

MEMORANDUM**The health effects of depleted uranium munitions: a summary****The Royal Society Working Group on the Health Hazards of Depleted Uranium Munitions**

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Abstract

There has been a substantial amount of public discussion on the health effects of the use of depleted uranium (DU) munitions. In response to this concern the Royal Society set up an independent, expert working group to investigate the health effects of DU munitions. The Royal Society has now produced two reports, and this summary covering the key conclusions and recommendations from both reports. The part I report considered the increased risks of radiation-induced cancer from exposures to DU on the battlefield. Part II dealt with the risks from the chemical toxicity of uranium, non-malignant radiation effects from DU intakes, the long-term environmental consequences of the deployment of DU munitions and responses to part I including issues arising at a public meeting to discuss the part I report.

The concerns

Munitions containing penetrator rods of depleted uranium (DU) are used on the battlefield to destroy heavily armoured vehicles. These munitions contain no explosive charge but the extremely dense DU rod, travelling at high speed, is able to pierce the heavy armour of a modern battle tank. About 340 tonnes of DU were used in munitions during the 1991 Gulf War, and an estimated 11 tonnes in the Balkans in the late 1990s.

Concerns have arisen as DU is a chemically toxic and weakly radioactive substance. Its use on the battlefield can lead to it being spread over a wide area, with potentially hazardous consequences for those on the battlefield during or shortly after an engagement, for those living or returning to live in the area and for the environment generally. This is additional, of course, to the obvious dangers faced by those inside a vehicle struck by a DU munition.

The military use of DU has therefore generated considerable public controversy, and various claims have been made about the dangers associated with it. The Royal Society therefore convened an independent expert working group to review the present state of scientific

knowledge on the subject. The group has produced two very detailed scientific reports, which have been published and are also available on the web¹. The two reports are: *The Health Effects of DU Part I* (likely exposure levels, radiological effects, epidemiology), May 2001 and *Part II* (effects from chemical toxicity, environmental impact and responses to part I), March 2002. The membership of the working group is given at the end of this document. This summary brings together the key points from both reports. It should be stressed that neither report considers whether DU munitions should or should not be deployed, the military merits of DU munitions or the phenomenon of Gulf War Syndrome. The Council of the Royal Society has endorsed both the reports and this summary of them.

The working group examined the extensive scientific literature relevant to the subject and consulted widely among all those with an interest, including those with direct personal experience of DU and DU munitions and those with relevant scientific expertise. Correspondence with interested parties has continued throughout the study. After publication of its first report, the group convened a public meeting where a panel comprising the Chairman, the Chief Scientific Adviser at the Ministry of Defence, the Chief Scientific Adviser to the Gulf Veterans Association and a representative of the Low Level Radiation Campaign commented on the report's conclusions and responded to questions from the audience of about 80.² This summary also addresses the key points arising from that public meeting.

Health effects

(i) *Radiological effects.* The three main routes of human exposure to DU on the battlefield are inhalation, ingestion and wounding. On impact with an armoured vehicle substantial amounts of DU may be dispersed as particles that can be inhaled and DU fragments may cause shrapnel wounds. Due to the lack of measurements of actual levels, our approach has been to estimate the typical levels of exposure on the battlefield over a wide range of scenarios, and the worst-case exposures that are unlikely to be exceeded. From these we calculated the potential health risks from radiation and toxic effects. We have also considered relevant animal studies and epidemiological studies of occupational exposures to uranium in other situations as an independent source of information on the risks of inhaling DU particles, although we recognise that the parallels may not be precise.

There are still uncertainties that need to be resolved, particularly in the estimates of DU intakes that could occur in different situations on the battlefield. Most of these uncertainties arise as a consequence of the lack of good experimental data on the amounts of DU that may be inhaled within and close to tanks struck by a DU penetrator, and the almost complete lack of any measurements of DU in urine samples taken soon after exposure to a DU impact aerosol. Despite these uncertainties, it is possible to set reasonable upper and lower limits on the intakes and subsequent health effects of DU on the battlefield.

The greatest exposure to radiation resulting from inhaled DU particles will be to the lungs and associated lymph nodes, and an increased risk of lung cancer is considered to be the main radiation risk. Using worst-case assumptions the predicted radiation doses to the thoracic lymph nodes are about ten times higher than those to the lungs, but the risks of cancer of the lymphatic system are considered to be much lower as the thoracic lymph nodes are more resistant to radiation-induced cancers than the lungs, although this view has

¹ Parts I and II are available in printed form at £17.50 each; orders should be sent to Jacqueline Knapp, The Royal Society, 6–9 Carlton House Terrace, London SW1 5AG, UK; telephone 020 7451 2645; e-mail sales@royalsoc.ac.uk. Electronic copies of the reports and their technical annexes can be also found on the web at www.royalsoc.ac.uk/policy.

