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DEPLETED URANIUM

Depleted uranium (DU) munitions were used in both the Gulf War and the Balkans. Exposure to DU has been suggested as a possible cause of unexplained illness among veterans of these campaigns. The House of Commons Defence Select Committee has monitored concerns over DU throughout the 1990s; it asked POST to prepare this briefing to address:

- **military advantages and disadvantages of DU and possible alternatives.**
- **potential risks posed to human health.**

Military uses of DU

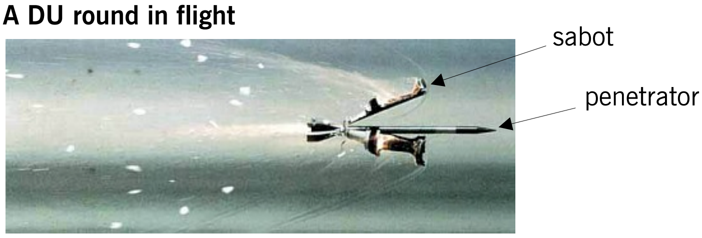
What is DU?

Uranium is a heavy metal, found naturally in small amounts in rock, soil and water. Nuclear weapons and most nuclear power stations use enriched uranium, which has a higher proportion of the more radioactive isotopes (see Box opposite). The uranium remaining after enrichment is 'depleted' and around 40% less radioactive than naturally occurring uranium. It has a very high density (a football-sized lump would weigh around 100kg) and is widely used for non-military purposes such as counter-weights on aircraft. DU is also used as radiation shielding in hospitals.

Use of DU in munitions

Armour-piercing ammunition fired from a tank typically consists of a rod about 50cm long (the penetrator) of tungsten or DU alloy, held in a 'sabot'. The sabot is discarded after the round leaves the muzzle (see Figure) and the rod continues at a speed of around 1.5km/s. On impact it punches a hole in heavy armour, producing a cloud of fine DU particles which burns fiercely (uranium dust ignites spontaneously in air). The rod itself does not contain explosive. Rather, it relies on the energy of the impact to pierce armour, and metal fragments from the penetrator and the vehicle's hull to destroy the tank. Such penetrators are most effective against heavy armour - if a light armoured vehicle is hit the rod can pass through, leaving only two small holes.

A DU round in flight



Properties of uranium

Naturally occurring uranium is weakly radioactive; it consists of three main types (isotopes). Of these, U-238 (with 238 particles in its nucleus) is the least radioactive and U-234 the most[1]. Uranium isotopes primarily emit alpha radiation, although beta and gamma radiation are also present. Alpha particles cannot pass through paper or skin, but are hazardous inside the body. Beta and gamma radiation can be an external health hazard.

In enriched uranium, the concentration of U-235 is enhanced. DU is produced as a by-product; it has less U-235 and U-234 (see Table below), so is less radioactive.

Composition of uranium

Isotope	Natural	Enriched	Depleted
U-234	0.005%	0.03%	0.001%
U-235	0.7%	3% to >90%	0.2%
U-238	99.3%	<10% to 97%	99.8%

DU is used for penetrating heavy armour because:

- It is very dense - the higher the density, the greater the energy upon impact.
- As a DU penetrator travels through armour, it deforms in such a way as to retain its sharpness, thereby increasing penetration. This is known as 'self-sharpening', and is in contrast to alternatives such as tungsten which deform into a 'mushroom' shape.

Overall, DU penetration of armour is 10-20% greater than tungsten; DU alloys are also easier to manufacture than tungsten alloys. The US Army began replacing tungsten rounds with DU in the 1970s. Because of its density and toughness, DU is also used by the US Army in tank armour, inserted between the layers of steel.

Which munitions contain DU?
DU is used by UK forces in two types of ammunition:
- 120mm anti-tank rounds for Army Challenger 2 tanks.
- 20mm rounds for the Phalanx close-in weapon system, deployed on some Royal Navy ships to defend against aircraft and sea-skimming missiles.

US forces use a wider range of DU munitions with various calibre rounds, in tanks, aircraft and ships. In particular, the A-10 anti-tank aircraft fires 30mm DU ammunition (widely used in the Gulf War, see Table below). As well as the UK and US, other countries including France, Russia, Israel and Turkey are developing or have acquired DU munitions but have not used them widely.

How much DU has been fired and where?
Apart from test firing (see Box below), the **Gulf War** of 1990-91 saw the first extensive use of DU munitions. This is the sole time UK forces have used DU in conflict. The only other confirmed use of DU munitions was by the US in the **Balkans** (1995 and1999 - see Table below.) As with all rounds fired in combat, most of these will not have hit their intended target. In total, around 290 (metric) tonnes (320 US tons) of DU was used in the Gulf. The US also used 594 tanks with DU armour - none of which was penetrated by Iraqi fire. No DU ammunition was fired by UK troops during the conflicts in the Balkans but US forces used around 11 tonnes of DU– about 25 times less than in the Gulf.

