UNEP/UNCHS Balkans Task Force (BTF)

The potential effects on human health and the environment arising from possible use of depleted uranium during the 1999 Kosovo conflict.

A preliminary assessment

October 1999

List of contents

Foreword

This report has been produced by an international expert 'Desk Assessment Group' as a contribution to the work of the UNEP/Habitat Balkans Task Force.

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Chapter 1

The Study

1. The task

The task of the Technical Mission of the UNEP/Habitat Balkans Task Force was to "assess the potential health and environmental impact of depleted uranium used in the Kosovo conflict" by:

1. collecting pre-information from existing material, in close co-operation with relevant institutions and organisations, concerning
   - potential effects of depleted uranium on human health or the environment;
   - quantity and quality of depleted uranium used in the conflict;
   - location of affected sites to be assessed.

2. assessing, by means of a desk study, the medium- and long-term potential health and environmental impacts of depleted uranium used in the Kosovo conflict, and depleted uranium dumped into the Adriatic Sea.

3. making a fact-finding mission to Kosovo to prepare a sampling campaign and field study.

4. considering the possibility of conducting a Field Study in Kosovo, (based on the findings of the desk assessment and preparatory mission), to gather information from selected sites by using appropriate methodologies to assess the radioactivity and toxicity of depleted uranium.

5. analysing information in order to quantify 'on the ground' problems in respective areas and to provide qualitative answers concerning the possible risks to human health and further environmental damage.

The purpose of the task was to obtain a reliable baseline for deciding whether people can move back to abandoned areas, to judge the need for special control and countermeasures, and, through information dissemination, to avoid unnecessary concern. The study concludes with some recommendations.

The task was limited to Kosovo, but the conclusions are applicable to other areas as well.

2. The organisation of the work

The work has been conducted by a small group of experts known as the 'Desk Assessment Group' (DAG). By studying literature, making assessments and conducting a Fact Finding Mission to Kosovo, the DAG has produced this report.

The purpose of the Fact Finding Mission to Kosovo was to determine whether it would be possible, under present conditions, to undertake a longer mission for taking measurements in any areas identified as affected by depleted uranium.

The report consists of a main text and several appendices giving more detailed background information. It has been reviewed by a group of international experts and their comments have been taken into due account.

3. The conditions of the work

3.1. Limitations

The possibilities to make a comprehensive and complete report have been limited by a number of influential factors and conditions:

- there are no official documents confirming that depleted uranium was, or was not, used in the Kosovo conflict. There are only various oral statements, some of which are contradictory;
- consequently there is no information on where and how depleted uranium has been used and therefore a scenario was developed based on conservative assumptions;
- it has not been possible, within the given time framework, to organise and perform measurements, or take samples, in areas identified as affected by depleted uranium (the limited Fact Finding Mission to Kosovo did not identify any contamination in the selected areas);
- there are a number of publications and articles of varying scientific quality quoted and used by persons engaged with this issue. These may influence judgements about the health effects of depleted uranium, leading to the magnitude of the risks being either over-estimated or under-estimated. Time has not allowed a thorough scientific review of all these documents;
- the work has been done pending results of new 'generic' assessments being developed by WHO of the health risks of exposure to depleted uranium, whilst other scientific assessments are in preparation;
- the human resources available for carrying out the work have been very limited.

3.2. Possibilities

On the other hand there is already a lot of reliable information and data which make it possible to draw up conclusions and recommendations, having in mind the limitations and uncertainties described above.

There is a great deal of knowledge concerning the physical and chemical properties and qualities of uranium and depleted uranium, its chemical toxic and radiological health effects, particularly in animals, its dispersion in air and uptake by plants, animals and human beings, and its metabolism in the body.

For example, it is known that:

- depleted uranium is radioactive and has a chemical toxicity that, at least in the case of oral intake, is significantly more important than the radiological effects;
- depleted uranium is much less radioactive than natural uranium and has a very low specific radioactivity (activity per gram);
- uranium occurs everywhere in the environment in varying concentrations and constitutes a part of the natural radiation affecting human beings;
- depleted uranium is used for civil purposes as counterweights in aeroplanes, as shields against radiation from strong radioactive sources in hospitals etc.;
- being radioactive, depleted uranium may expose people, if they come into direct contact with it - either by external radiation, or, if there is an intake into the body, internal radiation;
- radiation may cause cancer, with the risk increasing in proportion to the dose;
- high exposures to depleted uranium can cause acute lethal effects (demonstrated in animals) due to chemical toxicity, but is also harmful to health in smaller quantities;
- through experiments on animals, and observations of effects on exposed people, it has been possible to establish 'safe' values for exposure; i.e. limits, below which the risks are considered as tolerable.

3.3. Chosen approach

Because of these limitations and possibilities, it has been necessary, in order to obtain a basis for judgements, conclusions and recommendations, to approach the problem as follows:

- assume that depleted uranium was used in the Kosovo conflict;
- use information from the Gulf conflict concerning the military use of depleted uranium and its observed effects;
- use available information on other military uses of depleted uranium and its observed effects;
- apply scientific data and knowledge of depleted uranium with regard to its physical and chemical properties and qualities, behaviour in the environment, metabolism in the human body etc.;
- develop a scenario that considers and includes possible events and consequences;
- make comparisons between the results of the scenario study and existing natural levels of uranium/natural radiation, and present limits and hygiene standards etc. in order to put the possible risks into perspective;
- from the above, identify the significant risks arising from exposure, and taking the uncertainties into account, judge the results, draw conclusions and make recommendations.

The information and data available have been used with scientific discretion.

