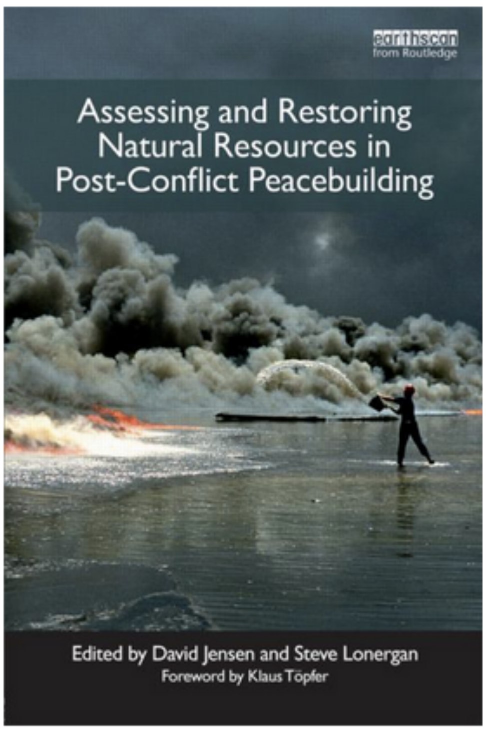

The risks of depleted uranium contamination in post-conflict countries: Findings and lessons learned from UNEP field assessments

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Many of the world's armies possess, or are thought to possess, depleted uranium (DU) munitions—conventional weapons that have been used in warfare on several occasions (Harley et al. 1999). DU is a dense metal used in munitions for its penetrating ability and on armored vehicles as a protective material. In warfare production, DU is an alternative for tungsten, which is more expensive and has fewer offensive capabilities. Munitions containing DU were used in Iraq during the 1990–1991 and 2003 Gulf wars, in Bosnia and Herzegovina in 1994–1995, and in the Kosovo conflict in 1999, including southern Serbia and Montenegro.

DU is the main by-product of enriching natural uranium ore for use as fuel in nuclear reactors and nuclear weapons. It is mildly radioactive, with approximately 60 percent of the radioactivity of natural uranium from which it is distinguished by its concentrations of uranium isotopes. Natural uranium has a uranium-235 (U-235 or 235U) content of 0.7 percent, whereas DU has a U-235 content of 0.2–0.3 percent. Like naturally occurring uranium, DU is an unstable, chemically toxic, radioactive heavy metal that emits ionizing radiation of three types: alpha, beta, and gamma. The scientific community is investigating the extent to which DU can filter through soil and contaminate groundwater as well as how wind or human activity can resuspend DU as dust.

DU ammunition forms a dust cloud on impact. Because the metal is pyrophoric (i.e., the reaction of the metal to oxygen in the air causes it to ignite spontaneously), the dust cloud burns and forms an aerosol of fine uranium oxide particles. The amount of DU transformed into dust depends on the type of munitions, the nature of the impact, and the target. Normally, 10–35 percent (up to 70 percent) of the penetrator becomes an aerosol upon impact with a hard target, such as a tank or an armored personnel carrier. Ignition of the DU-dust cloud can therefore cause total destruction of an impacted vehicle because

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of the secondary explosion of carried ammunitions (tanks carry a number of battle ammunitions that can explode). After an attack with DU munitions, DU is deposited on the ground and other surfaces as pieces of DU metal, fine fragments, and dust. If the DU catches fire, it is deposited as uranium oxide dust. Most of the DU dust lands within one hundred meters of a target (Nellis AFB 1997). When DU hits soft surfaces such as nonarmored vehicles and soft ground, it does not produce as much dust as it does when it encounters hard surfaces such as battle tanks and concrete surfaces.

DU AND HUMAN HEALTH

A variety of international studies examining the behavior of DU in the natural environment and medical aspects and risks have been published by international, regional, and national institutions, including the World Health Organization (WHO), the Scientific and Technological Options Assessment of the European Union, the National Research Center for Environment and Health in Germany, the Italian Ministry of Defense, the British Royal Society, and the Swedish Defence Research Agency (WHO 2001; EC 2001; Roth et al. 2003; MOD 2004; Royal Society 2001, 2002; and Waleij et al. 2004).