DU ammunition used in the Gulf and Balkans

Campaign	UK		US	
	DU rounds	DU tonnes	DU rounds	DU tonnes
Gulf	<100 tank fired anti-tank[2]	~1	9,500 tank fired anti-tank	45
			800,000 A-10 anti-tank	235
			4-5 Phalanx	-
			70,000 Harrier anti-tank	10
Balkans	None	-	11,000 A-10 (Bosnia)	3
			31,000 A-10 (Kosovo)	8

Note: Royal Navy Phalanx DU rounds were not fired in the Gulf.

DU test firing
UK experimental test firing of DU began in the 1960s and a programme to develop armour penetrators followed in the early 1980s. Between 1981 and 1995 around 3,200 DU rounds were tested at Eskmeals in Cumbria, where 120mm penetrators were fired against armour plate. Since testing began at Kirkcudbright in Scotland in 1982, around 6,400 DU rounds have been fired into the Solway Firth . This is a total of about 40-50 tonnes at the two sites.[3] No DU rounds have been fired in Army training exercises in the UK.

Effects on human health
Leaving aside its lethality as a component of armour piercing weapons, DU can affect human health in two main ways: through its chemical toxicity, and through its radiological effects (uranium emits ionising radiation that can cause cancer). In general, the main risks are posed by **internal** exposure (uranium that is ingested, inhaled or embedded in the body). **External** exposure is a theoretical radiological risk, although levels of exposure are likely to be very low. For instance, while tank crew face exposure from DU munitions on board and from any DU in the armour, it is generally agreed that such exposures are too low to pose a measurable health risk.

Chemical toxicity - evidence from animal studies and from research in humans exposed to high levels of uranium shows that the kidney is the organ most sensitive to uranium poisoning. As outlined in the Box below, the greater the solubility of DU, the higher the levels in the kidney and the greater the toxicological risk.

Radiological risk - exposure to alpha particles (see Box page 1) increases the risk of developing cancer, by damaging DNA. In contrast to chemical toxicity, radiological concerns centre on insoluble DU (see Box below), either in the form of insoluble particles in DU aerosols or as metallic shards embedded in the body.

The fate of DU within the body
This depends on two main factors: solubility and size.
Solubility - different forms of DU vary as to how readily they dissolve in bodily fluids, and thus how long they are retained within the body. Metal alloy in embedded shards is highly insoluble, and is thus retained within the body for many years. DU aerosol contains varying proportions of soluble and insoluble particles. The more soluble portion is rapidly excreted from the body (90% within 1-2 days) and this can lead to short-term elevation of DU levels in the kidney that might pose a toxicological risk.
Size – the size of particles in a DU aerosol influences where in the body they are likely to end up. Those smaller than 0.01mm can be inhaled deep into the small airways of the lung. In general, small, insoluble particles may be retained in the lung or lymph nodes for several years, and thus pose a long-term radiological risk

Protection standards
Current protection standards are outlined in the Table on page 3. In general, long-term **toxicological** standards are designed to protect the health of workers exposed to uranium dust and are expressed in mg of uranium per m^3 of air. They aim to ensure that steady state levels of uranium in kidney tissue do not exceed ~1 part per million (ppm, or 1 µg uranium per gram kidney)[4]. Such a level could be achieved by inhaling ~5mg of soluble DU aerosol or ingesting 60 mg of soluble DU.
Radiological protection standards are expressed in Sieverts (Sv); these take into account the amount of biological damage done. They assume there is no threshold for radiation effects; i.e. any radiation dose, no matter how small, is associated with an increased risk of cancer. For instance, the public health protection standard of 1mSv per year is roughly equivalent to one extra cancer death per 20,000 people annually.

Issues
Source and composition of DU
There has been some recent concern over the presence of contaminants such as plutonium in DU. In early 2001,

Toxicological and Radiological Protection Standards

Type	Value
Toxicological – US long-term[1] occupational exposure	0.05 mg/m^3 soluble uranium 0.25 mg/m^3 insoluble uranium
Toxicological - UK long-term[2] occupational exposure	0.2 mg/m^3 soluble uranium
Toxicological – US/UK short-term[3] occupational exposure	0.6mg/m^3 soluble uranium
Radiological – whole body dose for public	1 mSv per year
Radiological – whole body for occupational exposure	20 mSv per year (UK) 50 mSv per year (US)

Notes: 1 *Continuous exposure at 40 hours a week, 50 weeks a year.*
2 *Average daily (8 hour) exposure.*
3 *10 minute average exposure.*

the United Nations Environment Programme (UNEP) confirmed[5] that traces of plutonium and uranium-236 had been detected in American DU penetrators found in Kosovo. These are not found in natural uranium; their presence indicates contamination by material that has been 'recycled' through nuclear reactors. Such contamination is small (around 30 parts per million of U-236 and a few parts per trillion of plutonium) and UNEP concluded that this did not increase the penetrators' overall radioactivity significantly. Machinery used to manufacture DU is thought to have been contaminated by previous use for reprocessing nuclear fuel. Because the DU originates from the same source - the US Department of Energy - such contaminants will also be present in UK rounds. The Ministry of Defence (MoD) intends to analyse the composition of its 120mm rounds for these elements.

