The health effects of depleted uranium munitions

ANNEXE F Previous assessments of doses from DU exposures

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(Note that in this annexe our comments are in this format: ie in italics and brackets, to distinguish them from comments in the original reports.)

F1 AMCCOM (1990)

US Army Armament, Munitions and Chemical Command (AMCCOM) Task Group Report. Kinetic Energy Penetrators: Environmental and Health Considerations (Abridged) Kinetic Energy Penetrator Long Term Strategy Study Picatinny Arsenal NJ (referred to as Danesi M E 1990 in AEPI 1995).

Note: Other relevant aspects of this report are included in annexe E, section E1.

F1.1 Combat issues

Combat issues are described in volume 1 p 4-5, volume 2 appendix D pp D-10 – D-12 and pp D-18 – D-20 and appendix F.

Overall it recommended that studies of combat health and environmental impacts be performed. It expected that "impacts to civilian populations will not be significant from combat use, including post-combat impacts. However, aerosol DU exposures to soldiers on the battlefield could be significant with potential radiological and toxicological effects. These health impacts may be impossible to quantify reliably even with additional detailed studies. It is not our intention to overstate this issue given other combat risks, nor to imply that the health of soldiers will definitely be compromised. We are simply highlighting the potential for levels of exposure to military personnel during combat that would be unacceptable during peacetime conditions."

However, the assessments described do not seem to lead to high doses. Three situations are considered.

- For radiation from a half-filled DU kinetic penetrator ammunition rack measured at a location occupied by the tank crew member closest to the rack for 6 hours/day, 7 days/week, 52 weeks/year, the maximum radiation exposure is of the order of 0.25 rem/year (2.5 mSv/year).
- Cole (1989) estimated that for a soldier taking refuge in a tank that had been struck by a DU penetrator the maximum exposure is 23 mrem (0.23 mSv). *(We did not obtain the internal report by Cole.)* This use of unpublished work was criticized by AEPI (1995, p 96): "Reports should be reviewed inside and outside DoD to increase the number of expert reviewers and to enhance the credibility of reports. Independent peer review is crucial because too often studies are performed by or for an organization that has a vested interest in the results. For example, based partly on Cole's experimentation and analysis, Danesi concluded that soldiers can safely take refuge in a DU-contaminated vehicle (Cole 1989, Danesi 1990). Cole works for a DU munitions manufacturer, and Danesi cited an internal report, sponsored by the manufacturer, that did not undergo an independent review. In spite of the high quality of Cole's report, its conclusions are less credible because they lack rigorous independent confirmation."
- A "major tank battle" scenario is described: "The largest tank battle recorded to date took place in the Arab-Israeli war of 1973, a 150-tank armor engagement. Using this as a unit of

tank battle, the following assumptions are made to quantify exposures:
1) four rounds are fired for every tank kill;
2) all tanks are killed (600 rounds);
3) the largest penetrators (5 kg) are used (total 3000 kg);
4) 25% of the penetrator is aerosolized on impact (total 750 kg);
5) all aerosolized DU settles on the 50-hectare battlefield (750 kg over 500,000 m^2 = 1.5 g m^{-2});
6) the soil is mixed to a depth of 0.005 m (hence aerosolized DU concentration = 1.5 g/(0.005 m^3);
7) the soil bulk density is 1.5×10^3 kg m^{-3} (hence aerosolized DU concentration = 1500 mg/(0.005 m^3 $\times1.5\ 10^3$) kg m^{-3} = 200 mg DU/ kg soil)."
The resulting maximum contaminant level at the soil surface is calculated to be 200 mg kg^{-1}, or about 100 times background levels. Until the first rainfall, the settled aerosol can be resuspended due to the movement of ground troops or ground vehicles. Assuming a maximum total suspended solids concentration of 0.25 mg m^{-3}, and a 24 hour exposure during two months of combat, then the lifetime increased cancer risk for military personnel in such a battle is 1.5×10^{-7}. *(An air concentration of 0.25 mg m^{-3} and breathing rate of about 20 m^3 per day (ICRP 1994a) gives an intake of 5 mg soil per day or 0.3 g in 2 months. At a concentration of 200 mg DU per kg soil this is a total intake of 0.06 mg DU, for which the dose is about 0.006 mSv. For a risk of 5% Sv^{-1}, this gives a risk of 3 ´ 10^{-7}.)* Assuming that this air concentration did not decrease with time (unreasonable), the risk to population immediately downwind over 70 years was estimated at 3×10^{-5}.