The effects of DU on human health depend on the types and magnitudes of exposure, as well as on characteristics such as particle size, chemical form, and solubility. Where DU munitions have been used, the penetrators, penetrator fragments, and jackets (or casings) can be found on the ground or buried at varying depths, where they have the potential to contaminate air, soil, water, and vegetation.

Human exposure to radiation from DU can be external (through contact with the skin) or internal (through inhalation or ingestion of DU particles). Radiation may increase the risk of cancer, with the degree of risk depending on the part of the body exposed and the dose rate (EC 2001). The estimated annual radiation doses that can arise from exposure to DU residues are low, estimated to be less than 0.1 mSv[1] (IAEA 2010). This radiation dose is less than those received on an annual average by individuals from natural sources of radiation in the environment (2.4 mSv). It is also below the internationally recommended annual dose limit for members of the public (1 mSv) and below the annual action level of 10 mSv established by the International Commission on Radiological Protection (ICRP) (ICRP 1999; IAEA 2010). While people who handle objects hit by DU or DU remnants will not likely receive doses that exceed the annual

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[1] The sievert (Sv) is the International System of Units–derived unit of dose equivalent radiation (the biological effect of ionizing radiation) equal to an effective dose of a joule of energy per kilogram of recipient mass. One millisievert (mSv) is one thousandth of a sievert. The unit is named after Rolf Maximilian Sievert, a Swedish medical physicist, renowned for work on radiation-dosage measurement and research into the biological effects of radiation.

action level, a person present during an attack may receive a higher dose by inhaling air with a high concentration of DU dust (IAEA 2003; ICRP 1999).

Like naturally occurring uranium and other heavy metals, DU is chemically toxic when ingested or inhaled. If certain uranium compounds accumulate in the kidney tubules and kidneys, severe poisoning can result within hours or days. DU's chemical toxicity is usually considered the dominant risk factor, relative to its radioactivity.

But comparison of the chemical and radiological hazards of uranium is complex given the following:

- *The insufficiency of chemical toxicity data for long-term ingestion of uranium*. Currently, literature only covers intermediate-term adverse effects on animals.
- *Noncomparable standards for radiation doses and chemical toxicity*. For radiation and cancer-inducing effects of toxic substances, a linear dose-to-effect relationship is assumed at low doses and low-dose rates; the occurring probability of an adverse effect is therefore not reduced by the selection of a standard.[2] At low doses, the absence of linearity in the dose-effect curve for noncancerous effects of toxic substances allows identification and selection of nonadverse-effect levels.

The absence of comparability can be illustrated by the ingestion of uranium. The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) estimated a tolerable daily intake (TDI) of pure uranium in its natural-isotope composition for use in calculating the annual limit on intake (ALI) of the element.[3] The value obtained (for a 70 kilogram (kg) body weight) is equal to 51.2 milligram (mg) (ATSDR 1999; WISE n.d.). But according to the WHO, the ALI is 15.3 mg (WHO 1998: WISE n.d.).

The ICRP, whose methodologies are based on radiological hazard studies, uses an annual dose-rate threshold of 1 mSv to define the ALI for the public.[4] This methodology gives ALI values for natural uranium (with progeny) of 31.5 mg, for uranium with natural isotope composition (without progeny) of 813 mg, for enriched (3.5 percent U-235) uranium of 251 mg, and for depleted (0.2 percent U-235) uranium of 1,410 mg (WISE n.d.). The variability of ALI for uranium composed of natural isotopes (without progeny) calculated with the chemical toxicity methods (51.2 mg, according to ATSDR, and 15.3 mg, according to WHO) and the ALI calculated with radiation methods (813 mg) is therefore relatively significant.

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2 Doses and dose rates include the toxicological and radiological dimensions (milligram/kilogram (mg/kg), Sv, mg/kg/time, Sv/time).

3 The TDI relates to the chemical toxicity of a substance.

4 The field of radiation protection distinguishes between members of the public and radiation workers. For the public, the annual radiation-exposure limit is 1 mSv; for radiation workers, it is 20 mSv.

Taking into account the radioactivity of uranium, a member of the public weighing 70 kg would be allowed to ingest fifteen times more naturally composed uranium than the ATSDR chemical toxicity of the uranium would allow. But in both cases, there would be a very low probability of harm.