Alternatives to DU

MoD views DU ammunition as the best available way of penetrating tank armour, mainly due to its self-sharpening properties. Research underway to find an effective DU replacement is focussed on developing tungsten alloys. However, for tungsten to be as effective as DU, the penetrators may need to travel at higher speeds than those achievable with current tank guns. In contrast, DU rounds used by the Phalanx naval system are not intended for piercing heavy armour and are being replaced by tungsten. MoD state that this replacement is solely driven by operational (not safety) considerations - tungsten has been shown to provide longer range and greater effectiveness while costing ~40% less. MoD buys Phalanx rounds from the US, where production of DU rounds has already stopped. The MoD has procured tungsten Phalanx ammunition since 1996, but will use DU rounds until current stocks are exhausted (~2004).

Assessing exposures

Assessing exposures requires a range of assumptions about the amount of DU dispersed in particulate form (aerosol) on impact or ignition, particle sizes, solubility, etc. (see Box opposite). These are fed into metabolic models to predict how much DU will be taken into the body, where it will end up and for how long. The US Department of Defense (DoD) and others have calculated exposures for a range of scenarios, some of which are outlined in the Box on page 4. According to DoD, only military personnel inside a vehicle at the time of a DU impact could suffer exposures high enough to exceed protection standards.

However, these calculations are highly dependent on assumptions about solubility and size, which determine how rapidly DU is cleared from the body; some of the source data on the aerosol released during impact has also been questioned. Calculations by other groups, based on different assumptions, have pointed to the possibility of higher exposures, particularly for teams working in struck vehicles sometime after impact. DoD has assessed people exposed to long-term low-level radiation (e.g. by inhaling insoluble particles) as being at very low risk, although some veterans groups argue that it has underestimated these risks.

Properties of DU aerosol

Hard impact - US government funded tests show that in an impact against a hard target the amount of aerosol formed can vary from 3-70% of the DU mass (National Defense Research Institute estimates put the figure at 10-35%). Up to 96% of this may be respirable (0.01mm or less), 17-43% of which is soluble. Overall, it has been estimated that 20% of DU is converted to respirable dust in a hard impact. This is based on test firings at tanks; because air samplers inside a tank have a tendency to stop working shortly after impact, the tests may underestimate levels of DU aerosol. The robustness of this data is one of the issues currently being considered by a Royal Society Working Group on DU, which is expected to report in Summer 2001.

Fires - significantly less DU is converted to respirable dust in a fire. One estimate puts the proportion at less than 0.05%, 3-7% of which is soluble.

Source: Science & Global Security, 1999, 8:2, 125-161

Epidemiological studies and health monitoring

A large body of research has built up on the health of people exposed to uranium at work. Few adverse health effects have been seen among workers exposed to levels of uranium far higher than currently permitted. There are some claims of increased cancer rates among civilians likely to have been exposed to DU in the Gulf or the Balkans, but no reliable epidemiological studies have been conducted among such populations. The only large-scale studies involve military personnel. Research involving Gulf veterans is useful because the time-scale (10 years) is sufficiently long for potential health problems to have started to emerge. Health monitoring programmes for veterans in the US and UK show none of the health effects - increased rates of chronic kidney disease or cancer - that would be characteristic of excessive exposure to DU. However, it is possible that these programmes will pick up more long-term chronic effects in the years to come.

Another group of interest is the 15 or so US Gulf veterans with DU shards embedded in their bodies from 'friendly' fire incidents. These veterans have elevated levels of uranium detectable in their urine, as DU from the metal shards gradually leaches out. Over the ten years since the Gulf War, none of this group has developed conditions such as cancer or kidney disorders that might result from their DU exposure.

Scenarios for DU exposure

Inside a tank during multiple impact

For a person inside a tank struck by two DU penetrators the maximum inhaled dose is ~50mg of DU. This is based on the worst scenario arising from 'friendly' fire incidents in the Gulf War. Such exposure could lead to levels of DU in the kidney (4ppm) that exceed toxicity thresholds and result in a maximum whole body radiation dose (40-48mSv) outside the UK annual occupational radiation limit (20 mSv/year).

One km downwind of a struck tank

It has been calculated that a 120mm DU anti-tank round releases ~1kg of respirable aerosol when it hits a hard target. Total inhaled levels of exposure 1 km downwind of such a strike are ~2-20µg. At such doses toxicological or radiological safety levels are unlikely to be exceeded.