It is also assumed that half the penetrators reflect off the tank armour and the fragments are scattered over the 50-hectare battlefield. This gives 1125 kg, which is assumed to dissolve at 1% per year, giving 3 mg kg^{-1} in the surface soil, but no further use is made of this.

Volume 2, appendix F "Potential Radiation Doses Associated with the Battlefield Use of Depleted Uranium Munitions" is described as a preliminary assessment of some of the issues involved in potential battlefield radiation doses. However, it uses as sources PNL-5415 (Mishima et al 1985) and PNL-5298 (Haggard et al 1986). These relate to trials in which penetrators were heated in fires rather than impact tests, and so do not seem appropriate.

F2 DRPS (1993)

Defence Radiological Protection Service. Radiological and Chemical Hazards of Depleted Uranium. DRPS report 13/93. Available at www.mod.uk.

This document provides the results of an assessment of the radiological and chemical risks associated with the use of DU in munitions. It considers a number of exposure pathways, as summarised below. However, it gives no information on the methodology used, models, assumptions made or sources and quality of data. The document consists of only 24 paragraphs with no references.

F2.1 Radiological hazard

External
It notes that the external radiation hazard is mainly from beta-, gamma- and X-ray radiation; the alpha radiation poses no external hazard to intact skin. It reports that measurements made by AWE and DRPS showed that personnel would need to be in a fully DU loaded tank for 1500 hours to reach the then current annual whole body dose limit (50 mSv). *(This suggests dose-rates up to ~30 µSv h^{-1}, considerably higher than the 1–2 µSv h^{-1} reported by Harley et al 1999 (annexe E, section*

E5.3).) The annual whole body dose limit in the UK is now 20 mSv.)

In armament depots or stores, over 5000 hours of exposure to DU are needed to exceed a whole body dose of 50 mSv.

The main external radiation hazard from DU is from contact with bare skin; the current dose limit to the skin would be exceeded by continuous contact of more than 250 hours per year. *(This seems consistent with a dose rate to skin of ~2 mSv h^{-1} (section 2.2 'External exposure' of appendix 1) and a dose limit for skin of 500 mSv y^{-1}.)*

Internal

The internal radiation hazard during normal handling of DU ammunition is negligible as the DU has a protective coating. The main internal radiation hazard is to the lungs from the inhalation of the insoluble oxides formed when DU burns in air. Inhalation of 80 mg of insoluble DU would result in the (effective) whole body dose limit being exceeded. Entry of these oxides into the body by ingestion or through wounds is unlikely to be significant.

F2.2 Chemical toxicity

Permissible working levels for soluble and insoluble uranium compounds are based on chemical toxicity and radiation hazards respectively. The Health and Safety Executive has published Occupational Exposure Limits for 'Uranium compounds, natural, soluble': a long term exposure limit (8 hour time average) of 0.2 mg m^{-3}, and a short term exposure limit (10 minute time average) of 0.6 mg m^{-3}.

F2.3 Use in combat and immediate aftermath

Personnel in a vehicle surviving the impact of a DU round could possibly inhale ~3 mg DU per second.

At 100 m downwind of the impact of a large calibre DU round, an unprotected person would inhale less than 0.2 mg DU, and the external radiation dose rate from material deposited on the ground would be about 0.15 µSv per year.

Around a vehicle (with full load of DU ammunition) struck by a large calibre DU round, the external radiation dose from material deposited on the ground would be about 5 mSv per year. In a post combat zone personnel working around a battle-damaged tank could inhale up to 0.3 mg of DU.

