OPINION

OF THE GROUP OF EXPERTS ESTABLISHED ACCORDING TO ARTICLE 31 OF THE EURATOM TREATY

DEPLETED URANIUM

6th March 2001

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
ENVIRONMENT
Directorate C - Nuclear safety and civil protection
ENV.C 4 - Radiation protection

FOREWORD

1. The European Commission is fully conscious of the concerns which have been expressed relating to the health effects of *exposure* to depleted uranium (DU). This followed reports of cases of cancer in soldiers who had served in the Balkans. A link with DU, which has been used in ammunition to improve its armour penetrating capacity, has been claimed. The use of DU in the Balkans has been confirmed by NATO.

2. It is against this background, and the facts that many of the soldiers who had served in the region are EU citizens, and that some EU civilians had also visited the region for prolonged periods, that the Commission felt it would be helpful to obtain a scientific opinion on the potential radiological health effects of DU.

   The Community has certain responsibilities under the Euratom Treaty in relation to dangers arising from ionising radiation. For this purpose the Commission relies on independent scientific opinions. The experts who provide these opinions are also well placed to advise on the possible health effects of DU on humans as well as effects on the environment.

3. The Commission therefore convened a Working Party of the group of independent scientific experts established according to Article 31 of the Euratom Treaty with a view to providing such an Opinion. The group's competence, according to the text of the Treaty, is to advise on the protection of the health of workers and the general public against the dangers arising only from *ionizing radiation*. The attached Opinion provides this advice but is limited to the legal competence exercised by the Commission and thus relates to overall issues of potential health consequences and associated risks under varying circumstances of radiological *exposure* to DU. The Opinion is so worded as to be of general application to both civil and military applications of DU. Nevertheless, it is important to underline the context in which this advice was sought. In addition, the group was asked to take note of the chemical toxicity of uranium, but the Opinion relates only to the radiological health consequences.

4. To relate the Opinion to the potential problems in Kosovo, it is worth noting that NATO has now confirmed that 31,000 rounds of DU ammunition, each containing about 300 g DU, were fired in Kosovo. This approximates to 10 *tonnes* in total, or in volume terms, approximately one half of a cubic metre. It is believed that a high proportion (90%-95%) of the projectiles did not hit intended "hard targets" and therefore did not lead to any significant production of uranium compounds in aerosol form, and that many are buried in the ground. The radiological consequences of the different *exposure* pathways are examined in the Opinion.

Bâtiment Jean Monnet, Rue Alcide de Gasperi, L-2920 Luxembourg - Office: WAG C/320.
Telephone: direct line (+352)4301.33073, switchboard 43011. Fax: 4301.34646. Telex: COMEU B 21877.
Telegraphic address: COMEUR Luxembourg

5. The Commission holds the view that the use of depleted uranium in any application other than in a military conflict is subject to the requirements of the basic safety standards (BSS[1]) for the radiation protection of workers and members of the public. The Opinion relates to uses of depleted uranium in metal form or high-density compounds for its elemental properties, not because of its radioactivity or possible further use in the nuclear fuel cycle.

   The findings obtained in the light of the specific context will enable the Commission to judge whether there is a need to amend the BSS for the considered uses of DU.

   As well as requesting the Article 31 Experts to study the available information and to produce this Opinion, the Commission has exchanged information and collaborated with other international organisations which are also working in this area, namely the IAEA, UNEP, WHO and NATO.

6. The Group of experts had sufficient scientific information available as to the chemical and physical behaviour of uranium and on its behaviour within the human body to deliver its Opinion. The group also had sufficient information on pathways to man and the potential radiological consequences.

7. More information is being collected and analysed by the responsible authorities on location of deployment of personnel, proximity of the local population to attacks involving DU, and precise composition of the DU. In addition, more information is expected relating to the incidence of diseases in different categories of affected populations. It is noted that UNEP will report in March on the results of samples taken in Kosovo. Member Nations of NATO, including Member States of the EU, are also conducting monitoring campaigns on the environment and on personnel sent to the region.

8. It is not expected that the additional data will affect the main conclusions drawn by the Experts, but of course unexpected findings may need to be examined thoroughly as to their implications for these conclusions. Pending the collection of further data and the publication of detailed reports by UNEP and WHO, the Opinion of the Experts will help the Commission to consider whether further action needs to be taken or further efforts need to be spent in the assessment of the situation. The Commission also hopes that the publication of this Opinion will allow the general public and the press to understand better the possible health consequences of DU.

S. Kaiser
Head of Unit
6th March 2001

[1] Council Directive 96/29/EURATOM.

THE OPINION

OF THE GROUP OF EXPERTS ESTABLISHED ACCORDING TO ARTICLE 31 OF THE EURATOM TREATY

DEPLETED URANIUM

Properties and uses of Depleted Uranium

Properties

1. Uranium is a naturally occurring heavy element which is found in all soils and rocks. The average content in soil is about 3 grams per *tonne*[2] (3 mg/kg, UNSCEAR 2000). In seawater the concentration is fairly constant at 3.3 μg/l, increasing with salinity.

2. Natural uranium consists of a mixture of three radioactive isotopes which are identified by mass numbers: ^{238}U (99.27% by mass), ^{235}U (0.72%) and ^{234}U (0.0054%). The isotopes of uranium were present at the time of formation of the Earth's crust. Their very long half-lives result in a very low specific radioactivity. Uranium is used in nuclear power plants and most reactors require uranium fuel which is enriched in ^{235}U from its normal level of 0.72% to about 3%. The uranium remaining after removal of the enriched fraction contains about 0.2% of ^{235}U, 99.8% of ^{238}U and about 0.001% of ^{234}U; this uranium is referred to as depleted uranium and is only about half as radioactive as natural uranium. The chemical and biological properties of depleted uranium are identical to those of natural uranium.

3. In nature, uranium is in *secular equilibrium* with the daughters of the decay chain. Natural uranium together with its daughters yield 7-8 times as many α decays per unit time as pure uranium. In the decay chain of ^{238}U is ^{222}Rn, a natural radioactive noble gas which escapes from soil or rock and accumulates in dwellings, workplaces and mine galleries. The inhalation of short-lived α-emitting daughters of radon may cause significant exposure and is a major contributor to the world-average radiation *dose*. When uranium is separated from its ore, the decay products, being different elements, are removed. After separation, the uranium isotopes continue to decay, and the daughters "grow" back in. The first members of the decay chains (Annex 1) have short half-lives, and soon return to their equilibrium values. However, ^{230}Th (formed from ^{234}U), and ^{231}Pa (formed from ^{231}Th) have long half-lives, and so grow in very slowly. Hence in processed uranium (natural or depleted) the activities of ^{230}Th and ^{231}Pa and subsequent members of the chains are negligible.

4. Depleted uranium (DU) may also be obtained from uranium extracted from spent fuel by *reprocessing*. In that case ^{236}U, an isotope not found in natural uranium, will be present. It is then possible that trace amounts of *transuranics* (Am, Np, Pu) and *fission products* (^{99}Tc) are also present (OSAGWI)[3]. On the basis of measured concentrations of these radionuclides in samples of DU, it has been calculated that in the event of an intake of DU, they would increase the radiation *dose* resulting from the uranium isotopes by less than 1%.