4. The work done

4.1. Fact Finding Mission to Kosovo

The purpose of this visit to Kosovo was to conduct a fact finding mission in the context of the aims and objectives of the UNEP/Balkans Task Force (BTF); i.e. to determine whether it

would be possible, under present conditions, to make an expanded field study (sampling and measurements campaign) related to depleted uranium (DU) in the environment.

The finding of the Fact Finding Mission was that under the present circumstances, it was not meaningful to conduct extensive field measurements to investigate the contamination of DU in Kosovo. As the effects of DU are mainly localised to the places where DU ammunition has been used and the affected areas are likely to be rather small, it is difficult to find these areas without information on the exact location of the areas. It has not been possible to obtain such information. Furthermore, an imperative condition is that the areas to be investigated should be cleared from landmines and be safe.

During the Mission, the team performed some preliminary measurements. For example, absorbed dose rates in the air, and surface alpha and beta contamination levels around destroyed and damaged military vehicles along the roads on which the team travelled, and, in Pristina, around the damaged Police Station and Post Office (interiors also partly checked). In addition to these measurements, two sets of swipe samples were taken from the surfaces of destroyed tanks for subsequent isotopic analysis. These samples were taken for the purposes of establishing 'background' levels, since the tanks were not attacked using DU weapons.

4.2. Compilation of data and information

The group has compiled available information on a number of relevant issues such as:

- general information on natural and depleted uranium regarding physical and chemical properties, natural levels of uranium and radiation, exposure pathways in the environment, metabolism of uranium in the body, and observed health effects caused by chemical and radiological toxicity;
- use of depleted uranium for military purposes;
- long-term environmental behaviour and effects of depleted uranium;
- immediate and short-term problems, including some introductory remarks and reflections on the problems of measurement, possible decontamination, waste management and disposal.

4.3. Scenario and conclusions

Through the use of available information, a hypothetical scenario was described, based on a number of conditions and assumptions. These were chosen to be as realistic as possible. In case of uncertainties, conservative assumptions were made; i.e. the real levels and consequences would most probably be less than those described. Through these means, all possible exposures to depleted uranium were discussed and conclusions drawn about their significance.

4.4. Recommendations

On the basis of these conclusions the expert group finalised the study by making a number of recommendations on actions that should be taken within the short-term future.

5. Work that was not done

Some points of the Terms of Reference were not fulfilled. These included the suggested study of possible environmental effects of dumping of DU ammunition in the Adriatic Sea. However, according to available information, such dumping is not very likely to have occurred.
Secondly, no extensive measurements in Kosovo were performed because there was no information on if, where and how depleted uranium was used.
Thirdly, the study does not consider possible problems arising from damage to facilities containing radioactive materials like Co-60, Cs-137, Ra-226 and others used in industry and in medicine as radioactive sources.

Chapter 2

The Results

1. The Fact Finding Mission

The Fact Finding Mission to Kosovo was conducted to determine whether it would be possible, under present conditions, to organise a further mission for taking measurements in any areas identified as affected by depleted uranium (DU).

The Mission did not locate and sample any targets that had been hit by depleted uranium. There were no elevated levels of radiation measured in the vicinity of the destroyed military vehicles in Klina. No elevated levels of radiation were found on, or alongside, the roads the mission team travelled along, or at Pristina Police Station and Post Office. Based on these preliminary measurements, the team did not find any evidence or indication of the presence of DU at the locations visited.

2. The scenario study.

2.1. The scenario and assumptions

- The basic assumption is that depleted uranium has been used in Kosovo.
- It has been used only by aircraft.
- It is assumed that an attack includes 3 aircraft and the total depleted uranium (DU) used in the attack is 10 kg.

- The target is one or several vehicles, and the area affected by the subsequent DU contamination is 1000 m^2.
- The impact of DU on soldiers and civilians in the vehicles and on the affected area during the attack is not considered specifically.

- Most of the dust that is caused by explosions and fire is assumed to settle on the ground within the area of 1000 m^2.
- However, it is assumed that persons in the immediate vicinity are instantaneously exposed, for a short duration, to the dust cloud, which probably has a very high density (100 mg m^{-3} is assumed).

- After some time, other people enter the area, which may contain cultivation. By entering the area, these people cause re-suspension of dust, breathe contaminated air, touch contaminated objects, and are externally exposed from solid pieces of DU ammunition that are picked up.

- Some of the DU will be dissolved by water percolating through the soil, contaminating the groundwater, which serves a well nearby.

- Some animal will graze in the area, be contaminated, eventually be used as meat, and thereby contaminate people.

2.2. The consequences

In the scenario, various possible means of exposure are considered. The highest exposures occur in the target area (assumed to be 1000 m^2) and its immediate surroundings. Therefore, the consequences described below relate to people and the environment in these areas. Outside these areas, the exposures and the consequences will be significantly less.

In order to put the consequences given below into perspective comparison can be made with natural levels, limits, standards and action levels. It is important to point out that limits and standards are applicable only for normal, planned situations and not in a situation like the one in Kosovo after the conflict. In these situations it is more appropriate to speak about action levels. However, for the sake of comparison only, some values are given for radiation.

Radiation dose is given in a unit named sievert (abbreviated as Sv). Because one Sv is a very high dose (lethal), smaller units are used: *mSv* (millisievert = 0.001 Sv) and *μSv* (microsievert = 0.000001 Sv)
Natural radiation from the ground, buildings, cosmos, food, water and the body itself, varies from place to place, but, on average, is in the range, *2-4 mSv per year*.
The recognised limits for total radiation exposure from all human radiation work (except medical and natural radiation) is *1 mSv per year for the general public* and *20 mSv per year for radiation workers*.
Action levels are applied when these limits are significantly exceeded because of some accident, natural condition, or past event etc. Normally, an action (coutermeasure) is only justified if the radiation dose can be reduced by *more than 10 mSv* (sometimes as an annual dose).