The most significant radiation hazard in vehicles penetrated by DU rounds arises from the inhalation of DU. Under post-combat conditions, personnel could inhale 1.6 mg of DU per hour and in 50 hours the dose limit (50 mSv) for the whole body would be exceeded. Ingestion of DU could occur in this situation but it is unlikely to exceed 160 mg per day.

F3 Fetter and von Hippel (1999)

The hazard posed by depleted uranium munitions. Science and Global Security **8**, 125 – 161.

This is a comprehensive assessment of the radiological and chemical hazards resulting from the use of DU munitions. A notable and praiseworthy feature of this paper is that the various calculations performed are explained clearly and fully. As noted in the Introduction: "In order to make our results more transparent we also include an Appendix where the most important radiation doses are estimated using a back-of-the-envelope approach". The "tentative conclusion" is that risks

appear to be very low to surrounding populations and persons not in direct unprotected contact with vehicles struck with DU munitions or any areas heavily contaminated by burning DU. However, it is noted that it is more difficult to assess the risk to soldiers in vehicles struck by munitions personally or involved in rescue, repair and clean-up operations.

Two minor limitations from a European standpoint are the use of non-SI units (curies and rem) and ICRP publication 30 models rather than the current ICRP models (annexe A).

F3.1 External exposure

Individual exposure

It states that the theoretical maximum whole body gamma dose-rate from external exposure to DU is 2.5 millirem h^{-1} (0.025 mSv h^{-1}). Footnote 9 gives the basis for the statement. This is compared to values reported by Harley et al (1999) for the dose rate in a fully loaded tank of <0.2 millirem h^{-1}. The dose rate to a person standing on flat ground uniformly contaminated with 1 ton of DU km^2 (a reasonable upper limit for battlefield areas) would be about 1 millirem y^{-1} (0.01 mSv y^{-1}). Footnote 12 gives the derivation. This is 10% of the dose rate from uranium naturally present in soil.

The dose-rate for DU in contact with bare skin is given as about 230 millirem h^{-1} to the skin (2.3 mSv h^{-1}). It is noted that the skin is relatively insensitive to radiation and even continuous direct contact is unlikely to produce radiation burns or any other short-term effect. The rationale behind that statement is given.

Population exposure

It is explained that an important prediction of a linear no-threshold dose-response relationship is that the number of predicted cancer deaths does not depend on how the dose is distributed among the population. The number of cancer deaths is proportional to the sum of the doses to all the exposed persons or the 'population dose' (collective dose, annexe C, section C4.1). The population dose for external exposure to contaminated soil D_e (person-rem y^{-1}) is given by:

$$D_e = C_e M r$$

where C_e is the dose rate conversion factor, M is the total amount of DU dispersed, and r is the population density. On this basis it was calculated that if 300 tons of DU were dispersed over an area with a population density of 50 km^{-2}, the total population dose would be roughly 200 person-rem which would result in 0.1 cancer deaths, ie a 1 in 10 chance of one cancer.

F3.2 Internal exposure

Based on the research report summaries in OSAGWI (1998) it was estimated that in hard target impacts, about 20% of the DU mass is converted into respirable aerosol and in fires <0.05%.

F3.3 Health effects of internal exposure

It is noted that the health risks posed by DU aerosols depend on size and solubility in body fluid. ICRP publication 30 models are used to calculate the amounts of uranium in various organs as a function of time after intake, and hence the resulting radiation doses.

Radiation effects

Masses are calculated which would lead to the current US occupational exposure limit of 5 rem (50 mSv) y^{-1}: about 0.1 gm of insoluble aerosol, 3 gm of soluble aerosol or, by ingestion, 30 gm of soluble material or 600 gm of insoluble material.

Chemical toxicity

It is noted that the kidney is generally considered to be the most sensitive organ and that significant cell death is believed to occur above a concentration of 3 parts per million uranium (ppm) in kidney tissue, ie 3 μg U g^{-1} kidney. It is noted that the US Occupational Health and Safety Administration (OSHA) has set "permissible exposure levels" for uranium aerosols of 0.05 mg m^{-3} for soluble compounds and 0.25 mg m^{-3} for insoluble compounds. These are based on continuous exposure that would result in a concentration of about 1 ppm in the kidney. It notes that a concentration of 1 ppm in kidney would result from inhaling about 5 mg of soluble uranium or 300 to 1400 mg of insoluble aerosol. However, it notes that lower doses of uranium might have adverse, but as yet unrecognised, health effects.