For uranium inhalation, under the toxicological approach, the minimal risk level (MRL) sets the daily human exposure to a hazardous substance at or below the level at which the substance is unlikely to pose a measurable risk of adverse and cancerous effects. MRLs are calculated for specific pathways (inhalation and oral) over a specified time period (acute, intermediate, or chronic). In the case of highly soluble uranium salts, the ATSDR value for intermediate-period inhalation is 0.0004 milligram per cubic meter (mg/m^3), and the value for chronic inhalation is 0.0003 mg/m^3. The MRL for intermediate inhalation of insoluble uranium–compounds is 0.008 mg/m^3 (WISE n.d.).

Using the radiological risks posed by the inhalation of uranium radioisotopes, it is possible to calculate derived-air concentrations (DACs) based on the annual 1 mSv value for the public, with a breathing rate of 0.9 m^3/hour on a continuous exposure (WISE n.d.). The DACs and the associated values are more or less comparable to the MRLs. The values are generally in the low microgram-per-cubic-meter range.

For the DU assessments conducted in the Balkans (see below), the approach was to estimate the hazard posed by the DU contamination at a selected location, using the ICRP methodology. In the cases of intermediate and chronic inhalation, the results were comparable to the radiological and chemical risks. In the case of ingestion, chemical toxicity is the dominant factor. The consequences of radiation were considered insignificant for doses less than 1 mSv/year and significant for doses higher than 1 mSv/year.

ASSESSMENTS OF DU

For the safety of local populations and international workers in post-conflict situations, accurate information must be available in order to evaluate the risks to human health from the environmental consequences of the conflict and to take appropriate measures for mitigation. Where DU munitions have been used during conflict, environmental assessments should be undertaken to determine potential risks.

The United Nations Environment Programme (UNEP) has conducted three comprehensive environmental assessments of DU in the Balkans. The first was carried out in Kosovo in 2000–2001. It was followed by assessments in Serbia and Montenegro in 2001–2002 and in Bosnia and Herzegovina in 2002–2003. Because security constraints prevented international experts from traveling to Iraq during 2003–2007, UNEP focused on delivering capacity building and training to national staff to enable them to conduct DU-assessment fieldwork in the country during 2006–2007. In 2010, the International Atomic Energy Agency (IAEA) published the outcomes of the national assessments in Iraq.

In conducting the various DU assessments, which included a combination of fieldwork and laboratory analysis, UNEP worked with the IAEA and WHO.

UNEP managed the assessment process, including the field sampling and laboratory analysis. IAEA made all calculations necessary to determine radiological conditions in areas contaminated with DU residue and discussed the results with partner organizations. WHO calculated the toxicity of DU, developed scenarios, and published health-related materials on the basis of UNEP's findings.

Kosovo, 1999–2001

UNEP first conducted a fact-finding mission to Kosovo in August 1999. The mission determined that DU contamination was likely not widespread because no traces of DU were detected. Although site-specific contamination could not be ruled out, the mission was unable to identify the locations where DU had been used because it lacked essential information from the North Atlantic Treaty Organization (NATO) on firing locations and targets. Even though the preliminary findings helped quell public fears about widespread contamination, there was still an urgent need to conduct more detailed site-specific analysis.

In 2000, NATO provided UNEP with vital information on the use of DU during the Kosovo conflict, including maps, number of rounds fired, and coordinates of targets. The data enabled UNEP to carry out the first international environmental assessment of DU in a conflict situation.

Because more than a year had elapsed since the conflict, the overall aim of the UNEP mission of autumn 2000 was to examine risks posed by remaining DU contamination of soil, water, and plants, as well as by intact and fragmented DU penetrators still in the environment. The mission faced the following key questions: What were the levels of DU contamination in Kosovo? What were the corresponding radiological and chemical risks, then and for the future? Was there any need for remedial measures or restrictions? If so, which measures were reasonable and realistic?