1. *Picked up solid pieces of DU.*
By keeping a piece of DU in the pocket for several weeks in the same position, it might be possible that the skin dose will exceed values corresponding to the limit for the general public and radiation workers. It is out of the question that there will be any deterministic effects (skin burns).

2. *Bullets that passed or missed the target and can contaminate the ground and groundwater.*
The bullet can be intact and the risks are as descried above in paragraph 1. Alternatively, the bullet may be damaged and the risks are as those described below for inhalation, ingestion and groundwater contamination.

3. *Instantaneous inhalation of DU dust after an attack.*
The dust concentration will be very high and, if the person survives the attack but is unprotected, there is a great risk that they will have received a very high exposure, possibly leading to chemical toxic effects. The radiation dose will probably be moderate, less than 10 mSv.

4. *Inhalation of re-suspended DU.*
Due to the effects of wind, people walking in the area, digging etc., dust from the ground may be re-suspended in the air and then inhaled. All DU is assumed to be present in the form of small particles (<10 μ) and to be in the form of insoluble oxides (Type S), which are cleared from the lungs only slowly.
An assumed 2 hours stay in the target area, would lead to a person receiving doses in the range of 0.1-10 μSv. An unprotected stay in the area for a whole year, 24 hours per day, and with normal dusty conditions, would lead to doses of the order of 1 mSv per year the first year. After some time, rainfall makes the depleted uranium less accessible for re-suspension and the inhalation risks decreases.
The chemical risks are of the order of acceptable standards.
No acute radiation effect on the lung is expected to be caused by radioactive particles.

5. *Ingestion of DU.*
- from soil taken into a person's mouth (e.g. a child)
  Risk of acute chemical effects. The radiation doses are low (less than 1 mSv per year).

- by surface contamination of leafy vegetables (before rainfall washes the vegetables)
  A significant risk of chemical toxic effects. The radiation doses are low.

- by contaminated hands (after touching contaminated surfaces)
  No acute chemical effects and only low radiation doses are expected.

- by contaminated open wounds (e.g. contaminated hands with open wounds)
  The resulting radiation doses are difficult to predict as well as the chemical toxic effects and the risk of internal contamination by contaminated blood. The risks should not be underestimated.

- by contaminated water (in a nearby well)
  Chemical toxic effects cannot be excluded because the concentration may exceed hygiene standards by orders of magnitude. The radiation doses could be around 1 mSv per year.

- by contaminated food (other than vegetables)
  Human consumption of meat and milk, from animals grazing on the area shortly after the attack but before the first rain, may be a risk factor. Soon after the attack, there might still be substantial surface contamination of grass etc. The animals themselves might receive high exposure from internal contamination.
  After some time, the contamination of plants is mainly by root uptake and the chemical toxic effects and radiation doses will be insignificant (less than 10 μSv per year). Root vegetables contaminated on the surface by DU-contaminated soil might be considered as a potential risk, even if the risk is minor. It very much depends on the hygiene standards followed in food preparation.
  Ingestion of soil is an important factor for DU intake by grazing animals and the contamination of soil by DU will remain for some time, even though diluted. Therefore, it can not be excluded that contamination of animals and indirectly of humans eating products from these animals might be significant even in the long time perspective.

6. *External radiation*
The external doses from gamma radiation will be insignificant (less than 10 μSv per year) or low (less than 1 mSv per year).

7. *Activity spread over large areas*
It has been suggested that depleted uranium will be spread over much larger areas and cause many health effects. However, if DU was spread over a wide area, the concentration in the environment will be much less than assumed in the assessments above. Consequently, no chemical toxic effects are expected, and the radiation doses will be negligible.

2.3. The judgements

On the basis of known facts, and the results of the assessments in this report, combined with the general approach and attitude in the area of health and environmental protection, the following judgements seem reasonable:

1. The risks of picking up solid pieces of DU should not be disregarded and such action should be avoided.

2. Persons close to the target during the attack might have received a high exposure.

3. Inhalation of re-suspended DU is not expected to lead to any significant radiation or chemical risks.

4. The risk of high intake of DU by ingestion of soil in the mouth (children), from leafy vegetables or through open wounds is significant for a time after the attack (until heavy rain falls).

5. Consumption of meat and milk from animals grazing on the attack area shortly after the attack but prior to any heavy rain, could lead to significant risk taking into account both chemical toxicity and radiation exposure. The animals themselves might receive high exposure from internal contamination. Because ingestion of soil will continue to be an important factor for DU intake by grazing animals for some time, the risk of exposure of animals and humans should not be disregarded in a longer time perspective.

6. Concentration of DU in fruit and vegetables caused by uptake from roots is low . The possible exceptions are root vegetables, e.g. potatoes, that are not carefully washed. In a nearby well, the resulting concentrations of DU might be higher and could cause significant risks.

7. The external radiation exposure caused by deposited DU on ground is insignificant.

8. The exposures from DU assumed to be dispersed over large areas are considerably reduced.

Note. The judgement ‘low’ or ‘insignificant’ is used in cases when the expected radiation doses are less, or much less, than 1 mSv per year and the chemical risks are very low or zero; ‘significant’ if the doses are in the region of 1 mSv per year or the chemical risks are in the region of the values corresponding to given hygiene standards; and ‘high’ or ‘very high’

when the dose is above, or much above, 1 mSv per year, or above (or much above) the chemical standards, or the risks are acute.