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2 Items in *italic* are explained in the glossary

3 In the United States, 60 samples have been analysed which are supposedly representative of the stockpile of DU used to manufacture all ammunition and armour since the Gulf War.

5. As is the case with all heavy metals, uranium in all its soluble forms has a recognised chemical toxicity and depending on circumstances this factor may be more important than, and should not be confused with, its radiological toxicity.

Uses of Depleted Uranium

6. Because of its high density (19×10^3 kg.m^{-3} or 19 tonnes. m^{-3}) and other physical properties, depleted uranium is used for military purposes, particularly to penetrate armour plate, and also defensively as it possesses advantages when used in armour.

7. Civilian uses of depleted uranium include use as counterweights in airplane construction, shields for irradiation units in hospitals and containers for transport of radioactive sources.

8. In addition to the above uses of DU as a metal or high-density alloy or compound, DU is used in lower concentrations in the fabrication of porcelains and glasses and in catalysts. This document does not consider in further detail any low-density uses. Unless otherwise specified the uses dealt with in this document relate to DU metal.

Pathways of exposure to DU

9. Irradiation from DU can occur if it is outside the body (*external exposure*) or inside the body (intake by ingestion, inhalation or other pathways of incorporation resulting in *internal exposure*).

10. It is useful to put the exposure pathways in the context of exposure from uranium as it arises in the natural environment. UNSCEAR has estimated the world average *doses* from *natural radiation sources* (Annex 2). In nature, the entire decay chain has built up over millions of years. In addition to ^{222}Rn which yields a world average dose of 1 mSv, the ^{238}U decay serie is an important source of external exposure (about 0.5 mSv per year) from soil and from building materials. For ^{238}U, in nature, only the ingestion pathway (food and drinking water) is worth considering, but doses are extremely small: 0.25 μSv per year is the world average. This is a very small contribution compared to the total ingestion dose from other natural nuclides. Doses above the world average may result from drinking certain mineral waters. The inhalation dose from ^{238}U in nature (and from other nuclides) is even smaller than the ingestion dose.

11. A *practice* involving the disposal of large amounts of DU or its dispersion in the environment, in particular in soluble form or in a form which may eventually dissolve by weathering, may increase the exposure by ingestion. This is examined further in the chapter on potential *environmental pathways*. In a workplace on the other hand ingestion is a pathway which in general does not need to be taken into consideration compared to external exposure and intake by inhalation Similar exposure pathways need to be considered for the use of DU penetrators or counterweights..

12. A third possible pathway of DU incorporation is through contamination of open wounds or by being hit by shrapnel from DU ammunition. Wounds will then be cleaned and treated. However some particles or fragments may not be removable and may remain incorporated for very long times; they may cause local irradiation of the surrounding tissue. In addition DU may slowly be incorporated in body fluids and thus be transferred to other organs. Incorporation in shrapnel wounds has been documented for soldiers injured in the Gulf War.

External exposure

13. It is relatively straightforward to calculate external exposures. Such exposures are readily measured and controlled. DU emits three types of ionising radiation: alpha particles, beta particles, and photons (x-rays and gamma rays). Alpha particles are stopped by a sheet of paper, and most will be stopped by the inert outer layer of skin. Beta particles can travel about a centimetre into the body. Photons (x-rays and gamma rays) are more penetrating and can pass straight through the body. The principal decay mode of all the uranium isotopes present in DU is by emission of an alpha particle (Annex I). ^{235}U emits photons. The daughters ^{234}Th and ^{234}Pa of ^{238}U build up to equilibrium in a few months; they emit beta particles and photons. Long-lived daughters will not build up to a significant activity within a time span of 1000 years.

14. The gamma rays emitted by even enhanced environmental levels of uranium in soil yield a negligible exposure. In a uranium store or in a vehicle reinforced by DU containing amor *dose* rates would be higher, but not very high as a result of self attenuation in high-density uranium. Measurements by the U.S. Army showed that the highest exposures from gamma radiation are likely to arise in a DU-armoured vehicle carrying DU ammunition. Measurements have shown that driving such a vehicle for 1000 hours gives a dose (i.e. about 1 mSv) similar to the average annual external dose from natural background radiation[4].

15. The radiation dose-rate to the skin in direct contact (on naked skin, not in a pocket or on clothes) with a piece of DU comes mainly from the beta particles. Even continuous direct contact for several weeks is unlikely to produce a radiation burn or other short-term effect. There would, however, be expected to be a small increase in the risk of developing skin cancer in the irradiated area. Prolonged skin contact with DU should therefore be avoided. Planned uses of DU involving skin contact have not been identified and there would seem to be no benefit from such uses. Where handling is required the dose can readily be reduced by wearing gloves and/or encasing the DU in another material. Hence skin exposure would occur only among people e.g. wearing inadvertently DU as an ornament and who are not aware that there is a risk of radiation.

16. A piece of DU metal placed near to but not in contact with the body, e.g. on a shelf at the bedside, would cause only a negligible exposure.

Intake by inhalation

17. In workplaces of the nuclear fuel cycle where workers handle ores, concentrates or powders of uranium oxides these may be suspended in air in the form of an aerosol. The larger particles (more than a few μm aerodynamic equivalent diameter[5]) will settle by gravitation

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4 Harley, N. H., Foulkes, E. C., Hilborne, L. H., Hudson, A., Anthony, C. R. (1999) A review of the scientific literature as it pertains to Gulf war illnesses. Volume 7, Depleted Uranium. RAND Corporation National Defense Research Institute. Washington, USA. http://www.gulflink.osd.mil/library/randrep/du/]

5 The aerodynamic equivalent diameter, AED, of a particle is the diameter of a sphere of density 1 g.cm^{-3} with the same settling velocity under gravity as the particle. For particles larger than about 1 μm AED it takes account of the size, shape and density of the particle in determining its behaviour in air. Particles larger than about 10 μm AED do not usually enter the lungs, and are often termed non-respirable. In case of a distribution of particles in

and yield a dust layer which may give rise to intake by ingestion through hand contamination. The settled dust and deposited aerosol particles may later be resuspended when the surface is disturbed, together with other dust or soil. In a work environment, intake by inhalation is in general more important than by ingestion.

18. Accidental dispersion may arise e.g. in case of a fire in a DU store, or in the crash of an aircraft carrying DU. However, tests have shown that large pieces of DU oxidise slowly in a fire and normally only a very small fraction is dispersed as respirable particles. In contrast, in the case of direct impact of a DU penetrator on a hard surface it has been demonstrated that part of the DU itself will burn explosively. A significant fraction can be dispersed as an aerosol of oxide particles, most of which are respirable.

Internal exposure

Behaviour of uranium in the body

19. Because uranium has been used extensively as a nuclear fuel, there have been many studies carried out on the behaviour of uranium in the body.