F3.4 Individual exposure

It notes the difficulty of making estimates because the concentration is sensitive to the nature of the release, weather conditions etc. A combination of estimates and test data is used to estimate doses individuals might receive in various circumstances.

Outside struck vehicles

An estimate is made of the size of the initial cloud of aerosol formed, based on the explosive yield. It is noted that the kinetic energy of a 5-kg DU penetrator is equivalent to about 1.4 kg of TNT. A large fraction of this kinetic energy is converted to heat in less than one millisecond. The initial concentration within the cloud is estimated, and the duration of exposure calculated from the radius of the cloud and the wind speed. This leads to a maximum estimated inhaled dose of about 0.1 mg. Consideration is then given to being downwind of a number of such impacts, and to inhalation downwind of fires.

Inside struck vehicles

Reference is made to measurements indicating intakes of 10 to 20 mg based on measurements by Fliszar et al (1989) as reported in OSAGWI (1998). A similar estimate is made based on urine excretion from veterans who were in struck vehicles but who do not have retained shrapnel (note 40, see also annexe C section C2.3).

Doses from retained fragments are calculated: from dissolution of the fragments and resulting doses to other organs; and doses around the fragments themselves.

Consideration is then given to people entering contaminated vehicles. It is noted that such doses are very difficult to estimate. As a hypothetical example it is considered that a vehicle might be contaminated with 100 g of DU. If 1% of the aerosol were resuspended at any time and the interior volume was 10 m^3, the concentration would be 100 mg m^{-3}, giving rise to an intake rate of 150 mg of DU h^{-1}. On this basis, kidney damage cannot easily be dismissed, emphasising the importance of education and use of protective equipment.

F3.5 Population exposure

Inhalation

Population dose from inhalation is estimated using a simple 'wedge model' from which the population dose can be estimated from the mass of DU dispersed, the fraction released as respirable aerosol, the average population density and the average deposition velocity of the DU aerosol. On the basis of 10% of 300 tons of DU converted to aerosol, and dispersed over an area with an average population density of 50 km^{-2}, the population dose would be roughly 2000 person-rem, equivalent to 1 additional cancer death. There were however large uncertainties on this, giving a range of 40 to 20,000 person-rem.

Resuspension

Again, the wedge model was used to calculate the population dose from resuspension. For the same 30 tons of DU aerosol, the estimated population dose is in the range 30 to 14,000 person-rem, similar to that from inhalation of the initial cloud.

Ingestion

It is assessed that because of the low solubility and low transfer of uranium by root uptake and ingestion by animals, the main contribution results from consumption of produce contaminated by direct deposition on to leaves, either from the cloud or resuspension. Using the same scenario it is estimated that the population dose is about 600 person-rem.

F3.6 Environmental effects

A detailed investigation was beyond the scope of the article but it is considered likely that when averaged over reasonably large areas the effects are likely to be perturbations similar in magnitude to those resulting from variations in the concentration of natural uranium. In the US the average concentration is about 2 ppm but with a range of 1 to 4, and in some areas of the world concentrations as high as 10 ppm are found.

F4 Liolios (1999)

Assessing the risk from the depleted uranium weapons used in Operation Allied Force. Science and Global Security **8**, 163 – 181.

This is concerned specifically with the possible impact of the use of DU by NATO in Kosovo, but was researched before details were available on the number and type of weapons used. It starts with descriptions of weapons that might (or might not) have carried DU. As with Fetter and von Hippel (1999) the wedge model is used to estimate the average long-term dose. The total amount (*I*) of DU inhaled is given by:

$$I = M\, b\, r\, u^{-1}$$

where M is the total amount of DU released, b the breathing rate, r the average population density and u the deposition velocity.