Chapter 3

Conclusions and Recommendations

1. The Conclusions

The conclusions are based on known facts, made assumptions and results of the scenario analyses. The amount of depleted uranium used in each attack is that assumed to be used by aircraft. It is assumed that depleted uranium has not been used in missiles and in ammunition from tanks. There are no data on this whatsoever.

1. The lack of official confirmation from NATO that depleted uranium has, or has not, been used, distorts the prerequisites of this study.

2. The absence of systematic radiation measurements and sampling in Kosovo is a fundamentally weak point in this study. Measurements and sampling are necessary to verify the extent of the problem. These should focus on attacked areas and especially on attacked targets.

3. The results of the study depend on the assumptions made for the assessments. Some of these assumptions can not be verified at this time and therefore the results are subject to uncertainties. This is taken into account in formulating the recommendations by framing them conservatively.

4. With the given conditions and assumptions, the significant risks are restricted to a limited area around the target. If the depleted uranium is dispersed to larger areas, the corresponding risks are considerably reduced.

5. If contaminated vehicles and apparent accumulations of uranium pieces and dust are removed from the target area, the possible risks of significant exposures are related to a few specific circumstances that could be avoided by provision of adequate information and instructions.

6. Some of the early significant risks of exposure are no longer (after some months) relevant, e.g. open wounds, contaminated leafy vegetables, milk and meat from the target area. However, possible risk of continued contamination of animals, milk and meat because the animals eat contaminated soil should be considered.

7. The possible contamination of land from depleted uranium is not an obstacle to moving back to those villages and regions that were affected by attacks, and at which DU ammunition may have been used, providing that the recommendations of this report are taken into account.

8. During and immediately after an attack at which depleted uranium has been used, some people in the immediate vicinity may have been heavily exposed to depleted uranium by inhalation. The extent of this possible problem might be verified by special health examinations. This is applicable also to potentially affected individuals who are no longer in the area.

9. The results of these analyses are general in nature and, therefore, applicable not only to Kosovo but also to other areas in the Balkan region.

2. The Recommendations

1. Obtain information from NATO concerning if, how and where depleted uranium has been used in order to be able to verify risk assessments, make necessary measurements, and take justifiable precautionary actions.

   If it is officially confirmed that depleted uranium has not been used in the Kosovo conflict, this study can be concluded.
   If it is officially confirmed that depleted uranium has been used, or if no conclusive information is obtained, the following recommendations apply:

2. The study of the situation in Kosovo concerning depleted uranium should continue according to the Terms of Reference. The steps listed below should be given high priority.

3. Further measurements should be organised, as soon as reasonable, to identify possible contamination and verify assumptions. Highest priority should be given to finding pieces of depleted uranium, heavily contaminated surfaces and other 'hot spots'.

4. Pieces of depleted uranium, heavily contaminated objects and loose contamination should be collected and removed. This work should be done under controlled conditions with proper protection of people involved. The collected depleted uranium should be stored in safe conditions under the responsibility of a designated authority and until further instructions are given.

5. At places where contamination has been confirmed by measurements, or where there is an apparent risk of contamination, signs should be put up to forbid public access. These areas should also be clearly marked (i.e. by tapes or fences). Access of grazing animals should be prevented.

6. The local authorities and the people concerned should be informed about the results of the investigations, as well as the possible risks and countermeasures.

7. A programme of measurements (central and local), and a strategy for dissemination of safety instructions, countermeasures and waste disposal measures should be developed.

8. If contamination is confirmed, necessary measures and remedial actions should be implemented.

9. A programme for possible health examination of people in, or close to, attacked areas where DU was or might have been used, should be devised. If justified by further information, this programme should be implemented, giving priority to people most at risk of having been heavily contaminated.

10. A thorough review of the effects on health of exposure to DU in the medium and long term perspective is required.

Appendix 1

Overview of the appendices

The purpose of this appendix is to assist the reader in finding the relevant appendix for a specific question related to the main text of the report.

Appendix 2 gives the *Terms of Reference*. As discussed in the main text not all required has been done mainly because of lack of necessary information and time.

Appendix 3 describes in short the *background of the study*.
It describes what the question is about, the underlying problems and the uncertainties about the reported effects.
There are a large number of publications concerning depleted uranium, its military use and resulting detrimental effects. The appendix refers to some of these publications with the purpose of illustrating the information that makes people frustrated and doubtful about the harmful effects of depleted uranium. Many of the results on harmful effects refer to relatively high exposure to uranium and it is important to sort out exaggerations as well as under estimations of the risks and identify the real problems.

Appendix 4 gives *general information on natural and depleted uranium*.
The purpose is to give the most important information about uranium in general and depleted uranium in particular in order to understand the significance of the current problems and facts. It will help to put the potential risks related to depleted uranium into perspective as compared with natural levels of uranium and natural radiation, international recommendations and standards.
The physical and chemical properties are presented, the dispersion characteristics, exposure pathways and the metabolism of uranium is explained and observed effects on health caused by the chemical toxicity and by radiation are described.
Most effects and the majority of results that are found in the literature are related to studies in animals, usually carried out at high dose levels. There is only limited evidence for health effects in humans related to exposure to depleted uranium.
Therefore, there is need of making relative judgements by comparing with natural levels, limits and other values if interest.

Appendix 5 discusses the *military use of depleted uranium ammunition.*
Because much information on the possible use of depleted uranium in the Kosovo conflict is classified military information, the facts given in the report are sparse and are mainly from open literature after the Gulf conflict. However, on reasons of precaution it is assumed in this study that depleted uranium has been used also in the Kosovo conflict.

Appendix 6 discusses the *environmental long-term behaviour and effects of depleted uranium.*
It describes the chemical characteristics of uranium in nature and how they might change depending on the environment. It discusses the leakage to groundwater, uptake by plants and animal in the long time perspective.