20. DU can enter the body by inhalation, ingestion, contamination of an open wound and on the battlefield by the embedding of shrapnel fragments. Models have been developed by the International Commission on Radiological Protection (ICRP) which describe the behaviour of inhaled and ingested uranium. These enable organ *doses* to be calculated from intakes, and intakes from monitoring data such as urinary and faecal excretion. The most recent models for the respiratory tract and for uranium absorbed into blood were published in 1994 and 1995 (ICRP 66 and 69).

21. In case of ingestion of uranium-contaminated soil, water or foodstuffs, most of the ingested DU (between 98% and 99.8%, depending on the solubility of the uranium compound) will be rapidly eliminated in the faeces. The remaining fraction will be absorbed into the blood. It is rapidly cleared from blood (in a few minutes), with approximately 75% leaving the body in urine within the first week, and the remainder being distributed to tissues. In particular, about 10% deposits in the kidneys. Since the kidneys are relatively small (about 300 grams in an adult), the concentration will be higher than in other organs. However, most of the uranium deposited in the kidneys is eliminated in a few weeks. About another 15% deposits in bone, but since the mass of bone (5000 g) is much greater than that of the kidneys, the concentration is lower. Uranium does stay much longer in the bone, so there will still be a few percent left after 5 years, and about 1% after 25 years.

22. In case of dispersion of DU in the form of a respirable aerosol, as may result from a fire or the impact of a DU penetrator on a hard target, inhalation represents the major route of intake.

    Inhaled DU particles may enter the body through the nose and/or the mouth. Depending on their sizes (AED), some particles will be exhaled, some will deposit in the upper airways (the nose, mouth and bronchial tree), and some will deposit deep in the lungs. Most particles larger than a few μm AED are filtered out in the upper airways and so do not reach the deep lungs. Most particles that deposit in the upper airways are trapped in mucus that

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an aerosol, calculations are performed for an Aerodynamic Median Aerosol Diameter (AMAD). Fifty percent of the activity in an aerosol is associated with particles greater than the AMAD.

moves to the throat and are swallowed within a few hours. Most particles that deposit in the deep lungs are quickly captured by macrophages. They may move the particles to the bronchial tree, to be carried away in mucus and swallowed, but this is a very slow process, and some particles may remain in the lungs for years.

It is generally found that when dusts are inhaled and deposit in the lungs, a fraction of the material dissolves rapidly and the rest at a fairly steady rate. Tests that simulated dissolution in the lungs have been carried out on DU oxides. These showed that for the particles formed when pieces of DU are heated in a fire, a few percent dissolves rapidly, but the rest very slowly. For the particles formed when a DU penetrator impacts on armour plate, a larger fraction, about 25%, dissolves quickly. Other tests have shown that in both situations, the particles consist mostly of U_3O_8, with some UO_2, both of which are relatively insoluble (ICRP default absorption *Type S*). Once in the blood, uranium will be cleared essentially as described for ingested DU. In that case, the lung is usually the organ that receives the highest *dose*.

Dose estimates

23. The worst scenario envisaged in the preliminary assessment made in October 1999 by UNEP was inhalation (at the site and times of an explosion of a DU penetrator, of up to 100 mg inhaled DU.The *committed effective dose* would correspond to a maximum of about 10 mSv (using the current ICRP models, and assuming ICRP default *Type S* absorption), and the highest *organ dose* calculated to be to the lungs, at about 80 mSv (for adults). Compared to the dose to the lungs, doses to bone surface, kidneys and red bone marrow, would be 150, 400 and 1400 times lower, respectively, and the dose to the thoracic lymph nodes (treated by ICRP as a region of the lungs) about 10 times higher. The resulting doses (external or internal) are unlikely to cause any deterministic effects, and are far below the minimal doses at which lung or lymph node fibrosis and leukocytopenia have been observed in animals. It is noted that organ doses from DU inhalation are delivered at a very low rate, whereas deterministic effects appear rather for acute high doses. The UNEP report states that the inhalation of 100 mg DU might lead to acute chemical toxicity.

24. Instantaneous inhalation of DU dust after an attack is relevant only to the victims of the attack. Following such attacks there may well be DU contamination within and around the vehicles in the form of DU dust and fragments ranging in size up to complete penetrators. The UNEP report also considers inhalation of DU in resuspended dust from ground. Realistic parameters for this *exposure* scenario are given in Annexe 3. A two-hours stay in the target area would lead to doses in the range 0.1-10 µSv. It does not seem very likely that an individual would reside permanently in close proximity to the target area, nor would wind or human activities perturbing the soil cause a constantly high dust load, but even in this assumption the annual dose would be of the order of 1 mSv only. One could imagine a higher dust load or DU concentration inside a hit vehicle or building. In the absence of field data it is difficult to assess this situation. On the other hand people are not expected to enter such risk areas (chemicals, explosives) without elementary precautions. The possible *exposure* is therefore estimated to be of the same order of magnitude as the considered case of resuspension from the ground.

25. Outside the military context however, similar exposure situations may arise in case of a fire or an aircraft crash. A detailed assessment of the crash in the Bijlmer (Nl) in 1992 resulted in a calculated dose to bystanders of 1 µSv (best estimate), with an upper value of 0.7 mSv (P.A.M. Uijt de Haag & al, 2000).

26. The above exposure scenarios relate to acute situations resulting from uses in a military conflict or from accidents. The lasting contamination resulting from such events should be regarded as an *intervention* situation from the point of view of radiation protection. The processing of DU in the nuclear fuel cycle on the other hand is a regulated *practice*. In practices, the concentration of DU in ambient air is controlled and workers are subject to regular medical examination and to specific bio-assay in case of suspected incorporation of DU.

Experience

27. Uranium fuel manufacture or the machining of metallic uranium give rise to varying levels of uranium in ambient air in the workplace. Such workplaces are monitored and where appropriate, workers exposed to uranium in such *practices* are individually monitored for radiation *exposure* and may be subject to medical follow up procedures. This experience extends over 50 years and epidemiological studies have not established, among a large population of workers with varying levels of exposure, any clear evidence of cancers in excess of the expected incidence in a non-exposed reference population. Detailed information on exposure levels has not always been available in these studies however[6].

28. Exposure to uranium needs to be considered also for non-nuclear industries processing ores containing naturally elevated levels of uranium. Uranium concentrations in the range of 200 to 400 mg/kg may be reached in ore and dust associated with phosphate rocks and phosphogypsum. Elevated levels may also be encountered in fly-ash from coal combustion, zircon sands used in the ceramics industry, the production of titanium dioxide pigments, the processing and application of phosphate fertilisers (WHO draft 2001). Exposures are low but further research is going on to implement the BSS.

29. The very long experience with exposure to uranium in industries of the nuclear fuel cycle and industries processing natural ores, in different physico-chemical forms and at different enrichments, including DU, is an important argument confirming the estimated low radiological consequences.