Eleven out of a total of 112 known sites were selected for analysis by UNEP (see figure 1). A total of 361 samples were collected from the eleven sites, including 249 soil, 13 smear,[5] 46 water, 37 botanical, 3 milk, 7 penetrators, and 6 jackets. UNEP independently chose sites that were most heavily targeted, as well as sites that were in or closest to inhabited areas. In selecting the sites, diversity was also sought in the surrounding natural environment, soil types, and vegetation. Sampling in some areas was limited by the fact that the sites had not been cleared of mines and unexploded ordnance. In *Depleted Uranium in Kosovo: Post-Conflict Environmental Assessment* (UNEP 2001), UNEP reported that low levels of radiation had been detected in the immediate vicinity of the points of DU impact and that mild contamination from DU dust had been measured near the targets. However, the report concluded that there was no significant risk related to the

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5 Smear sampling of undisturbed surfaces is one of the most precise methods for detecting DU. UNEP has detected the impact of as little as two 30-millimeter DU penetrators of 300 grams each and has confirmed the presence of DU within 300 meters of a target.

Figure 1. UN environmental assessment sites in Kosovo, 2000–2001
Source: UNEP (2001).
Note: As with UN peace operations in other countries, UNMIK (United Nations Interim Administration Mission in Kosovo) defines its own districts. Each district has a district center and a responsible international commander. In a district, UN-mandated troops are present.

points in terms of possible contamination of air, water, or plants. Analyses of the samples collected also showed only low levels of radioactivity. Furthermore, there was no detectable, widespread contamination of the ground surface by DU. The results suggested that there was no immediate cause for concern regarding toxicity.

But major scientific uncertainties persisted about DU's long-term environmental behavior and potential adverse impacts. The assessment concluded that many DU munitions on the ground surface or hidden in the ground constituted a risk of future DU contamination of groundwater and drinking water. Therefore, UNEP called for precaution and recommended cleaning up polluted sites, raising the awareness of the local population, and monitoring environmental quality.

Serbia and Montenegro, 2001–2002

During the Kosovo conflict, a few sites in Serbia and Montenegro were also targeted with ordnance containing DU. Thus a second phase of scientific work started in September 2001 and was concluded in March 2002 with the publication of *Depleted Uranium in Serbia and Montenegro: Post-Conflict Environmental Assessment in the Federal Republic of Yugoslavia* (UNEP 2002). Eight sites were

Figure 2. UN environmental assessment sites in Serbia and Montenegro, 2001–2002
Source: UNEP (2002).
Notes:
1. At the time of UNEP's assessment, Serbia and Montenegro was one country, called the Federal Republic of Yugoslavia.
2. This figure shows the general location of assessment sites. A few sites are too close in proximity to reflect all eight visited.

selected for analysis based on their accessibility and the high number of rounds fired (see figure 2). A total of 129 samples were collected, including 54 soil, 4 smear, 11 water, 30 botanical, 17 air, 9 penetrators, and 4 fragments of jackets or penetrators.

The report confirmed the findings of the Kosovo assessment, provided additional information, and revealed important discoveries about the environmental behavior of DU. More than two years after the conflict, DU dust could be detected in soil samples and sensitive bio-indicators like lichens. However, because levels were extremely low, only state-of-the-art laboratory analyses could detect them. Based on the findings, UNEP confirmed that targeted sites were

Figure 3. UN environmental assessment sites in Bosnia and Herzegovina, 2002–2003
Source: UNEP (2003).
Note: This figure shows general location of assessment sites. Some sites are too close in proximity to reflect all fifteen visited.

contaminated, though experts measured no significant levels of radioactivity. One or two meters from the impact holes, the amount of DU dust detected fell below the natural presence of uranium in the soil.

The UNEP team also used air-sampling techniques to detect airborne DU particles at two sites. Although all levels detected were below international safety limits, valuable information on DU's behavior was obtained. Discussions began on decontamination and construction standards for DU-contaminated sites.

As in the Kosovo report, UNEP called for precautionary measures such as monitoring groundwater in populated areas and raising awareness of the local population. The report included detailed recommendations for cleanup and decontamination, which started during the assessment.