Various worst case scenarios are put forward. However, the conclusion is that for neighbouring countries radiological and chemical risks are negligible while for the people of Yugoslavia itself any increase in cancer mortality will be so low that it would remain undetected.

F5 NUREG (1999)

United States Nuclear Regulatory Commission. Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials. Draft Report for Comment (NUREG-1717).

This report is an assessment of potential radiation doses associated with current exemptions from requirements for domestic licensing for certain radioactive materials in the USA. Doses were estimated for the normal life cycle of a product or material, covering distribution and transport, intended or expected routine use, and disposal. In addition, assessments of potential doses due to accidents and misuse were estimated. The report covers applications of DU as counterweights in aircraft etc, and shielding in containers for transporting radioactive sources. In particular, a hypothetical aircraft accident and fire involving 850 kg DU is considered. Effective doses are estimated to be 0.3 mSv to a fireman and 4 mSv to a clean-up worker (page 3-253, table 3.17.8).

However, the models used are generic; they do not consider specific information on the combustion of DU.

F6 UNEP (1999)

United Nations Environment Programme. The Potential Effects on Human Health and the Environment arising from Possible use of Depleted Uranium During the 1999 Kosovo Conflict: A preliminary assessment.

The task of the Technical Mission of the UNEP/Habitat Balkans Task Force was to "assess the potential health and environmental impact of DU used in the Kosovo conflict". The work covered by the report consisted of a study of the literature, a Fact Finding Mission to Kosovo and a desk assessment. The report contains background information on:

- uranium and DU;
- military use of DU;
- environmental behaviour and effects of DU.

The purpose of the Fact Finding Mission to Kosovo was to determine whether it would be possible to make a field study (sampling and measurements campaign) related to DU in the environment. It concluded that under the circumstances at that time, it was not meaningful because the effects of DU are mainly localised to the places where DU ammunition had been used, the affected areas were likely to be small, and it would be difficult to find them without information. Furthermore, the areas to be investigated needed to be cleared of landmines and be safe.

F6.1 The scenario and assumptions

The work included "assessing, by means of a desk study, the medium- and long-term potential health and environmental impacts of depleted uranium used in the Kosovo conflict…". At the time, no information was available on the extent to which DU had been used by NATO in Kosovo. A hypothetical scenario was therefore considered, based on a number of assumptions. These were chosen to be as realistic as possible, but where there were uncertainties, conservative assumptions were made, ie the real levels and consequences would probably be less than those calculated. The scenario, and assessment of its consequences, are described in Appendix 8. Appendix 10 gives dose coefficients for DU, based on the current ICRP models (annexe A), but using default (reference) values only, ie AMAD of 1 µm (default for environmental exposure), absorption types F, M and S. Type S is assumed for inhalation exposures.

The basic assumption is that DU was used in Kosovo, but only by aircraft. It is assumed that an attack includes 3 aircraft and the total DU used in the attack is 10 kg; the target is one or more vehicles, and the area affected by the subsequent DU contamination is 1000 m^2.

The impact of DU on soldiers and civilians in the vehicles and on the affected area during the attack is not considered specifically. However, it is assumed that persons in the immediate vicinity are briefly exposed to the dust cloud, which has a very high density.

Most of the dust is assumed to settle on the ground within the area of 1000 m^2. After some time, other people enter the area, which may be cultivated. These people cause re-suspension of dust, breathe contaminated air, touch contaminated objects, and are externally exposed from solid

pieces of DU ammunition that are picked up. Some of the DU is dissolved by water percolating through the soil, contaminating the groundwater, which serves a well nearby.

Instantaneous inhalation of DU dust after an attack
Inhalation outside a target immediately after an attack is considered. It is accepted that the dust concentration would probably be very high initially. It is considered that instantaneous intake by breathing of more than 1 gram of dust is "unendurable". It is reasonable to assume that the dust is a mixture of DU and other materials: 10% DU is assumed, giving a maximum intake of 100 mg DU. It is considered that this might lead to acute chemical toxicity, but a total effective radiation dose of less than 10 mSv. However, such high dust concentrations can only occur immediately after an attack and close to the target.