30. An excess incidence of lung cancer has been observed in underground miners, in particular uranium miners. There is a strong correlation between the incidence of lung cancer and high radon[7] concentrations rather than levels of uranium dust. Many other agents were present in mines (e.g. diesel fumes) and, although the possible relation is still unclear, it cannot be excluded that these are associated with increased incidence of some other types of cancer including leukaemia[8]. A major confounding factor is tobacco smoking, but enhanced lung cancer incidence has been found both in smoking and non-smoking miners.

31. Embedded DU fragments and wound contamination might represent an accidental way of being contaminated by DU. Such a situation is reported for a small group (about 30) of American soldiers who have retained fragments of DU shrapnel in their bodies as a

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6 IOM report (Fulco et al, 2000)

7 Note that radon is a naturally occurring radioactive gas but it shall build up as a daughter product of DU only after tens of thousands years

8 Darby et al, JNCI, 1995

consequence of friendly fires incidents during the Gulf War. In that case, DU dissolves continuously from the tissue, and can still be measured in the urine after 7 years[9].

32. Illnesses among the soldiers who have been on mission in the Gulf, gave rise to the idea of a "Gulf syndrome". So far limited epidemiological assessment have been carried out on the different Gulf War population groups. Studies found no significant increase in incidence of disease[10]. In the Balkans similar concerns were generated ("Balkan syndrome") when soldiers developed leukaemia and it was confirmed that DU was also used.

Predicted health effects

33. The International Commission on Radiological Protection (ICRP) has estimated the risks of *stochastic* effects of exposure to ionising radiation, mainly from studies of people who were exposed to high levels of radiation. While the most important study is that of the survivors of the atomic bomb attacks on Japan, studies on various other groups of patients and workers, and results of animal experiments, were also used. These include internal as well as external exposures.

34. All the evidence about cancer causation by exposure to *ionizing radiation*, essentially collected on the basis of a follow-up of survivors of the atomic weapons explosions at Hiroshima and Nagasaki, has been consolidated by the ICRP into the concept of "*effective dose*" and in a single value for the probability of cancer induction per unit of exposure expressed as *effective dose*.

35. The risk of harm resulting from irradiation of tissue by *ionising radiation* is generally considered to be related to the '*absorbed dose*', which is the amount of energy absorbed per unit mass of tissue. For the same *absorbed dose* to a tissue or organ, some types of ionising radiation, notably alpha particles, are more harmful than others. To take account of this, the *absorbed dose* is 'weighted', which means that it is multiplied by a factor (the radiation weighting factor), to give the '*equivalent dose*' (BSS). The *effective dose* is the weighted sum of the *equivalent doses* in different organs. The tissue weighting factor relates to the relative sensitivity of the organ or tissue to radiation, which is to a large extent proportional to the spontaneous incidence of tumours in these organ.

36. After intake of long-lived radionuclides such as the components of DU some are excreted rapidly in urine and faeces. The dose is delivered mainly in the organs (lungs, bone) where the remaining nuclides are retained. The subsequent long-term elimination rate is low but nevertheless allows assessment of possible incorporation by biological monitoring. The implication is also that the dose to tissue by emission of particles or photons from incorporated nuclides is not received immediately but spread over a lifetime. The *committed dose* is the sum of annual doses over a lifetime. The risk of a health detriment also builds up with accumulated dose.

37. According to ICRP Publication 60: "In humans, the period between *exposure* to radiation and recognition of a cancer lasts a number of years. This period is called the latency period. In adults, the median latency period may be about 8 years in the case of leukaemia and two or three times longer in the case of many induced solid tumours, such as in the breast or

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9 McDiarmid et al, Environmental Research (2000), 82(2), 168-80

10 G.J. Macfarlane et al, Mortality among UK Gulf War veterans, The Lancet Vol 356, July 1, 2000)

lung. The minimum latency period is the shortest time in which a specified radiation-induced tumour is known or believed to occur after exposure. The minimum latency period is about two years for acute myeloid leukaemia and of 5-10 years for other cancers."

38. In the case of DU the latency period of cancer recognition is added to the time it takes for the build-up of committed dose. For insoluble (*Type S*) uranium, about 50% of the committed dose to lungs is received in the first year after intake, but for the red bone marrow and thoracic lymph nodes about 10% and 1% respectively.

39. It is generally difficult to detect a raised cancer risk due to radiation *exposure* at doses lower than 100 mSv either in human studies or animal experiments, because the excess risk at low doses is small, and the same types of cancers occur naturally. For radiation protection purposes it is nevertheless generally assumed that the additional risk of cancer at low doses is proportional to the radiation dose.

40. A review of the epidemiological data by ICRP in 1990 yielded a lethal cancer risk over a lifetime of 5% per unit *effective dose* (Sv). A single exposure at the *annual dose limit* for members of the public (1 mSv) thus would cause theoretically the expression of one lethal cancer in a population of 20,000 people.

41. On the basis of an assessment of the possible exposure from depleted uranium, taking all pathways of exposure into account, it is concluded that it could not result in a *deterministic radiation detriment*, except perhaps in the case of embedded DU shrapnel. In terms of *stochastic risk*, the basic hypothesis of radiation protection about the effect of low doses implies that such risks, e.g. of cancer or a genetic effect, are presumed to exist. However at low doses (below 100 mSv) no observable health effect compared to the base line incidence would be observed.

42. On the basis of available information, it is concluded that *exposure* to DU could not produce any detectable health effects under realistic assumptions of the doses that would be received. Moreover, in view of the fact that committed doses from incorporated DU build up over a lifetime and in view of the minimum latency period of cancer induction, such effects could not occur during the first few years after incorporation as a result of radiological exposure.

43. This conclusion applies in particular to leukaemia: while the latency period for leukaemia is shorter than for solid cancers, uranium accumulates very little in blood forming organs such as bone marrow. Following inhalation of insoluble uranium, the calculated risk of leukaemia is orders of magnitude lower than the risk of lung cancer induction.

44. On the basis of available knowledge of chemical toxicity one would expect to observe uranium renal toxicity before any other damage including cancer. The possibility of a combined effect of *exposure* to toxic or carcinogenic chemicals and to radiation can not a priori be excluded but there is no evidence to support this hypothesis. Under the considered scenarios, exposures to DU give low doses, comparable to natural background. Hence there is no reason to believe that chemicals may change the magnitude of the potential radiation effects.

Potential environmental pathways

45. A potential effect on the environment through the presence of depleted uranium is contamination of drinking water. This only becomes an issue where the depleted uranium is dispersed or disposed of in soluble form in the environment. Some studies on such dispersion of depleted uranium into the environment have been conducted in the US at test sites with no measurable resulting effects on the drinking water[11]. Relatively high concentrations of naturally occurring uranium in drinking water, over the WHO guideline level and up to 15 mg/l, are experienced in Nordic countries, linked to high natural radioactivity, with no observed health effects as a result in the population.

46. The WHO guideline provisional level of 2 µg/l for drinking water was established so as to preclude any effect of the chemical toxicity of uranium on the kidneys.

47. A scenario for drinking water contamination has been considered, on the basis of the possible slow dissolution of 10 kg DU (33 penetrators, 0.3-kg each, buried in soil) into a ground water table. This would lead to an annual dose of some tens of µSv per year. A generic assessment for a total amount of 10 *tonnes* over a wide area yields even lower doses.