Bosnia and Herzegovina, 2002–2003

DU was also used in Bosnia and Herzegovina during the conflict of the mid-1990s, and UNEP undertook an assessment of its effects in September 2002. Fifteen sites with reportedly high use of DU ammunition and evidence of environmental consequences were selected for analysis (see figure 3). Five of the sites were areas where NATO had reported using DU munitions. The local population and authorities were concerned that DU had been used in the other ten. A total of 132 samples were collected, including 4 penetrators, 46 surface soil, 3 soil profiles of 60 cm each, 5 smear, 2 scratch, 19 water, 24 air, and 29 vegetation.[6] The final report, *Depleted Uranium in Bosnia and Herzegovina: Post-Conflict Environmental Assessment*, was released in March 2003 (UNEP 2003a).

In addition to confirming the results of the earlier DU assessments, the report presented four new findings. First, detailed laboratory analyses of surface-soil samples revealed low levels of localized ground contamination. Although local ground contamination could be detected up to 200 meters from the impact zone, it was typically found within a 100-meter radius.

Second, penetrators buried near the surface had decreased in mass by approximately 25 percent over seven years. The correlation between these findings and the results of previous UNEP studies proved the relatively short time in which DU decomposed. Within twenty-five to thirty years, DU penetrators can completely degrade into uranium oxides and carbonates as a result of pitting corrosion.[7] Degradation products with different chemical and toxicological properties remain, and radioactivity does not change.

Third, DU-contaminated drinking water was found for the first time at one of the surveyed sites. The concentrations were very low, and the corresponding radiation doses were insignificant to human health. Nevertheless, because the mechanism that governs the contamination of water in a given environment is not well understood, UNEP recommended that water sampling and measurements continue for several years and that an alternative water source be used when DU was found in the drinking water. In Hadjici (west of Sarajevo), the local authorities shut down the contaminated well used by local workers, and added the site to a water-quality survey.

Fourth, DU contamination was found in the air in and around two buildings that had been hit by DU. Resuspension of DU particles by wind or human activity was the most likely cause. The concentrations in the air were very low, and calculated radiation doses from inhaling the dust were insignificant. However, precautionary decontamination and cleanup steps were recommended for the buildings, which the military and civilians used.

Overall, the findings of the study were consistent with those of UNEP's earlier assessments in the region: the levels of DU contamination were not a cause for alarm, but there was potential for groundwater contamination from penetrator-corrosion products or bioaccumulation of uranium salts from degraded DU dust.

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6 A scratch sample is a solid sample of material scraped off of a supposedly contaminated medium or structure.

7 When a DU penetrator makes contact with an object, the penetrator's surface cracks deeply. When the metallic uranium reacts with the environment, cavities, pores, and corrosion pits result.

Iraq, 2004–2007

The 1990–1991 Gulf War was the first conflict in which DU munitions were used extensively. In total, some 300 metric tons of DU-containing munitions were fired by the United Kingdom and the United States in the course of the war, and DU remained in the environment as dust or small fragments. To date, no independent scientific assessment of the impacts of the 1990–1991 conflict has been conducted in Iraq.

The 2003 Gulf War, which the United States named Operation Iraqi Freedom, began on March 19, 2003. Approximately 120,000 troops from the United States, 45,000 from the United Kingdom, and smaller forces from other nations (collectively called the Coalition Forces) were deployed to Iraq.

The war itself was preceded by air attacks, which continued during the land invasion. Several air attacks were conducted by A-10 Thunderbolt II aircraft, which fired DU munitions. UK and U.S. tanks also launched DU munitions in several land battles, mainly against Iraqi tanks. The UK Ministry of Defence reported that its troops fired approximately 1.9 metric tons of DU munitions during the conflict, and in June 2003 it provided UNEP with the coordinates of DU-firing points of the UK Challenger 2 tanks. The United States has not made available information concerning the quantity of DU munitions it used and the corresponding coordinates of firing points.

Rumors about health effects from a high concentration of DU residue on the battlefield concerned Iraqis and the international community. In July 2004, UNEP was requested to strengthen environmental governance in Iraq and was provided funding through the Iraq Trust Fund from the government of Japan. In addition, the United Kingdom funded an assessment of the environmental consequences of the conflict and helped build the capacity of Iraqi authorities to assess the potential risks caused by the use of DU munitions during the 2003 war.