² A summary of the public meeting can be found on the Royal Society website (<http://www.royalsoc.ac.uk/events/DUPubMeetRevReport.pdf>).

been challenged by some. The central estimate is intended to be representative of the average individual in a group. The central estimate of the excess risk of fatal lung cancer was about one in a thousand for any soldier receiving a large intake (e.g. surviving in a struck tank) and was about one in 40 000, or less, for other scenarios. This compares with the lifetime risk of fatal lung cancer in the general population of about one in 250 for non-smokers and one in six for cigarette smokers. Central estimates of risks of other cancers, including leukaemia, were lower than those for lung cancer for all DU exposure scenarios. Under worst-case assumptions the excess risk of fatal lung cancer for the most heavily exposed soldier could be about one in 15.

One issue raised at the public meeting was the possibility of effects on the immune system from inhaling DU particles. Effects on components of the immune system have been observed in humans and animals exposed to large intakes of radioisotopes that irradiate the red bone marrow. The levels of irradiation of the red bone marrow for all DU exposure scenarios are predicted to be less than those from background sources, except for a soldier receiving a very large intake under worst-case assumptions, where they could be considerably higher than background levels, but would probably still be too low to cause effects on the immune system that would increase susceptibility to infection.

(ii) *Chemical toxicity.* It is well established from animal studies, and there is supporting evidence from human exposures, that the kidney is the organ most susceptible to the toxic effects of uranium. A large body of literature exists about the toxic effects of inhaled, ingested and injected uranium compounds on laboratory animals. However, there are large differences in the susceptibilities of animal species to uranium, which make it difficult to use the animal data to estimate the intakes of uranium that have adverse effects in humans.

There are few studies of humans exposed to substantial intakes of uranium and hence the concentrations of uranium in the kidney that lead to serious adverse effects are not well documented. Very few humans have had sufficiently large acute intakes of uranium compounds to lead to severe kidney dysfunction or kidney failure. Studies of these few cases indicate that kidney failure is likely to occur within a few days at concentrations above about 50 μg uranium per gram kidney.

The levels of kidney uranium for extended periods of time that lead to minor kidney dysfunction in humans (measurable by sensitive biochemical tests of kidney function) are not well established, but are considered to be at least tenfold less than the value of 3 μg uranium per gram kidney that has often been used as the basis for occupational exposure limits. Acute, or short-term, exposures that lead to concentrations of about 1 μg uranium per gram kidney have been associated with minor kidney dysfunction, but the levels of kidney uranium that can occur for a short period without causing long-term adverse effects on the kidney have not been defined.

The available evidence suggests that there is little, if any, increase in kidney disease among workers involved in the processing of uranium ores or in uranium fabrication plants. However, this is not necessarily reassuring since the daily intakes that occurred from chronic inhalation exposure to uranium particles in these industries would typically have been much lower than the acute intakes that could be received by the most heavily exposed soldiers in a military conflict. Also, the typical forms of the inhaled particles in industrial settings and on the battlefield will be different, and these alternative forms might not have the same adverse effects.

The kidney is a resilient organ and in a young adult about two-thirds of kidney function can be impaired without obvious clinical signs of disease. Similarly, apparently normal kidney function can be restored even after a large acute intake of uranium. This raises difficulties when assessing the health of Gulf War veterans, since large intakes of DU, which could increase the

chance of lung cancer or kidney disease in later life, would probably not be apparent from a clinical examination or from standard blood and urine analyses carried out several years after exposure. For those who may have been exposed at some time in the past to substantial intakes of DU an analysis of uranium isotopes in urine is required to assess intakes and the possibility of any long-term health consequences.

From the estimated DU intakes for most soldiers on the battlefield it is not expected that adverse effects on the kidney would occur. Levels of uranium in the kidney of soldiers surviving in tanks struck by DU rounds, or of soldiers working for protracted periods in heavily contaminated vehicles, could lead to some short-term kidney dysfunction, but whether this would lead to any long-term adverse effects is unclear. According to worst-case assumptions, kidney uranium levels in some soldiers could be very high, and would probably lead to kidney failure within a few days of exposure, although we are unaware of any such cases of kidney failure.