Inhalation of resuspended DU
Dust from the ground may become airborne through action of the wind, walking, digging etc and be inhaled. All the DU is assumed to be present in the form of small particles (<10 μm) and to be in the form of insoluble oxides (type S). For the purpose of the assessment it is assumed that all the DU is mixed into a 1-mm thick soil layer that contributes to the airborne dust load. A dust loading approach is used (annexe C, section C3.4).

It is assumed that 10 kg DU is spread over 1000 m^2 containing 1 m^3 of soil (weight 1500 kg) down to 1 mm. Hence the DU concentration of the dust will be 6 μg DU per mg dust.

Normal dust concentration is 50 μg m^{-3} in air outdoors and in very dusty air 5 mg m^{-3} which leads to 0.3 μg DU m^{-3} and 30 μg DU m^{-3}, respectively. (From a chemical point of view these levels are lower than or within the range of hygiene standards for chronic exposure.)

A breathing rate of 1 m^3 per hour is assumed. A stay in the area of 2 hours would lead to an intake of 0.6 – 60 μg of DU, and an effective dose of 0.07 – 7 μSv. A continuous stay of a year under the most dusty conditions would lead to no more than a few tens of mSv. Normally dusty conditions would lead to 100 times less. A safety margin comes from the possibility that only a minor part will be resuspended. From studies on particle sizes of DU aerosols almost 90% of the particles were larger than 125 μm, but significant resuspension can only be expected for particles less than 20 μm. The basis for this is given in Appendix 4, section 5: "…a study of the environmental consequences of using DU rounds from A-10 aircraft for training purposes (Nellis 1997)…suggest that dispersion and deposition would be fairly localised. The impact of past use of DU munitions at the US Nellis Air Force Range (Nellis 1997) included a program of soil sampling which indicated that only 13% of soil particles were smaller than 125 μm. It also concluded that particles larger than 100 μm are unlikely to be resuspended by the action of wind or the movement of vehicles and that only particles smaller than 20 μm in diameter were likely to remain airborne long enough to reach air samplers around the DU impact area. This indicates that, at least for the site considered, the potential for resuspension of particles remaining in the environment will be low."

Conversely, the area might be smaller eg 100 m^2, in which case the individual dose for a 2-hour stay might be 10 times higher ie 0.7 – 70 μSv. However assumption of a smaller area decreases the probability that anyone would stay in the same narrow wind direction all the year which reduces the resulting annual dose correspondingly.

Other pathways
Consideration is given to ingestion by transferring soil to the mouth (children), by eating contaminated vegetables, from hands coming in contact with contaminated skin and clothes, from contaminated water and from meat of contaminated animals. Consideration is also given to

wounds and to picking up penetrators.

F7 Brown (2000)

Depleted Uranium Munitions and Assessment of the Potential Hazards. Notes of a Presentation to the Royal Society Working Group on 19 January 2000.

These notes contain some details of the inputs used in DRPS assessments of the potential hazards that might arise from the use of DU munitions (DRPS 1993, section F2). It is noted that this is not a comprehensive review and that reference should also be made to other publicly available documents. Some observations are made on related topics such as the suggestions that the use of DU munitions during the Gulf conflict has led to illnesses amongst some veterans of that conflict and an increased incidence of ill health amongst the civilian population of southern Iraq. Comments are also provided on the uranium-in-urine testing carried out on some UK Gulf veterans. They do not address health effects or chemical toxicology. They also contain some previously unpublished data from DU ammunition trials (annexe G, section G9).