In April 2005, UNEP convened a meeting in Geneva with the IAEA and WHO to discuss, coordinate, and plan work on the environmental and health effects of DU residue in Iraq. The three organizations agreed to collaborate on DU-related matters with the Iraqi Radiation Protection Center (RPC) of the Iraqi Ministry of Environment.

Because security constraints prevented international experts from traveling to Iraq, UNEP's DU capacity-building project had five main objectives: first, to train Iraqi experts to undertake a field-based assessment of DU using internationally accepted methodologies and modern equipment; second, to provide those trained with precise information on sites to assess and the type of samples to collect; third, to supervise the assessment remotely and retrieve samples for detailed analysis in the Swiss Spiez Laboratory on ISO/IEC 17025 accredited procedures;[8] fourth, to evaluate the field observations, monitoring

[8] ISO/IEC 17025 specifies the general requirements for competence to carry out tests and calibrations, including sampling. It covers testing and calibration performed using standard, nonstandard, and laboratory-developed methods.

results, and samples to draw conclusions on the effectiveness of the capacity-building activities; and, fifth, to review the results and provide recommendations for follow-up to the Ministry of Environment. The outcomes of the capacity-building project were detailed in a report published in August 2007 (UNEP 2007).

UNEP trained Iraqi experts from the RPC in three workshops designed to cover all aspects of conducting DU assessments. The first workshop, which was held at the Spiez Laboratory in May 2004, focused broadly on environmental inspections and laboratory analyses. UNEP and Spiez Laboratory experts trained participants on the basics of environmental inspections, as well as on soil, air, and water pollution; hazardous chemicals; and waste management.

The second workshop—on DU site–investigation techniques—took place in June 2005 in Amman, Jordan. The objective of the workshop was to provide training, equipment, and technical assistance to staff from the Ministry of Environment's RPC and from the Ministry of Health. Participants were trained to use portable field instruments and laboratory equipment, which were then handed over to the head of the delegation from the Ministry of Environment.

A third workshop held in Geneva in August 2005 concentrated on site-investigation techniques in urban areas. The practical training session of the workshop had a comprehensive agenda covering nearly all the measurement techniques useful in urban areas. It also comprised detailed training on sampling methods, cleanup, and small-scale decontamination measures. The practical fieldwork focused on realistically simulating the conditions of a site targeted by DU weapons. Measurement and cleanup techniques were demonstrated by the UNEP team and tried by each participant. Sampling strategies and techniques were also developed.

Based on the training and documentation received from UNEP and Spiez Laboratory (UNEP 2005, 2006), Iraqi staff collected environmental samples at selected sites in southern Iraq during sampling campaigns conducted in 2006–2007. Four areas in southern Iraq were selected for analysis, namely, Samawah, Nasiriyah, Basra, and Zubayr (see figure 4). The basis for site selection included battle reports, mainly collected through extensive Internet research; high-resolution satellite images, taken as close as possible to the end of the war; and UK coordinates of DU firing sites. The Iraqi team collected 520 soil, water, vegetation, and smear samples.

In order to ensure scientific reliability, samples were shipped to UNEP in Geneva for analysis by Spiez Laboratory. Analysts measured the content of uranium isotopes (U-238, U-236, U-235, and U-234), using high-resolution inductively coupled plasma mass spectrometry.

The radioanalytical results were shared with UNEP and the IAEA to estimate the radiation doses and corresponding exposure risk to Iraqis living at the four locations investigated. On the basis of the measurements and the committed doses calculated, analysts concluded that DU residues in the environment did not pose a