48. An important parameter is the dissolution rate of DU penetrators which depends on soil pH and weathering conditions. The dissolution rate may in fact be very low.

49. Deposition of depleted uranium on vegetation presents a potential for incorporation through the food chain, but it is limited in time until rainfall. Transfer factors from soil contaminated with uranium to plants are known to be extremely low and no observable health effects are likely to be produced.

50. Direct ingestion of contaminated soil must be taken into consideration, in particular for children, as well as ingestion through hand contamination, but even in that case, doses will be negligible.

51. Direct ingestion of contaminated soil by cattle and sheep as a pathway to human ingestion could also be considered. The transfer factor is comparable to the one for transfer to plants and since the contaminated area is small it cannot be grazed and cultivated for vegetables at the same time.

52. Possible contamination of drinking water must be considered since it is a possible pathway of *exposure* if very large amounts of DU are buried in soil, depending on the solubility of the uranium or the acidity and reducing properties of the environment, and the hydrological characteristics of the region. For soluble uranium it is necessary to take the chemical toxicity of uranium into account and monitoring of drinking water should ensure compliance with appropriate standards. Such monitoring should allow for the natural occurrence of uranium, at very high levels in some regions of Europe. A generic assessment however yields nothing but very low doses resulting from drinking water.

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[11] US AEPI (1995) Health and Environmental Consequences of Depleted Uranium use in the U.S. Army: Technical Report, U.S. Army Environmental Policy Institute, June 1995

53. Test firing is being carried out in the sea. Due to the low corrosion rate and to the large volume of surrounding seawater, no detectable increase of uranium concentration in seawater or biota is expected.

Monitoring and intervention

54. In workplaces where workers are routinely exposed to uranium possible intakes are controlled by ambient air monitoring (aspiration of room aerosols on filters). General measures of work hygiene preclude intake by ingestion (gloves, banning of food consumption in controlled areas). In general it is not necessary to wear a mask to protect against inhalation except for specific operations e.g. in uranium mills.

55. For workers involved in such operations routine urine analysis can allow unknown incorporation incidents to be detected. In the event of an incident urine and faeces analysis has to be carried out promptly so that the incorporation can be assessed with optimal precision.

    In vivo measurements of DU in the lungs can be made by external counting ("Whole Body Monitoring") using specialised equipment. If there is more than a few mg of DU in the lungs, its presence can be detected with such equipment. This technique is most useful if measurements can be made soon after the *exposure* took place. For exposures taking place years previously, only a small fraction of the amount initially inhaled remains in the lungs. Furthermore, it is difficult to determine whether the long-term thoracic retention of uranium represents material retained in the lung, lymph nodes or skeleton (sternum).

56. In the case of accidental dispersion of DU or in relation to the use of DU penetrators in a conflict it is difficult to specify the actual exposure situation. In the absence of further information it is not possible to give useful guidance. Individual monitoring of people involved in such situations (firemen, rescue workers, soldiers) may be used to assess whether they suffered a significant incorporation. Nevertheless, as in the case of workplaces, it is more appropriate to monitor the environment for DU, on surfaces, in soil or ambient air. Individual monitoring would usually be indicated only if environmental monitoring gave significant levels of contamination or if such monitoring cannot be carried out (or no longer can, in case of acute exposure situations). A number of Experts note that for individuals most at risk of significant exposure, biological monitoring helps to assess the real exposure situation.

57. Guidance on appropriate means of individual monitoring is widely available. The experts feel however that in the absence of area monitoring data and information on actual working conditions no useful guidance can be given on the need for individual monitoring.

58. A number of Member States have carried out individual uranium in urine monitoring of soldiers on mission in the Balkans (Belgium, Germany, …). The German measurements were of sufficient precision to measure uranium excretion at natural background levels (about 10 – 100 nanograms per day). All the measurements were within the range of natural background concentrations (varying among individuals in relation to e.g. the consumption of mineral waters). While such monitoring may not be required from a radiological protection point of view, it is able to confirm the absence of significant intakes and can provide reassurance to concerned individuals.

59. Monitoring of drinking water wells near a site where a significant amount of DU is dispersed or buried in soil is equally a precautionary measure which may be worth

considering. Measurements already available did not indicate contamination by DU[12]. Where appropriate, monitoring of drinking water supplies should ensure compliance with relevant standards for the chemical toxicity of uranium.

60. Even though the expected exposure of children eating soil or of people picking up a piece of DU metal such as a debris of a penetrator or counterweight is low, such exposures are usually avoidable and appropriate measures should be considered to avoid exposure (fencing, information, warning) and/or removing the source. It is noted that it may be difficult to find buried pieces of DU since the emitted radiation is shielded by soil, but such buried penetrators or fragments pose relatively little hazard.

61. It is not possible to provide general guidance in the absence of firm data. *Intervention* should be justified taking into account the specific situation which may arise. Where appropriate, specific protection measures should be proposed by a radiation protection advisor with knowledge of the local situation.

Conclusions

1. On the basis of an assessment of the possible *exposure* from depleted uranium, taking all pathways of *exposure* into account, it is concluded that it could not result in a *deterministic radiation detriment*, except perhaps in the case of embedded DU shrapnel. The basic hypothesis of radiation protection implies that the *stochastic risk* exist even for low doses. However at low *doses* (below 100 mSv) no observable health effect compared to the base line incidence would be observed.

   On the basis of available information, it is concluded that exposure to DU could not produce any detectable health effects under realistic assumptions of the *doses* that might be received. Moreover, in view of the fact that committed doses from incorporated DU build up over a lifetime and in view of the minimum latency period of cancer induction, such effects could not occur during the first few years after incorporation as a result of radiological exposure.

   This conclusion applies in particular to leukaemia: while the latency period for leukaemia is shorter than for solid cancers, uranium accumulates very little in blood forming organs such as bone marrow. Following inhalation of insoluble uranium the calculated risk of leukaemia is orders of magnitude lower than the risk of lung cancer induction.

   The possibility of a combined effect of exposure to toxic or carcinogenic chemicals and to radiation can not a priori be excluded but there is no evidence to support this hypothesis either. Under the considered scenarios, exposures to DU give low doses, comparable to natural background. Hence there is no reason to believe that chemicals may change the magnitude of the potential radiation effects.

2. Deposition of depleted uranium on vegetation presents a potential for incorporation through the food chain, but it is limited in time until rainfall. Direct ingestion of contaminated soil must be taken into consideration, in particular for children, as well as ingestion through

12 Portuguese mission report, February 2001, http://www.mct.pt/relatoriopreliminar

hand contamination. Direct ingestion of contaminated soil by cattle and sheep as a pathway to human ingestion could also be considered. Doses that may results both from direct ingestion of soil and contamination of foodstuffs will be extremely low.

Possible contamination of drinking water must be considered since it is a possible pathway of exposure if very large amounts of DU are buried in soil, depending on the solubility of the uranium or the acidity and reducing properties of the environment, and the hydrological characteristics of the region. A generic assessment however yields nothing but very low doses resulting from drinking water.