Paragraph 5 discusses monitoring of Gulf War veterans. It notes that published data suggests that no "unusual" levels of urinary excretion of uranium have been found in US veterans who were in or on vehicles when struck by DU munitions, but do not have retained DU shrapnel (Hooper et al 1999, McDiarmid et al 1999, annexe C, section C2.3). It also states that: "No DU contamination above the limit of detection of the monitoring equipment was found when lung monitoring was carried out on a small number of UK veterans for reassurance purposes in 1991 and 1993. The limits of detection of the equipment were 2000Bq and 70Bq in 1991 and 1993 respectively". *(These activities, presumably of uranium isotopes, correspond to about 130 mg and 5 mg DU respectively (14.9 Bq per mg, table 2 of appendix 1). The time between potential exposure and the first measurement is not given, but even at 1 – 10 days after intake, lung retention using the current ICRP model is about 5 – 10% of the intake, and so the first measurement would only exclude intakes of about a gram or more (depending on the time between exposure and measurement, etc). The latter, more sensitive, measurements were made after about 2 years, by which time predicted lung retention would be 2% of the intake for type S material or 0.05% for type M material. Lung retention of less than 5 mg therefore excludes intakes of 250 mg and 10 gram respectively.)*

Paragraph 6 notes that "MOD believes that it is possible that small quantities of DU dust may have been inhaled or ingested by some UK troops taking part in the Gulf conflict. However no DU munitions were used in attacks on British troops and assessments carried out to date suggest that any risks arising from these exposures, whether radiological or toxic, have been small". *(However, no reference is given here, and as noted in section F2 the published assessment (DRPS 1993) gives few details.)* It further notes that "The Government accepts (and has often stated) that there could be possible risks to health to anyone spending prolonged periods within a few tens of metres of the point at which a DU round had impacted with a hard target".

F7.1 DU hazard assessment input and results

Paragraphs 9-18 mainly summarise the US assessments and their findings (eg OSAGWI 1998, Harley et al 1999, AEPI 1995). It concludes that "The broad picture that emerges from all these documents is that most contamination from the impact of DU on a hard surface is contained within several tens of metres of the point of impact and these contaminated areas are separated by large tracts of essentially uncontaminated land… Trials indicate that the proportion of DU converted to

an aerosol when a DU penetrator strikes a target depends on factors such as the hardness of the target, the velocity of the round and the angle of incidence of the penetrator on the target. Very little particulate is formed if the target is easily penetrated and the largest quantities of particulate result from impacts on armour plate of the type used in main battle tanks".

With regard to chemical form, it notes that "…there seems to be general agreement that uranium ignites and burns in air at 700-1,000°C and that heating DU at temperatures greater than 1,000°C gives primarily U_3O_8. At temperatures below 1,000°C, UO_2 predominates. One paper suggests that temperatures of the order of 3000°C are reached when a DU penetrator hits armour plate and that UO_2 and U_3O_8 are the main species formed".

F7.2 Monitoring of Iraqi vehicles

Between 1992 and 1994, DRPS visited Army establishments in the UK and Germany to undertake radiation surveys of foreign vehicles and trophies brought back from the Gulf. No traces of DU were detected in any of these surveys, with a limit of detection of 5 Bq cm^{-2}. *(This corresponds to ~0.3 mg cm^{-2} (14.9 Bq per mg, appendix 1, table 2), which, co-incidentally, is close to the central estimate of internal contamination used here in assessing exposures inside vehicles (annexe C, section C3.3). Clearly, the surface contamination (if any) in the vehicles monitored could have been far lower than this. However, it is not stated whether these vehicles had actually been struck by DU weapons and if so whether they had been cleaned.)*

F7.3 Reprocessed DU

"DU produced from uranium which has been used as a fuel in nuclear reactors will inevitably contain traces of long lived isotopes not found in natural uranium and trace activities of long lived beta-gamma radioactive fission products," including uranium-236 (appendix 1, table 2). However it notes that "...uranium-232 may also be present as a result of neutron interactions with protactinium-231, but the amount will be very small. Some plutonium may also be present, but isotopes such as uranium-237 and those uranium isotopes with mass numbers higher than 238 have such short half-lives that they are of no importance...". It is reported that although the DU used in UK tank ammunition has passed through plant that has also been used for processing uranium from nuclear reactors, the manufacturers have confirmed that this material is not 'reprocessed uranium' as it does not contain the levels of fission products and transuranic elements found in reprocessed material. This is supported by the results of periodic radiochemical analyses and radiation dose-rate measurements carried out by MOD.