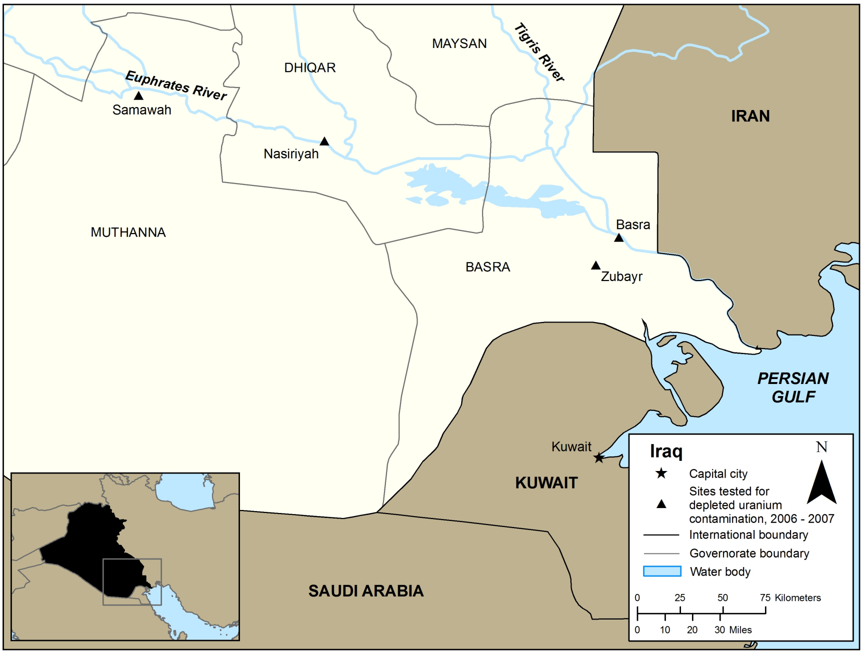

Figure 4. National assessment sites for depleted uranium in southern Iraq, 2006–2007
Sources: UNEP (2005, 2006).

radiological hazard to the population of the four studied locations, as long as people took minimum safety measures. The precautions included not entering vehicles hit by DU munitions, not undertaking long activities around objects hit by DU, not collecting penetrators or shrapnel that could contain DU residues, and not recycling or processing objects hit by DU. If these steps were taken, the estimated annual radiation doses that could arise from exposure to DU would be low (less than 0.1 mSv)—below the annual doses received by Iraqis from natural sources of radiation and therefore of little concern. The doses were also far below the annual action level of 10 mSv suggested by the ICRP as a criterion for determining whether remedial action is necessary.

Analysts concluded that a person would receive a significant dose of radiation only if he or she handled DU penetrators and penetrator fragments for a considerable period of time. A higher radiological risk was found where people entered vehicles hit by DU ammunition. Of particular concern were scrapyards where destroyed military equipment was stored and scrapping operations were conducted. But the doses received by workers involved in remelting DU-contaminated scrap metal were difficult to measure. Despite the lack of relevant data, not mixing DU-contaminated scrap metal with other scrap metal would be prudent. Using protective equipment, authorized personnel should dispose of scrap in accordance with international recommendations.

From a scientific point of view, the conclusions cannot be extrapolated to other locations in Iraq where DU ammunition was used because they depend on the amount of DU munitions fired, geographical and meteorological conditions, land use practices, and the population's habits. Without knowing the exact coordinates and firing data, it is difficult to predict potential contamination levels at other sites with any certainty. However, places exhibiting characteristics like those of the sites sampled would likely show similar contamination levels.

In 2010, the IAEA published the findings in *Radiological Conditions in Selected Areas of Southern Iraq with Residues of Depleted Uranium: Report by an International Group of Experts*, as part of the Radiological Assessment Reports Series (IAEA 2010).

LESSONS LEARNED AND RECOMMENDATIONS

The assessments resulted in a number of lessons learned and detailed recommendations to address and mitigate risks from the use of DU munitions. The recommendations are valid for any location potentially contaminated by DU.

Lessons learned

The main lessons learned from the post-conflict assessments of DU contamination are the following:

General

- Obtaining precise information on the location of DU-targeted sites, as well as secure site access, is an essential prerequisite for conducting effective measurements of DU contamination. Parties to conflicts should release the target coordinates and the number of rounds of DU fired in advance of any DU assessment.
- Localized surface contamination (i.e., a couple of grams of DU) can occur through four main pathways: dispersion and deposition (aerosolization) of fine DU particles immediately following an attack; weatherization of metallic DU pieces into corrosion products; dispersal of penetrators, smaller fragments, and dust on the soil surface, mainly through dilution by rainwater; or further redistribution by wind or flowing water, as in the case of smaller fragments and DU dust.
- The inner and outer surfaces of armored vehicles destroyed by DU ammunition will often be heavily contaminated by DU dust.