Test firing or disposal of unused ammunition is being carried out in the sea. Due to the low corrosion rate and to the large volume of surrounding seawater, no detectable increase of uranium concentration in seawater or biota is expected.

3. The experts feel that no useful guidance can be given with regard to the need for monitoring individuals for incorporation of DU without knowing the specific exposure situation. In general it will be more appropriate to monitor the environment rather than individuals. Nevertheless individual monitoring may be useful for confirmatory purposes and to provide reassurance.
4. The experts also conclude that no guidance can be given on the need for *intervention* measures specific to a given situation. *Intervention* should be justified taking the specific situation into account. Straightforward general protective measures should be considered on the basis of a common-sense approach to justification for easily avoidable exposures. Where appropriate, specific protection against exposure to depleted uranium should be proposed by a radiation protection advisor with knowledge of the local situation.
5. The experts see no need to derogate depleted uranium from any provision of the BSS, nor to introduce stricter requirements in the BSS for specific uses of DU.

Glossary

Absorbed dose (D): the energy absorbed per unit mass averaged over a tissue or an organ. The unit for absorbed dose is the gray.

Becquerel (Bq): the special name of the unit of activity. One Becquerel is equivalent to one transition (radioactive decay) per second: 1 Bq = 1 s^{-1}

Committed effective dose (E): the sum of the committed organ or tissue equivalent doses (H) resulting from an intake, each multiplied by the appropriate tissue weighting factor. The unit for committed effective dose is the *Sievert*.

Committed equivalent dose (H): the sum over time (years) of the equivalent dose rate in a tissue or organ that will be received by an individual as a result of an intake. A period of 50 years is assumed for adults and up to age 70 for children. The unit for committed equivalent dose is *Sievert*.

Deterministic radiation detriment: effect of radiation that has a threshold dose above which damage is certain to occur (contrary to *stochastic risk*) and below which there is no effect.

Daughters: see *decay series* and *secular equilibrium*.

Decay series: the decay of a radionuclide by spontaneous transformation produces daughter nuclides. The rate of decay is specific to each nuclide and is expressed as the activity in Becquerel (Bq) indicating the number of transformations per second.

Dose: a measure of the radiation received or "*absorbed*" by a target (man, biota, …). The quantities termed *absorbed dose*, *organ dose*, *equivalent dose*, *effective dose, committed equivalent dose* or *committed effective dose* are used depending on the context. The modifying terms are often omitted when they are not necessary for defining the quantity of interest.

Dose limit: maximum reference for the doses resulting from the exposure of workers, apprentices and students and members of the public to *ionizing radiation* covered by the BSS Directive. It applies to the sum of the relevant doses from external exposures in the specified period and the 50-year committed doses (up to age 70 for children) from intakes in the same period.
The limit on effective dose for exposed workers is 100 mSv in a consecutive five-year period, subject to a maximum effective dose of 50 mSv in any single year.
The limit on equivalent dose for the skin is 500 mSv in a year. It applies to the dose averaged over any area of 1 cm^2, regardless of the area exposed.
The *dose limit* for members of the public is 1 mSv in a year (effective dose); in a single year and in special circumstances a higher effective dose may be authorised provided that the average over five consecutive years does not exceed 1 mSv per year. The limit on equivalent dose for the skin is 50 mSv in a year.
The *dose limits* to organs (e.g. skin) preclude the occurrence of *deterministic* effects. The limits on effective dose are set so as to ensure an equitable distribution of doses among a given population for planned *practices*. *Dose limits* do not apply in de facto situations where *intervention* may be required.

The following qualifications are used when comparing doses to the *dose limits* for justified *practices*:

- above the *dose limit*: unacceptable
- below the *dose limit*: tolerable
- after optimisation of the protection measures: acceptable
- more than a factor 100 below the *dose limit* for members of the public (i.e. 10 µSv): negligible.

There is no standard qualification for doses below "negligible"; such doses are of no radiation protection concern but are nevertheless calculated (down to the order of nSv) for the sake of completeness of the assessment.

Effective dose (E): the sum of the weighted (over organ and type of radiation) equivalent dosesin all the tissues and organs of the body from internal and external irradiation. The unit for effective dose is the *Sievert*.

Environment pathways: the different possible ways one can imagine for transfer of radioactivity in the environment from the source term to man.

Equivalent dose (H_T): the absorbed dose, in a tissue or organ weighted for the type and quality of radiation. The unit for equivalent dose is the *Sievert*. The radiation weighing factor equals 1 for γ and β rays, 20 for α particles.

Exposure: the process of being subject to irradiation. Exposure can be either external or internal exposure (see *dose*)

Intervention: a human activity that prevents or decreases the exposure of individuals to radiation from sources which are not part of a *practice* or which are out of control, by acting on sources (e.g. clean up), transmission *pathways* and individuals themselves

Ionizing radiation: the transfer of energy in the form of particles or electromagnetic capable of producing ions directly or indirectly.

Isotopes: isotopes of an element have the same number of protons but different numbers of neutrons forming the atomic nucleus. Accordingly they have a different mass; radioactive isotopes are called radionuclides and are identified by their mass numbers.

Natural radiation sources: sources of ionizing radiation from natural terrestrial or cosmic origin.

Practice: a human activity that can increase the exposure of individuals to radiation from an artificial source, or from a *natural radiation source* where natural radionuclides are processed for their radioactive, fissile or fertile properties, except in the case of an emergency exposure.

Reprocessing: when uranium fuel (enriched in ^{235}U) is used in a nuclear power plant, the amount of ^{235}U decreases and transuranic or fission products (^{236}U, ^{239}Pu, ^{234}Am, ^{99}Tc) will appear in the fuel. After some time the percentage of ^{235}U is to low and the downloaded fuel becomes waste or can be reprocessed to recover fissile material. The recovered uranium can be enriched for reuse as nuclear fuel. The residue of this enrichment is a type of depleted uranium (DU) which therefore contains ^{236}U and possibly very small amounts of transuranics and fission products.

Secular equilibrium: as a result of radioactive *decay*, a nuclide produces daughter nuclides. With time, daughter and parent nuclides are in equilibrium when production and decay are at the same rate, in equilibrium, the activities of parent and daughter nuclides are identical.

Sievert (Sv): the special name of the unit of equivalent or effective dose. One Sievert is equivalent to one joule per kilogram: $1\ Sv = 1\ J.kg^{-1}$,
One Sievert equals to thousand milliSievert (1000 mSv) or one million microSievert (1,000,000 µSv)

Stochastic risk: a risk of radiation effect that is statistically related to the *dose*; an increase in dose gives an increased probability of the effect (contrary to *deterministic risk*); the main stochastic risks are cancer induction and genetic detriment.

Tonne (t): this is a unit for weight; 1 tonne = 1000 kilograms (kg), 1 kg = 1000 grams (g) and 1,000,000 µg

Transuranics, Fission products: see *reprocessing*

Type S: the least soluble type of aerosol particle as regards the behaviour of radionuclides in the respiratory track.