F7.4 UK Test and Evaluation Work

Particle size distributions and air concentrations near impacted targets are reported and used in annexe G (section G9). It also reports on limited data available on the effects of DU munitions striking high density concrete from incidents in which experimental DU rounds malfunctioned during test-firing. Results from some low volume air samplers are presented but they also relate to the clean-up operation and several earlier trials. High volume air samplers at greater distances gave activity concentrations for the month that were broadly consistent with the results obtained during routine site operations. "An important point to note is that very little contamination was discovered on the ground around the point of impact and that most of the DU was recovered in physically large fragments."

It is stated that in 1992 the atmospheric dispersion and consequence analysis code CRACUK was used to assess the health risks from DU particles released during test-firing at hard targets. It was assumed that 20% of the DU was dispersed to atmosphere, that 10% of the kinetic energy of the

penetrator was supplied to the plume, and that all material dispersed is 1 μm. Smoke trials gave confidence that CRACUK could be used effectively in this situation and the study indicated that any radiation doses to the public from the test-firing of DU munitions would be very much lower than the doses from natural background radiation sources.

F7.5 DRPS hazard assessments

This section provides some background information to UK assessments, including DRPS (1993). The earliest reference to any DRPS assessment of the risks from using DU in combat dates from the mid-1980s when Vulcan Phalanx systems were being introduced into the Royal Navy. There are no details of how this risk assessment was carried out, but it concludes that health risks from the use of DU munitions will be of much less significance than the other risks that troops face in combat situations. This is in agreement with the views expressed in contemporary US documents.

More recent DRPS assessments were based on data from US trials referenced in this note and information from a limited number of UK studies. The principal UK finding arose from a 'Total Recovery Exercise' in which it was determined that 80% of the DU used during firings of large calibre ammunition into armour plate could be recovered by simple mechanical means (ie by sweeping and hosing) from an area within 50 m of the target. Some of this material remains embedded within the target as a result of the DU and steel melting together during the impact and this gives rise to beta dose-rates of the order of 100 $\mu Sv\ h^{-1}$ at the metal's surface. Experience shows that there are many outcomes possible when a DU penetrator is fired at a target in combat: it may miss the target, glance off the surface, become lodged in the target or penetrate the vehicle.

"A study of the literature and data referenced in this note led DRPS to consider the following scenarios when assessing the possible radiation risks to UK troops in the Gulf. All cases referred to the impact of a single 5kg DU penetrator on armour plate of the type found on main battle tanks. It was also assumed that all particulate material would be highly insoluble (ie ICRP lung class Y now renamed as type S material) as this gives rise to the highest radiation dose per unit intake. For situations in which troops could have been exposed while well away from target vehicles, 20% (ie 1kg) of the DU was considered to be released to atmosphere in a respirable form. For situations in which troops could have been working alongside target vehicles after any plume of combustion products had dispersed, 40% (ie 2kg) of the DU was considered to be uniformly deposited on the ground within 50 m of the point of impact with 20% (ie 0.4kg) of this being in a respirable form. For work inside armoured vehicles penetrated by DU munitions, 40% (ie 2kg) of the DU was considered to have been deposited on horizontal surfaces within the vehicle with 20% of this material (ie 0.4kg) being in a respirable form. The professional judgement of the radiation protection advisers involved in the assessment was that these values were rather conservative but this was justified by the nature of the problem and quality of the source data. However, it was always expected that some would consider these figures to be unduly optimistic or unduly pessimistic."

Reference is made to Fetter and von Hippel (1999) as the only known peer-reviewed published hazard assessment.

F8 Snihs and Åkerblom (2000)

Use of depleted uranium in military conflicts and possible impact on health and environment. Swedish Radiation Protection Institute. SSI*news* volume 8, 1–8, Dec 2000

This article summarises much of the report of UNEP (2000), including the assessment. *(However it should be noted that it contains a number of printing errors in the units with 'm' used instead of 'm'.)* In addition, it gives a preliminary report on a mission by a Scientific Expert Team to Kosovo in November 2000. Using information provided by NATO, the team visited 11 sites where DU had been used. Samples of soil, water and vegetation were collected, and a number of DU penetrators and contaminated spots were found.