Appendix 7 is a short summary *report from the Fact Finding Mission to Kosovo*.
The purpose of the travel to Kosovo was to conduct a fact finding mission to determine whether it would be possible, under present conditions, to make an expanded field study concerning depleted uranium in the environment.
Even if the original objective of the visit was not met, there were some measurements made along a given route decided by responsible parties.
There was no indication of a radioactive contamination and the continued work has to be based on theoretical considerations only.

Appendix 8 presents the assessments on the *potential health and environmental impact of using depleted uranium in ammunition.*
It describes the expected levels and effects on humans and the environment. The presentation is in the form of a scenario, which includes a number of conditions and assumptions. They are all as realistic as possible and in case of uncertainties, conservative assumptions are made i.e. the real levels and consequences would most probably be less than those described.
The purpose of the chapter is to judge the possible situation in large and identify the weak, uncertain points and those parts where it is obvious or doubtful that there is a harmful situation or a condition that needs further studies or might need precautionary or remedial actions.

Appendix 9 discusses in general terms the *near future problems* of measurements, of remediation procedures like cleaning up and decontamination and the problem of disposal of depleted uranium as waste.

Appendix 10 describes and explain the *dose conversion factors for depleted uranium* which are used in the assessments.

Appendix 11 gives an example of *regulations on waste disposal* as regards depleted uranium.

Appendix 2

Terms of Reference
for
Technical Mission
Balkans Task Force

Assessment of the potential long term effects on human health and the environment due to the conflict

1. Objective

UNEP/Habitat Balkans Task Force is, as a part of an overall assessment of the environmental consequences of the conflict, and impacts of the conflict to human settlements in Kosovo, Macedonia, Montenegro, Albania and Serbia, organising a Technical Mission to provide independent, reliable and relevant information on:

- the state of the environment in the selected places which are identified as the worst environmentally damaged areas from the conflict and, potentially are consisting contaminated soil, water and large amounts of toxic substances which create a risk for further degradation of environment and ecological values and pose a risk to human health.
- overall situation regarding the human settlements in Kosovo.

The assessment should try to analyse, in particular, what were the impacts of the conflict and what was the state of the environment before the conflict.

The Technical Mission is organised in close co-operation with all interested parties, under the leadership of UNEP/BTF.

The findings and results from the Technical Mission are the property of the UNEP/Habitat BTF. A final report from all the Technical Missions will be submitted to the Secretary General of the United Nations in September/October 1999. After submission to the SG the recommendations and findings will be made available to all interested parties. The report will also consist of recommendations for organisations involved in the reconstruction of the region.

2. Elements of the Mission

The UNEP Technical Mission has five elements:

1. Environmental Assessment of the worst Damaged Industrial Sites

2. Complementary measurement to assess the environmental impacts of the conflict to the Danube River
3. Assessment of the damage to biodiversity in nature conservation areas
4. Assessment of the potential long term health and environmental effects due to the conflict (incl. depleted uranium)
5. Assessment of the Human Settlement situation in Kosovo

Each element of the Mission will be organised separately, but under the leadership of UNEP and following unilateral methods and rules. All the elements will contribute to the Final Report to be published by UNEP in September, 1999.

3. Tasks of the Mission

ASSESSMENT OF THE POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT OF DEPLETED URANIUM USED IN THE KOSOVO CONFLICT

1. Collect pre-information from existing material in close co-operation with relevant institutions and organisations.
- Potential effects of depleted uranium to human health or to environment.
- Quantities and quality of depleted uranium used in conflict.
- Locate sites to be assessed.

2. Desk Study to assess the medium and long term potential health and environmental impacts of depleted uranium used in Kosovo conflict and depleted uranium dumped into the Adriatic Sea.

- **The amounts of depleted uranium used in the Kosovo conflict**

An inventory of the depleted uranium used in weapons fired (or dumped) in each geographic region should be compiled.

- **The spatial distribution of depleted uranium and its likely form/s**

A rough indication is needed of the main areas where depleted uranium armaments were fired (or dumped) together with the form/s in which the bulk of the material will be found in the environment (i.e., the distribution between different types of armaments, the fraction/s likely to have been dispersed as an aerosol, the amount likely to have been dispersed as fragments of various sizes, etc).

Such data are needed for both the desk based study and to optimise any monitoring campaign.

- **Assessment of the Radiological Situation**

The overall radiological situation caused by anthropogenic sources of ionising radiation in specified locations should be assessed. This should include the possible existence of radioactive residues of depleted uranium. It will also be technically desirable to evaluate the potential impact of other anthropogenic radiation sources, such as those used in radiotherapy, radiodiagnosis and industrial applications that might be outside regulatory control as a result of the situation in Kosovo. The potential occupational exposure to ionising radiation of people working in the area may also need to be addressed. The technical framework for the assessment will be the International Basic Safety Standards for Protection against Ionizing

Radiation and the Safety of Radiation Sources (IAEA BSS) which are cosponsored by the relevant specialised organisations in the United Nations System.

- **The chemical toxicity of depleted uranium and relevant standards**[1]

The toxicity of depleted uranium should be addressed and how it can affect man and/or the environment. The main exposure pathways should be described (internal and external) together with prevailing standards for occupational and public exposure that can subsequently be used to evaluate the significance of any past or future exposure. The relative importance of chemical toxicity should be discussed depending on the form of the material.