(iii) Other health effects. Large inhalation intakes of DU particles may result in short-term respiratory effects, as would a large intake of any dust, but long-term respiratory effects are not expected, except perhaps for the most heavily exposed soldiers, under worst-case assumptions, where some fibrosis of the lung could occur from radiation effects, in addition to an increased risk of lung cancer.

Uranium is deposited in bone but there is insufficient evidence to conclude whether large intakes of DU on the battlefield could have adverse effects on the bone.

There is recent evidence that uranium may directly damage genetic material and there is a possibility of damage to DNA due to the chemical effects being enhanced by the effects of the alpha-particle irradiation.

(iv) Other evidence. Extensive evidence was taken from Dr Doug Rokke who was part of a unit involved in assessing battlefield damage after the Gulf War and in cleaning up allied and Iraqi tanks after combat. Dr Rokke considers that for a number of reasons the intakes for soldiers involved in these activities would have been substantially higher than we proposed. Some of these claims conflict with those in military reports. Nevertheless, we have provided estimates of DU intakes, and of the risks of cancer and adverse kidney effects, for these proposed levels of exposure. If these very large exposures to DU are realistic, a small number of soldiers who worked for very long periods cleaning up vehicles struck by DU munitions during the Gulf War might have suffered adverse health effects, involving kidney damage and a substantial increase in the risk of lung cancer.

Measurements of uranium isotopes in the urine of some veterans have been carried out in Canada. In discussions with Dr Asaf Durakovic on this subject it became clear that there are uncertainties about the reliability of these measurements of DU in urine, due to the absence of an appropriate control group and the difficulties associated with obtaining reliable isotope ratios from samples of urine containing small amounts of uranium. However, reliable measurements of DU in urine would be valuable even ten years after the Gulf War as they probably could still provide an assessment of intakes and risks.

Environmental impact

After a conflict in which large numbers of DU munitions are deployed, those who return to live in the area will be exposed to resuspended DU particles, and in some cases to contaminated food and water supplies. We have therefore assessed the long-term effects on the environment. Contamination will occur mainly from DU particles and penetrator fragments deposited on or in the soil and from intact penetrators buried in the ground. It is believed that in both the

Persian Gulf and the Balkans about 70–80% of all DU penetrators remain buried in the soil. The movement of DU from these sources, and from deposited DU particles and fragments, into susceptible components of the environment will depend on a number of factors, including the rates of corrosion, which depend on soil properties, the amount of resuspension of soils and the proximity of DU penetrators to surface soils, and water sources that feed into local water supplies. These sorts of factors will also influence the extent of uptake of DU by plants and intakes by food animals.

The levels of environmental contamination will be very variable, which makes it difficult to generalise about DU intakes. These levels could range from being so small that they do not materially increase the concentration of uranium naturally present in the environment to worst-case scenarios, such as the soil around a penetrator impact site, or a penetrator lodging directly in contact with groundwater which could feed uranium directly into a local water supply, such as a well.

Initially, exposure of the local population will be to DU particles resuspended from contaminated soil, and from contaminated food, but the inhalation exposure and intakes from food will decrease, and the proportion of exposure from intakes of DU from contaminated water sources will increase. Estimates of intakes from DU particles resuspended from soil suggest that they will not lead to a detectable increase in any cancer among those returning to the conflict area, or among peace-keepers, although there are major uncertainties in the estimates of inhalation intakes of DU in the years following a conflict. Intakes of DU from contaminated food and water will be dependent on variations in the distribution of DU, local soil conditions and human behaviour and site-specific assessments are required where there are grounds for concern.

Measurements of environmental contamination in Kosovo have not shown widespread contamination with DU although hot spots of contamination are present around penetrator impacts. Contamination of soil at impact sites can lead to significant exposure to DU, particularly for children playing in the area and ingestion of heavily contaminated soil. Most of the DU deployed in a military conflict remains in the ground and contamination of water supplies is a concern in the longer term. Environmental movement of DU from buried penetrators will be slow and monitoring of uranium contamination in water supplies therefore needs to be carried out for many decades in areas where DU munitions were deployed.

Conclusions

Based on our own estimates of intakes of DU, we have drawn the following conclusions:

- (a) Except in extreme circumstances, any extra risks of developing fatal cancers as a result of radiation from internal exposure to DU arising from battlefield conditions are likely to be undetectable above the general risk of dying from cancer over a normal lifetime. This remains true even if our estimates of risk resulting from likely exposures are 100 times too low.
- (b) The extreme circumstances will apply only to a very small fraction of the soldiers in a theatre of war, for example those who survive in a vehicle struck by a DU penetrator, or those involved in cleaning up struck vehicles. In such circumstances, and assuming the most unfavourable conditions, the lifetime risk of death from lung cancer could be about twice that in the general population.
- (c) Any extra risks of death from leukaemia, or other cancers, as a result of exposure to DU are estimated to be substantially lower than the risks of death from lung cancer. Under

all likely exposure scenarios the extra lifetime risks of fatal leukaemia are predicted to be too small to be detectable.