Inside a struck tank after impact

Damage assessment and clean-up teams entering struck vehicles after they have been hit can also be exposed to DU[6]. DoD estimates based on measurements of DU levels inside struck vehicles suggest that a maximum of 0.025mg per hour of DU could be inhaled and 0.057mg per hour ingested. Assuming 3 hours exposure (the maximum time spent on maintenance or damage assessment tasks) spent in each of the 31 tanks hit by 'friendly' DU fire, the resulting total kidney (0.15ppm) and whole body radiation doses (<0.5mSv) are inside the protection standards. Other estimates however lead to potentially higher exposures. For instance, if it is assumed that just 1% of the settled particles become re-suspended, then a dose of up to 150 mg DU per hour could be inhaled (less than 90 minutes inside the tank could lead to the kidney damage threshold being exceeded).

Population exposure

Members of the public may be exposed to DU, for example by ingesting vegetation coated with DU dust or drinking contaminated water. However, a European Commission expert group recently concluded that, taking into account 'realistic' scenarios of exposure, radiological exposure to DU could not result in a detectable effect on human health. A UNEP report in March 2001 assessed the environmental contamination and population exposure to DU in Kosovo. No widespread contamination was found, and the overall risks were assessed as insignificant. Although no DU was found in groundwater, UNEP were concerned about possible future contamination. In contaminated areas, uranium levels in groundwater could rise by 10-100 fold, enough to exceed World Health Organisation drinking water standards.

Sources: Science and Global Security 1999, 8:2, 125-61.
Environmental impact of DU used during the 1999 Kosovo conflict, UNEP 2001.
Exposure Investigation Report: Depleted Uranium in the Gulf (II), US DoD, December 2000.

Recent reports in the media have focussed on Balkans veterans from various countries who have developed leukaemia. Although there is no systematic evidence of excess cancer rates among such veterans, the reports have suggested DU as a possible cause of these leukaemias. However, evidence from the Japanese A-bomb survivors shows that it takes several years for leukaemia to emerge following radiological exposure. Some governments involved in the Balkans campaigns have announced initiatives to monitor the health of veterans. In the UK the MoD is currently consulting on a proposed voluntary screening programme for Balkans and Gulf veterans; this includes consideration of the most appropriate tests for uranium. The World Health Organisation is also taking steps to monitor the health of civilians in DU areas.

Assessing the pros and cons of DU

A formal cost benefit analysis of DU's military advantages against its potential health effects would be far from straightforward. Health 'costs' are difficult to value, while costs of military operations tend to be classified. Military benefits are also difficult to quantify as they are situation specific. For instance, if a DU round stands a better chance of disabling an enemy vehicle, how much does this contribute to the wider battle and to the overall war? Finally, even if such benefits can be quantified, there remains the problem of assigning a monetary value to them. Thus the calculations involved in cost benefit analysis of DU munitions are likely to be extremely complex, and the results subjective and inconclusive.

Overview

- MoD and DoD agree that DU is the most effective means currently available of penetrating heavy tank armour. Tungsten alloys remain the most promising alternative, but more development is needed.
- The main health risk to military personnel is from inhalation of DU aerosol in confined spaces. Personnel inside tanks struck by 'friendly fire' and those engaged in operations inside struck vehicles may have received doses in excess of protection standards. Risks to clean-up crews are readily minimised by ensuring that simple safety procedures are followed and basic protective clothing worn.
- UNEP assessed health risks to the Kosovan population from DU as insignificant but identified water contamination as a possible future issue. It recommended environmental clear-up of DU sites.
- Calculations of possible exposure are fraught with uncertainty. The Royal Society is undertaking a study of DU's effects on human health and the environment, due to be published in early summer 2001. This will review the primary evidence and assumptions on which exposure calculations are based.

Endnotes

1 A substance which decays slowly (i.e. is weakly radioactive) has a long half life.
2 A version of the Charm 1 120mm DU round being developed for the new generation of Challenger 2 tanks was used. It was modified to replace tungsten rounds in Challenger 1 tanks then in service. Some additional DU rounds were also used in training in the Gulf.
3 Around 500 rounds were also fired at West Freugh and Foulness.
4 It was based on evidence from animal experiments suggesting that kidney damage occurs above a threshold of around ~3 ppm. While this threshold has become widely accepted, its provenance is one of the factors being considered by the Royal Society Working Group.
5 Contamination by U-236, technecium-99 and transuranic elements such as plutonium had already been reported by DoD (for example, Exposure Investigation Report: Depleted Uranium in the Gulf (II), Dec 2000).
6 Personnel entering struck vehicles may also be exposed to other toxic chemicals (e.g. hydrocarbons & dioxins from burnt plastics).

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