- **Assessment of potential health and environmental impact**

The assessment should focus on the potential health impact from exposures to uranium during and after the conflict. Some reference to potential harm to the environment in a broader sense will be necessary but is likely to be a secondary consideration. At this stage (given the paucity of information on the amount and nature of weapons fired, their distribution and form/s in the environment, etc.) any estimates will, of necessity, be approximate and associated with much uncertainty. However, with the use of well considered scenarios, it should be possible to bound the problem as a basis for establishing sound recommendations on the need for any follow up or remedial action. Where information is lacking, conservative assumptions will have to be made; undue caution should however be avoided as it may undermine the worth of the study.

A range of credible scenarios should be formulated as the basis for assessing the potential intakes and exposures of the civil population (and also military personnel if the scope is to be extended as recommended in footnote 1).

During the conflict **-** Consideration will, inter alia, need to be given to inhalation of any uranium dispersed as an aerosol from contact with a target or other object, from uranium inhaled during recovery of injured personnel from damaged installations or hardware, or from shrapnel embedded in wounds for any protracted period.

Immediately after the conflict **-** Consideration will need to be given, inter alia, to potential exposure from resupsension of any dispersed and deposited uranium, from exposure as a result of access to and recovery of any damaged installation, military or other vehicles, etc, and from direct contact with larger fragments of uranium. Transfer of and exposure from deposited uranium through the food chain should also be assessed.

Medium and longer terms **-** Consideration will need to be given to all potential exposure pathways in the medium and longer term; these should be quantified, for re-assurance purposes, even where the expected impact is negligible. Inter alia, resuspension, food chain transfer, ground water contamination should be addressed as well as contact with fragments of material of various sizes, either inadvertently or deliberately (e.g., collection/re-use of scrap metals in the conflict area, etc).

- **Input to the design of the monitoring campaigns**

Time constraints will dictate that the desk study and field monitoring campaigns will proceed largely independently, albeit anticipating the respective needs of each. However, to the extent practicable, the monitoring campaign should be optimised with a view to providing essential

[1] Substantive and authoritative reports on uranium standards and toxicity have been compiled recently in the US in response to depleted uranium use in the Gulf War; they should, where appropriate, be used here to avoid unnecessary duplication of effort.

input to the desk study (e.g., airborne and deposited levels of depleted uranium in areas representative of the most heavily contaminated) and/or to validating its main findings. Specification of those monitoring data that would be most useful in this context should be a priority for the desk study and should be completed well in advance of the field campaigns. The schedule for the study should foresee a formal exchange/meeting between the desk study and monitoring teams in order to optimise the fieldwork.

- **Recommendations**

Based on the assessment, recommendations should be made as to the need for any follow up or remedial action (e.g., monitoring of sub-groups in the population, removal of uranium fragments from the environment, more detailed monitoring programmes, education/guidance for the population on the handling of debris from the conflict, especially scrap metal that may contain uranium, etc) deemed necessary to achieve an acceptable level of health and environmental protection in both the short and long term.

3. Fact-finding Mission to Kosovo to prepare the sampling campaign and the field study.

4. Based on the findings of the Desk Assessment and preparatory fact-finding mission, there might be a reason to run a Field Study in Kosovo to gather information from the selected sites by using appropriate methodologies for assessing the radioactivity and toxicity of depleted uranium in these places (sampling, taking measurements). The accuracy of Field Study will only be judged after the Desk Assessment results are available.

- Measurement from selected sites to assess the amount of radioactive residues of DU
  - Vehicles or other objects hit by DU ammunition ;
  - Area around the impact points;
  - Inhabited locations less than 5 km from locations hit by DU ;
  - Rural areas potentially having radioactive residues of depleted uranium;
  - Areas reported as unaffected.

5. Analyse information in order to quantify the actual problems in respective areas and to give qualitative answers on the possibilities for risk for human health and further environmental damage.

6. Review of the Desk Study by a larger group representing multidisciplinary scientifical experts.

7. Report on the findings

- Individual report from the experts
- Integration of the reports by rapporteur
- Final report by the Balkans Task Force.

Appendix 3

The background of the study

The purpose of this chapter is to give the general background of how the use of depleted uranium in military operations has caused worries among concerned people, politicians and others. There are a great number of reports and scientific articles on the use and related risks of depleted uranium and many of them are referred to in this chapter. However, there is no attempt in this chapter to make a critical review of the published information but only to present examples from the literature that illustrate the people's concerns. Part of the information given in this chapter is given just as introduction and developed further, particularly in appendices 4, 5 and 8.

1. Introduction

In a U.S. Department of Defense news briefing on Monday 3rd May, it was informed that depleted uranium (DU) weapons had been used by U.S. forces in the Balkans. It was reported that DU shells had been fired from A-10 aircraft (Secretary of Defense DoD News Briefing 1999). However, it is not known whether U.S. forces fired cruise missiles that contained DU. It is also not known whether other NATO forces used DU weapons in the Balkans. The present state of knowledge regarding DU use in Kosovo and possibly in Serbia is, therefore, that both the quantity of DU weapons used, and the location of targets hit by DU weapons, are unknown and formally there is no official document that confirms whether DU was used.

DU weapons were first used in a combat situation during the Gulf War. U.S. and U.K. tanks and U.S. aircraft fired weapons containing DU. Based on U.S. government information released under the Freedom of Information Act, it has been reported that over 300 tons of DU, mostly in the fragmented form (dust) were left on the battlefields in Iraq and Kuwait (Lancet 1998).

There has been concern regarding the possible environmental impacts of DU and it's possible health effects on both military personnel and on civilians following the Gulf War (e.g. LAKA 1999, CADU 1999). These issues have been raised by several non-government organization, some scientists and by a number of press reports. Since DU could have been used in the Balkan conflict, there is now also a concern about the possible consequences of its use for the people and for the environment of this region.