- (d) The radiological risks from the use of DU in munitions are for the most part low, but there are uncertainties in the levels of exposure that could occur under unfavourable conditions, and for small numbers of soldiers there could be circumstances in which the excess risks of lung cancer are substantial. It is for this reason that further work should be undertaken to clarify the extent of intakes on the battlefield.
- (e) The estimated DU intakes for most soldiers on the battlefield are not expected to result in concentrations of DU in the kidney that exceed $0.1 \mu\text{g}$ per gram kidney, even transiently. Consequently, in these cases it is not expected that adverse effects on the kidney or any other organ would occur.
- (f) Levels of uranium in the kidney of soldiers surviving in tanks struck by DU rounds, or of soldiers working for protracted periods in heavily contaminated vehicles, could reach concentrations that lead to some short-term kidney dysfunction, but whether this would lead to any long-term adverse effects is unclear as adequate studies of the long-term effects on the kidney of acute or protracted exposures to elevated levels of uranium are not available. According to worst-case assumptions, kidney uranium levels in some soldiers could be very high, and would probably lead to kidney failure within a few days of exposure. We are not aware of any cases of kidney failure, occurring within a few days of exposure, in US soldiers who would have received the highest DU intakes during the Gulf War, but we cannot rule out some kidney damage for such soldiers under worst-case assumptions.
- (g) For those returning to live in areas where DU munitions were deployed, including peacekeepers, the inhalation intakes from resuspended DU are considered to be unlikely to cause any substantial increase in lung cancer or any other cancers. The estimated excess lifetime risk of fatal lung cancer is about one in a million, although there could be higher risks for some individuals with worst-case intakes of DU due to higher levels of local contamination. Estimated risks of other cancers are at least 100-fold lower. There are, however, large uncertainties in the estimates of inhalation intakes in the years following a conflict.
- (h) No effects on kidney function from inhalation of resuspended DU are expected for most individuals who return after a conflict. Small effects on kidney function are possible using worst-case assumptions, but would at most only apply to a small number of individuals.
- (i) Ingestion of DU in contaminated water and food, and from soil, will be highly variable and may be significant in some cases, e.g. children playing in areas where DU penetrators have impacted, ingestion of heavily contaminated soil or where a buried penetrator feeds uranium directly into a well. Environmental movement of DU from buried penetrators into local water supplies is likely to be very slow and over a period of decades levels of uranium could increase in some local water supplies.

Recommendations

Against the background of these conclusions we recommend the following long-term studies, monitoring of health effects and further research.

Long-term studies:

- Long-term epidemiological studies of soldiers exposed to DU aerosols, or with retained DU shrapnel, should be undertaken to detect any increased incidence of cancers, non-malignant lung disease and kidney disease, in later life.

- Although there is no clear evidence that occupational exposures to uranium have consequences for reproductive health, effects on reproductive health have been observed in mice after high intakes of uranium. Accordingly, epidemiological studies of the reproductive health of Gulf War veterans and of the Iraqi population are underway. If effects are seen then further investigation would be required to estimate the relative contributions from DU and from other possible causes.
- Long-term environmental sampling, particularly of water and milk, is required and provides a cost-effective method of monitoring sensitive components of the environment, and of providing information about uranium levels to concerned local populations. Monitoring may need to be enhanced in some areas, by site-specific risk assessment, if the situation warrants further consideration.
- Localised areas of DU contamination provide a risk, particularly to young children, and areas should be cleared of visible penetrators and DU contamination removed from areas around known penetrator impacts.