- Lichens appear to be reliable indicators of airborne DU contamination but only if they are within 200 meters of the zone attacked.
- Environmental effects of DU can be long-term, with resuspension of particles and groundwater contamination.

Soil

- Detailed laboratory analyses of surface-soil samples in areas where DU munitions had been used revealed low levels of localized ground contamination up to 200 meters from a weapon's impact.
- None of the sites showed contamination over large surfaces 200 meters from the target.
- Ground-surface DU contamination detectable by portable beta- and gamma-radiation detectors was typically limited to areas within one to two meters of penetrators and localized points of contamination caused by a penetrator's impact.

Corrosion of penetrators

- Penetrators buried near the surface of the ground and recovered had decreased in mass by approximately 25 percent over seven years. This finding, combined with UNEP's earlier studies of penetrators, shows that a DU penetrator can be fully oxidized into corrosion products (e.g., uranium oxides and carbonates) twenty-five to thirty-five years after impact.
- Penetrators lying on the ground showed significantly lower corrosion rates than those buried near the surface.

Drinking water

- In all the assessments conducted, DU was clearly identified in only one drinking-water sample. A second drinking-water sample from a well also showed traces of DU, but it was detectable only through use of mass spectrometric measurements.
- Contamination of the well may have occurred because of its position in the line of air attack.
- The concentrations found in the drinking-water samples were very low, and the corresponding radiation doses were insignificant to human health. This is also true considering the chemical toxicity of uranium as a heavy metal.

Air

- DU has been measured in air samples at a few sites, including buildings and vehicles hit by DU ammunition.

- The most likely cause of DU in the air is resuspension of DU particles by wind and human activity from contamination points, corroded penetrators, or fragments on surfaces.
- The concentrations of DU in air samples were very low, and resulting radiation doses were minor and insignificant. Inhalation and ingestion can have different exposure limits.
- If many penetrators hit hard surfaces and are aerosolized on impact, people nearby may inhale airborne DU dust.

Recommendations

In post-conflict countries where DU munitions have been used, governments should do the following:

General

- As a precaution, raise awareness of DU. Programs should cover DU in general, the risks incurred from inhaling and touching DU, the hazards posed by handling and storing remnants of DU weapons, and contact information of relevant authorities. The leaflet *Depleted Uranium Awareness* provides information on the DU ammunition problem (UNEP 2003b).
- Launch a campaign to train people, particularly children, not to pick up, play with, or chew DU penetrators, fragments, or casings.
- Publicize locations where DU ammunition has been used.
- Take steps to prevent people from entering military vehicles hit by DU munitions.
- Apply precautionary measures after a conflict, giving high priority to reducing risks associated with DU. Move military equipment hit by DU to zones inaccessible to the public, and clean surfaces contaminated by DU penetrators, DU fragments, and DU-related ammunition parts.

Handling of DU-contaminated material

- Avoid scrapping and remelting DU-contaminated military equipment.
- Identify secure areas for storing DU-contaminated equipment.
- Assess all conflict-related equipment for DU and, when positively identified, move it to secure locations.
- Restrict access to secure locations and scrapyards where DU-contaminated equipment is stored.
- Avoid trying to decontaminate DU-contaminated equipment in order to prevent radiation and toxicological hazards and management problems associated with the radioactive and toxic waste generated.
- Task authorized personnel with removal of DU residue (DU penetrators, penetrator fragments, and corrosion products) from surfaces in targeted zones, using international best-storage practices.

Groundwater

- Have local authorities monitor drinking-water quality on a regular basis at sites attacked by DU ammunition and in surrounding zones. Because there is uncertainty about the mobility of DU and DU-corrosion products from the ground to groundwater, further research is justified to better understand the dispersion of DU in conflict zones and the efficacy of removing DU penetrators and remnants.
- Use an alternative water source if DU is found in drinking water.

Buildings

- Remove penetrators and fragments from buildings and conduct precautionary surface decontaminations of rooms in which there could be DU remnants.

The findings and lessons learned should help the international community form a better understanding of DU risks in real conflict situations. The knowledge gathered from the assessments and capacity-building activities conducted since 1999 can help post-conflict countries to measure potential risks from contamination of air, soil, water, and vegetation as well as design cleanup operations and longer-term environmental monitoring.

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