There are concerns that the use of DU weaponry during the Gulf War may be responsible for, or partly responsible for, significant increases in several diseases/conditions in Iraq. In particular, an increase in cancers, in birth defects (congenital abnormalities) and in diseases of the immune system (Kammas 1999, Lancet 1998). In addition, the possible contribution of DU in Gulf War Syndrome in U.S. and U.K. Gulf War army veterans has not been ruled out by the scientific community (Jamal 1999). However, the presidential Special Oversight Board for the Department of Defense Investigations of Gulf War Chemical and Biological Investigations of Gulf War Chemical and Biological Incidents stated in their Interim Report

of August 1999: “the Board agrees with the conclusion that the available doses not support claims that DU caused or is causing the undiagnosed illness some Gulf War veterans are experiencing (Special Oversight Board 1999).

In the report “Assessment of the Environmental Impact of Military Activities During the Yugoslavian Conflict. Preliminary Findings, June 1999”, to the European Commission DG-XI, Nuclear Safety and civil Protection, the Regional Environmental Center for Central and Eastern Europe (REC) reports on Yugoslavian claims that depleted uranium weapons have been used in the conflict. REC writes referring to chronic effects on human health of the pollution in Yugoslavia: ”Several of the above-described toxic compounds released after the bombings can cause chronic health problems. Perhaps the most dangerous is depleted uranium, but there are also other carcinogenic and toxic substances, such as vinyl chloride monomers, which have been released. Many of the compounds released can cause miscarriages and birth defects. Others are associated with fatal nerve and liver diseases” (REC 1999).

Since there is concern that the use of DU in war may pose a subsequent risk to health of both combatants and non-combatants, and may cause prolonged environmental contamination, the BTF “desk study” is being conducted to review existing information on DU and give appropriate recommendations in the aftermath of the Balkans conflict.

2. What is DU

DU is a waste product of the process that is used to enrich natural uranium ore for use in nuclear reactors and in nuclear weapons. Compared to natural uranium which has a U-235 isotopic content of 0.7%, the isotopic content of U-235 in DU is partially depleted to about a third of its original content (0.2%) (see also Appendix 4).

3. DU in weapons

DU is reported to have been used in the tips of bullets that are used with the intention of piercing armour plating. It may also be used in cruise missile nose cones and is used in the armoury of tanks. One of the main reasons why DU metal is used in these applications is because of its high density. In the case of weapons, this makes them extremely hard and able to pierce armour plating. In addition to its high density, other reasons for its use in military applications include its cheapness and the fact that it is available in huge quantities.

The effectiveness of using DU in kinetic energy penetrators (the rods of solid metal shot from guns) has been demonstrated by open air testing at various locations in the U.S. and in the Gulf War. Kinetic energy penetrators do not explode but they fragment into pieces and fine dust. Due to the pyrophoric nature of uranium metal and the extreme flash temperatures generated on impact the dust in many cases catch fire and burns forming particles of uranium oxides (see also Appendix 5).

4. DU weaponry and Uranium oxide aerosols

It has been suggested that much of the DU used in weapons during the Gulf War was converted at high temperature, upon impact, to minute insoluble particles of uranium oxide, i.e. uranium dioxide or uranium trioxide, in a mist or fog (Bertell 1999). Indeed, the formation of such particles has been demonstrated in controlled testing of DU weapons by the U.S. Army.

For examples, U.S. army testing found that 18 to 70% of a depleted uranium penetrator rod burns and oxidizes into extremely small particles during impact (ARDEC 1991a). A high percentage (50-96%) of particles, which are formed in the DU aerosol, upon impact of a weapon with armour, were shown to be of 'respirable' size.

'Respirable' size particles are particles which can be inhaled into the deep areas of the lungs. Unlike larger particles, which do not penetrate far into the lungs and are easily removed, respirable particles can penetrate into deepest airways of the lungs and cannot be expelled in the same way.

The oxides of uranium that are formed when DU weapons impact are insoluble. One study showed that 52 to 83% of the respirable size particles formed on impact of DU weapons are insoluble in lung fluids (ARDEC 1991b), although an earlier study reported that about 43% of the respirable DU particles dissolved in simulated lung fluids within seven days (Rao and Bhat 1997). Other research has shown that insoluble particles are not readily excreted from the body and may remain in the lungs or other organs for years (U.S.A. Department of Defense 1998) (see also Appendix 4).

5. Environmental impact and health effects reported following the Gulf War

5.1 Environmental contamination of DU

At testing sites for DU weapons in the U.K. and the U.S., it has been reported that contamination is significantly above background levels (Rao and Bhat 1997, CADU 1999b).

Other work has also shown environmental radioactive contamination in the Iraq. For instance, in 1995 and 1997, documentary film teams detected uranium contamination on destroyed vehicles and in the soil in southern Iraq (ITN TV 1996, Gabriel films and BBC (U.K.) 1997).

At a roundtable conference on Iraq, held in July 1999 in London, a paper was presented which documented that the CPIAB had investigated environmental contamination in Iraq in five areas in Basra province (Kammas 1999). Surface and groundwater sediment samples from areas close to attacked military vehicles were reported to contain increased levels of radioactive nuclides. Samples of plants/animals that were taken showed radioactive contamination.

5.2 Health impacts in Iraq and Kuwait

A report on DU in Iraq after the Gulf War has been compiled by an Irish petrochemical engineer who had access to material in the West and Iraq and was presented to the office of the UN Commissioner for Human Rights. It hypothesized that the current health and environmental problems in Iraq may be in part linked to DU. It notes that the incidence of several cancers has increased, including childhood leukemia. It also states that congenital malformations and diseases of the immune system have increased (Lancet 1998).