Monitoring of health effects:

- Any UK veterans with high level exposures should be identified, and invited to participate in an independent evaluation programme.
- In any future conflict using DU munitions, measurements of urinary uranium and sensitive modern biochemical tests of kidney function need to be carried out, as soon after exposure as practical, and at subsequent intervals, on soldiers who are exposed to substantial intakes of DU. This information is required to estimate radiation risks and also to estimate the levels of uranium in the kidney and the likely effects on health from the chemical toxicity of uranium. Any studies of individuals who might have received substantial intakes of DU must include the most modern sensitive biochemical methods to detect signs of kidney dysfunction and should involve an expert nephrologist.
- There are reports that DU has been detected in the urine of some Gulf War veterans but the reliability of the available measurements is subject to considerable uncertainty. A carefully validated method for measuring uranium isotope ratios in urine containing small amounts of uranium is required. These studies should be conducted at independent laboratories with the collaboration of veterans' groups. Such studies are being progressed by the MOD's DU Oversight Board.
- A small number of US veterans in the Gulf War worked for protracted periods in heavily contaminated vehicles, and so could have received large intakes of DU. There are anecdotal reports of deaths and illness in these veterans and an independent study of mortality and morbidity among them is required to examine possible causes.
- The risk of lung cancer from alpha-emitting particles in the lungs is well characterised but the risk of lymphoid and haemopoietic cancers from alpha-particle irradiation of thoracic lymph nodes is more controversial. A detailed review of the evidence concerning the contribution of alpha-particle irradiation of the thoracic lymph nodes to the development of lymphoid and haemopoietic cancers is warranted.
- Serious effects on the kidney and lung are possible under worst-case assumptions for a few soldiers who could receive large acute exposures to DU on the battlefield. Any case of acute kidney failure occurring within a few weeks of exposure should be thoroughly investigated to establish whether high kidney uranium levels could be the cause.

Further research:

- Better estimates of the levels of DU, and the properties of DU aerosols, resulting from test firing under realistic conditions into heavy-armour tanks are required. These should

include measurements of DU concentrations in air within and around struck tanks and those arising from resuspension of DU-containing dust in contaminated vehicles.

- Models should be developed and validated to enable DU exposures to be predicted in a wide range of circumstances. When further modelling and experimental data are available new independent assessments of the resultant risks, particularly from high exposures, should be undertaken.
- A better understanding of the behaviour of DU oxides produced during penetrator impacts and DU corrosion products is required. Applications of this include long-term studies of *in vivo* dissolution of DU oxides and the environmental behaviour of the corrosion products of DU–Ti alloys³ and particles relative to naturally occurring uranium minerals.
- Information should be obtained on the bioavailability of the DU–Ti products from DU munitions and their corrosion products (particles, metallic fragments and secondary precipitates associated with the corrosion process), and on whether bioconcentration of these materials occurs in local food animals or plants.

Résumé

Un nombre important de discussions publiques ont été consacrées aux effets sanitaires de l'emploi de munitions à l'uranium appauvri (UA). Pour répondre à ce souci, la Royal Society a constitué un groupe de travail formé d'experts indépendants, pour rechercher quels sont les effets sanitaires des munitions (UA). La Royal Society a écrit deux rapports; ce résumé regroupe les conclusions clés et les recommandations de ces deux rapports. Le rapport constituant la partie I considère l'augmentation des risques de cancers radio-induits résultant de l'exposition au (UA) sur le champ de bataille. La partie II a traité aux risques venant de la toxicité chimique de l'uranium, aux effets 'non malins' du rayonnement venant de l'(UA) ingéré; elle traite aussi de conséquences à long terme pour l'environnement du déploiement de munitions à l'(UA); elle répond à la partie I et donne les conclusions d'une réunion publique consacrée à discuter la partie I.

Zusammenfassung

Die gesundheitlichen Auswirkungen verbrauchter Uranmunition werden in der Öffentlichkeit intensiv diskutiert. Als Reaktion auf diese Sorge bildete die Royal Society eine unabhängige Arbeitsgruppe aus Sachverständigen zur Untersuchung der gesundheitlichen Auswirkungen verbrauchter Uranmunition. Die Royal Society hat jetzt zwei Berichte erstellt, sowie diesen Überblick, der die wichtigsten Schlussfolgerungen und Empfehlungen beider Reports zusammenfasst. Teil I des Reports befasste sich mit den erhöhten Risiken von strahlenverursachtem Krebs durch Strahlenbelastungen aufgrund verbrauchter Uranmunition auf dem Schlachtfeld. Teil II befasste sich mit den Risiken aufgrund der chemischen Toxizität von Uran, nicht bösartigen Strahlenauswirkungen in Folge der Aufnahme verbrauchter Uranmunition, den langfristigen Umweltfolgen des Einsatzes von verbrauchter Uranmunition, sowie Reaktionen auf Teil I, einschließlich Fragen, die bei einer öffentlichen Diskussion von Teil I des Reports gestellt wurden.

³ The DU used in penetrators and armour is alloyed with 0.75% titanium. The corrosion properties of this alloy may differ from that of pure DU.

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