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Annex 1

Uranium Decay Chain

Uranium-238 series (ICRP 1983)

Nuclide	Type of decay	Half-life	Average emitted energy per transformation		
			Alpha energy (MeV)	Beta energy (MeV)	Gamma energy (MeV)
Uranium-238 ^{238}U	α	4.479 10^9y	4.26	0.010	0.001
↓					
Thorium-234 ^{234}Th	β	24.1 d	-	0.059	0.009
↓					
*Protactinium-234m ^{234m}Pa (98.87%) +	β	1.17 m	-	0.820	0.013
Protactinium-234 (0.13%)	β	6.7 h		0.422	1.75
↓					
Uranium-234 ^{234}U	α	2.45 10^5y	4.84	0.013	0.002

*Branched decay

Uranium-235 series (ICRP 1983)

Nuclide	Type of decay	Half-life	Average emitted energy per transformation		
			Alpha energy (MeV)	Beta energy (MeV)	Gamma energy (MeV)
Uranium-235 ^{235}U	α	7.04 10^8y	4.47	0.048	0.154*
↓					
Thorium-231 ^{231}Th	β	25.52 h	-	0.163	0.026

* also a 0.186 Mev

Annex 2

Radiation dose from natural sources (UNSCEAR 2000)

"24. All living organisms are continually exposed to *ionizing radiation*, which has always existed naturally. The sources of that exposure are cosmic rays that come from outer space and from the surface of the Sun, terrestrial radionuclides that occur in the Earth's crust, in building materials and in air, water and foods and in the human body itself. Some of the exposures are fairly constant and uniform for all individuals everywhere, for example, the *dose* from ingestion of potassium-40 in foods. Other exposures vary widely depending on location. Cosmic rays, for example, are more intense at higher altitudes, and concentrations of uranium and thorium in soils are elevated in localized areas. Exposures can also vary as a result of human activities and *practices*. In particular, the building materials of houses and the design and ventilation systems strongly influence indoor levels of the radioactive gas radon and its decay products, which contribute significantly to *doses* through inhalation."

The major portion of the body burden of the decay series of uranium in the general population comes from ingestion of food and drinking water, giving a *committed effective dose* of 110 *μSv* per year for adults as compared to 5.8 *μSv* through inhalation, excluding radon (1.2 mSv).

This *dose* corresponds to 5% of the average annual *dose* due to internal and external exposure to natural sources of radiation (2.4 mSv). It relates essentially to ^{210}Pb and ^{210}Po; ^{238}U, with an annual ingestion of 0.5 mg per year, accounts only for 0.25 μSv and 0.021 μSv for inhalation. External exposure from all natural ^{238}U in soil is also negligible. ^{238}U series together with other primordial radionuclides, ^{232}Th and ^{40}K, cause a world-average annual external exposure of about 1 mSv per year.

"26. The annual worldwide per caput *effective dose* is determined by adding the various components, as summarized in Table 1. The annual global per caput *effective dose* due to *natural radiation sources* is 2.4 mSv. However, the range of individual *doses* is wide. In any large population about 65% would be expected to have annual *effective doses* between 1 mSv and 3 mSv, about 25% of the population would have annual *effective doses* less than 1 mSv and 10% would have annual *effective doses* greater than 3 mSv."

Table 1: see next page

Annex 2

Table 1: Average radiation dose from natural sources (UNSCEAR 2000)

Source	*Worldwide average annual effective dose (mSv)*	*Typical range (mSv)*
External exposure		
Cosmic rays	0.4	0.3-1.0 [a]
Terrestrial gamma rays	0.5	0.3-0.6 [b]
Internal exposure		
Inhalation (mainly radon)	1.2 *	0.2-10 [c]
Ingestion	0.3 **	0.2-0.8 [d]
Total	2.4	1-10

[a] Range from sea level to high ground elevation

[b] Depending on radionuclide composition of soil and building materials

[c] Depending on indoor accumulation of radon gas

[d] Depending on radionuclide composition of foods and drinking water

* 0.0058 mSv due to ^{238}U decay series

** 0.110 mSv due to ^{238}U decay series

Annex 3

Scenarios and corresponding effective doses from DU

Adapted from Ref: Appendix 8 - UNEP/UNCHS Balkan Task Force Report October 1999
including Brenk Systemplanung modelisation results (BS scenario) and other scenarios (*)

Scenario of exposure	Result / Comment
0. Common assumptions to all scenarios 10 kg DU particles < 10µm slow soluble oxide:*Type S* Area contaminated: 20 x 50 m = 1000 m2 BS scenario 1: 32 x 32 m = 1000 m2 BS scenario 2: radioactive build-up after 1000 years For BS, *effective dose* in this table are for adults. UNEP results are supposed for adults also. Based on this frame realistic scenario are used to evaluate an exposure …	This is the basic scenario described in UNEP October 1999 report Brenk Systemplanung (BS) gave some modelisation results with the same basic scenario (introducing a Darcy velocity in 5.5 = scenario 1) and assessing the impact in 1000 years time (considering then in 5.5 that yearly leaching of DU is reduced from 10% of initial amount – 1 kg – to 3.68 g.) … the results are given in this column. Comments on chemical toxicity come from UNEP report
1. Picked up solid pieces of DU In this scenario, fragment of penetrators are supposed to be picked up and either kept in a pocket, worn as an ornament or stored on a shelf on the bedside. β radiation : 2 $mSv.h^{-1}$ several weeks in pocket (reduced by 50%) * worn as ornament: 2.3 $mSv.year^{-1}$ 500h w_T = 1% tissue weighing factor Impact on 1 cm^2 / 2m^2 body * on a shelf on the bedside	Resulting skin dose is *negligible* (0.6 $\mu Sv.year^{-1}$) skin *dose* may be high but NO *deterministic effects* skin dose = 0.6 $\mu Sv.year^{-1}$
2. Solid pieces of DU in or on ground … in this case external exposure is considered	see **1** or **6**
3. Instantaneous inhalation of DU dust after an attack Following the explosion of a shell (with DU penetrator) or a plane crash (with DU counterweights) followed by a fire, inhalation of the resulting "aerosol" is considered. 1 mg dust maximum instantaneous intake 10% DU in dust * 1992 Plane crash + fire in Bijlmer (NL) Dose to bystanders: fraction - all DU counterweights converted to aerosols	Resulting 100 mg DU intake " might lead to acute chemical toxicity and total effective radiation dose caused by inhalation of less than 10 mSv." plane crash *1 µSv – 0.7 mSv

Scenario of exposure	Result / Comment
4. Inhalation of resuspended DU People are considered breathing air loaded with DU contaminated dust, considering it has been produced by an explosion, dispersed and settled on the 1000 m^2 area around target site. Due to wind it is resuspended ready to be breathed All DU dust is included in 1 mm upper layer of soil 2 hours stay – 1 $m^3.h^{-3}$ breathing rate Dust concentration : 50 $\mu g.m^{-3}$ to 5 $mg.m^{-3}$	Resulting concentration in dust = 6 µg DU / mg dust intake : 0.6 – 60 µg of DU effective dose negligible (0.07 – 7 µSv)
5. Ingestion of DU … in different situations	
5.1 Soil in mouth In this scenario a child is supposed playing on a contaminated area and eats soils soil concentration: 6 µg DU / mg 1 g soil ingested (by a child playing) BS scenario 2: 0.031 µg DU / mg 44 $g.year^{-1}$ ingested (or 1g)	Effective dose negligible (4 µSv) possible acute chemical toxic effect for 60µg DU BS: 1 $\mu Sv.year^{-1}$ (or 4 µSv also for BS model with same assumptions)
5.2 Contaminated vegetables Member of the public is supposed eating vegetables growing on the area contaminated by dust before it is washed away by a rainfall. Area contamination (from "0"): 10000 $mg.m^{-2}$ before washing by rainfall Intake: 60 $kg.year^{-1}$ or 1 $kg.week^{-1}$, growing on ~ 1m^2 of land	Intake ~ 100 mg DU … "significant from chemical risk point of view. Resulting radiation dose will be (tolerable) of the order of 0.1 mSv." (Washing reduces contamination by 99%)
5.3 Contaminated hand Same soil characteristics as 5.1 but the quantity ingested is lower. 10-100 times lower soil ingestion than 5.1	Effective dose negligible: 0.04 to 0.4 µSv
5.4 Open wounds In this case, the skin is in direct contact with dust particles, supposed not cleaned away. Contact α and β-radiation: < 50 $mSv.h^{-1}$	"No acute *deterministic effect*".

Scenario of exposure	Result / Comment
5.5 Contaminated water The ground water table is supposed contaminated by dissolution of DU spread on the surface: the water is used for drinking. soil depth between ground water table and surface of the "bedrock" is 3m 10 kg DU contaminated area: 1000 m^2 leakage of DU: 10% per year of deposited amount of DU Water content of the ground 30% BS scenario 1: Darcy velocity 150 $m.year^{-1}$ 500 $l.year^{-1}$ BS scenario 2: … release of 3.68 g DU per year	Doses are negligible (tolerable in any case) ? In UNEP report : 1 g $DU.m^{-3}$ in drinkable water. This is "above hygiene standards for chronic exposure … chemical toxic effects cannot be excluded. The annual radiation dose … about 1 $mSv.year^{-1}$" (UNEP considered a **stagnant groundwater** whereas BS, more realistic, considers it **flowing** and involving 16 times more water, equivalent ratio between doses) BS 1: 24 $\mu Sv.year^{-1}$ with conservative parameter value BS 2: 0.1 $\mu Sv.year^{-1}$
5.6 Contaminated food The food is contaminated either by soil ingestion (cattle) or because vegetables are growing on the contaminated groundwater table. <u>Contaminated meat and milk …</u> <u>Contaminated plants by root uptake:</u> 10 kg DU on 1000 m^2 – 10 cm deep soil density 1500 $kg.m^{-3}$: 70 mg $DU.kg^{-1}$ soil BS scenario 2: consumption 100 $kg.year^{-1}$	Dose negligible Meat and milk: "… less than 0.1 mSv per day …": keep –cattle away from contaminated areas. UNEP calculations give "effective dose by ingestion of 7 $\mu Sv.year^{-1}$ BS 2: 2.6 $\mu Sv.year^{-1}$
6 External radiation The population is exposed externally to the dust spread over the area. mixing of DU in 10 cm (70 mg $DU.kg^{-1}$ soil) - DU is 0.8% of γ radiation of natural U (17 $nGy.h^{-1}$ or 0.02 $mSv.year^{-1}$) indoor occupancy: 0.8 BS Scenario 2: mixing of DU in 5 cm 12 h per day inside house – 900 $h.year^{-1}$ in garden * Armor combat crew 1000 $h.year^{-1}$ 0.1 to 1.8 $\mu Sv.h$-*l*	Doses negligible for population 4 $\mu Sv.year^{-1}$ 2.7 $\mu Sv.year^{-1}$ * 0.1 to 1.8 $mSv.year^{-1}$ (AEPI, 1995)

Scenario of exposure	Result / Comment
7 According to extension of the impact If the total amount of DU used and resulting contamination is considered spread on larger areas than previously supposed or if all target sites are near and considered in the same region, dispersion is higher and resulting contamination reduced. 10 tonnes of DU on 112 targets have been used that is an average of 100 kg on each 1000 m^{-2} target area (see "0") of which 90% non exploded = 10 kg * If dispersion of DU dust is higher, … 5.5 and 5.6: depending on homogeneity of aquifer …	Effective dose should be lower than those highlighted above.

Dose Coefficients to Organs for Depleted Uranium (DU) **Annex 4**

Committed Equivalent Dose per Unit Intake (Sv/Bq)

Act. Bq/g (of individual RN)		DU Composition %	Act. Bq/g DU
231309727,9	U-234	0,001	2313,10
80015,07371	U-235	0,2	160,03
12444,616	U-238	99,8	12419,73
	Total DU	100	14892,85

ICRP 71 **Sv/Bq** AMAD 1 µm, Absorption Type S Adult

		Dose Coeff. Ratio Lung / Bone S, K,Red Marrow
Inhalation Dose Coefficients for **U-234**		
Bone surface	5,0E-07	156
Kidneys	1,9E-07	411
Red Marrow	5,2E-08	1500
Resp. Tract: ET Airways	3,6E-05	
Resp. Tract: Lungs	7,8E-05	
Inhalation Dose Coefficients for **U-235**		
Bone surface	4,7E-07	149
Kidneys	1,8E-07	389
Red Marrow	5,0E-08	1400
Resp. Tract: ET Airways	3,3E-05	
Resp. Tract: Lungs	7,0E-05	
Inhalation Dose Coefficients for **U-238**		
Bone surface	4,6E-07	146
Kidneys	1,7E-07	394
Red Marrow	4,9E-08	1367
Resp. Tract: ET Airways	3,1E-05	
Resp. Tract: Lungs	6,7E-05	
Inhalation Dose Coefficients for **DU 0,2% U 235**		
Bone surface	4,7E-07	147
Kidneys	1,7E-07	397
Red Marrow	4,9E-08	1389
Resp. Tract: ET Airways	3,2E-05	
Resp. Tract: Lungs	6,9E-05	

ICRP 69 **Sv/Bq** Adult

		Dose Coeff. Ratio Lung / Red Marrow
Ingestion Dose Coefficients for **U-234**		
Red Marrow	8,10E-08	
Lungs	2,80E-08	0,35
Ingestion Dose Coefficients for **U-235**		
Red Marrow	7,60E-08	
Lungs	2,60E-08	0,34
Ingestion Dose Coefficients for **U-238**		
Red Marrow	7,50E-08	
Lungs	2,50E-08	0,33
Ingestion Dose Coefficients for **DU 0,2% U 235**		
Red Marrow	7,59E-08	
Lungs	2,55E-08	0,34