Some data on environmental contamination and health effects in Iraq was presented and discussed at the roundtable conference held in London, July 1999. A study conducted by the Committee for Pollution Impact by Aggressive Bombing (CPIAB) in Iraq was presented. It reported an increase in cancers of all types amongst military personnel who were on the battlefield in Southern Iraq and in Kuwait during the conflict. The relative risk for cancer incidence between 1991-1997 compared to cancer incidence recorded in 1989 is 1.7; (i.e. there is a 1.7 fold greater risk of presenting with cancer since 1991 compared to 1989).

In addition Kammas (1999) has reported on substantial rises in the incidence of leukemia, lymphoma and bone cancer have been recorded in Iraq. It was noted that the relative risks for other diseases were also significantly increased including infertility, congenital abnormalities, and kidney failure. A German medic working in hospitals in Iraq has also reported on the increase in congenital abnormalities caused by genetic defects (Gunther 1999). In the presentation report of Gunther (1999), it is stated that the congenital deformities caused by genetic defects in children born to American soldiers and Iraqi children are identical. In these reports it is suggested that DU may be involved as one of the possible causes of the health effects.

5.3 Gulf War Syndrome in U.K. and U.S. Army Veterans

Thousands of American, Canadian and British soldiers who participated in the Gulf War have since claimed to be suffering with a variety of incapacitating symptoms which are generally termed as Gulf War Syndrome. The veterans were exposed to a variety of damaging or potentially damaging risk factors including environmental adversities, pesticides such as organophosphate chemicals, skin insect repellents, medical agents such as pyridostigime bromide (NAPS), possible low-levels of chemical warfare agents, multiple vaccinations in combinations and depleted uranium (Jamal 1998).

Today research has shown that many of the veterans with Gulf War Syndrome where exposed to a number of substances, However, little research has been carried out whether DU plays a role as an agent for the Gulf War Syndrome (Jarmal 1998).

Appendix 4

General information on natural and depleted uranium

1. Physical properties.

Uranium in nature exists as three isotopes, uranium-238 (U-238), uranium-235 (U-235) and uranium-234 (U-234). The concentration by weight of U-238 is 98.28%, of U-235 0.72% and of U-234 0.0056%. U-238 decays through 14 steps to lead-206 that is stable (Table 4.2) and U-235 through 11 steps to lead-207 (Table 4.3). Among the decay products are the elements radium-226 (Ra-226), which is a highly radioactive alpha emitter, bismuth-214 (Bi-214) and lead-214 (Pb-214) that emit nearly all gamma radiation in the uranium series. In nature, for example in an unprocessed uranium ore, uranium is almost in radioactive equilibrium with all its decay products from the whole uranium series.

However, in the chemical process when uranium ore is processed to pure uranium, the decay products of U-234 and U-235 respectively remain in the waste product. Thus, immediately after uranium has been extracted, it only consists of U-238, U-234 and U-235 (0.72%). After a few months the daughter products of U-238 - thorium-234 (Th-234) and protactinium-234m (Pa-234m) and the daughter product of U-235, thorium-231 (Th-231), will be in radioactive equilibrium with their parents.

Radioactive elements decay spontaneously. The time it takes for an element to decay to half of its original activity is called half-life. The half-life of U-238, U-234 and U-235 are $4.5\ 10^9$, $2.5\ 10^5$ and $7.1\ 10^8$ years, respectively. In depleted uranium (DU) radioactive equilibrium always exists between U-238 and the decay products Th-234 and Pa-234m as their half-lives are as short as 24.1 days and 1.17 minutes, respectively, and between U-235 and Th-231 that has a half-life of 25.5 hours.

Depleted uranium (composition see Table 4.1) is uranium that is a residual product obtained from the production of uranium fuel for nuclear reactors. Most reactors need uranium with a higher concentration of U-235 than found in natural uranium. In uranium enrichment plants, uranium in the form of UF_6 gas goes through a process based on the slight differences in the atomic mass of the uranium isotopes, and the concentration of U-235 in the gas is increased. Then the gas is transformed to UO_2 or uranium metal. The uranium that is to be used in the reactor, *enriched uranium,* usually has a concentration of U-235 that is 3.5% or higher. The concentration of U-235 as well as U-234 in the residual product, *depleted uranium,* is lower than in normal uranium. From this process large quantities of depleted uranium are obtained, which are only to some extent used as nuclear fuel (MOX) in some nuclear reactors.

However, mainly because of the high density (the specific gravity is 19) and strength of uranium metal, DU has found use in applications where high density is of particular value. Examples of such applications are as armour penetrating ammunition, armour in tanks, counterweights and ballast in aircraft and missiles, racing sailboat keels and as material used in hospitals for shielding of X-rays or gamma radiation from cobalt-60 sources used in

radiation therapy. When DU is used in ammunition, the U-235 concentration is 0.2-0.3% (RAND 1999).

Depleted uranium as a metal has a theoretical density of 19.07 g/cm^3 (1.7 times the density of lead). To achieve better strength and greater resistance to corrosion, molybdenum or zirconium and tungsten can be used as alloys (Blasch et. al 1970). The Nellis Air Force Range report gives the information that the DU ammunition used by the US A-10 Warthog attack airplays is alloyed with 0.75% titanium (NELLIS 1997). The titanium is added to make the uranium metal less brittle and more corrosion-resistant.

In DU, only minute traces exist of the decay products beyond U-234. As described above, this is due to the fact that all the later decay products are separated in the processing of uranium ore, and the new post-U-234 decay products have not had time to form (the half-life of the daughter of U-234, Th-230, is as long as 7.50 10^4 years). It takes about 10 half-life times of Th-230 to reach near full radioactive equilibrium with the mother product U-234 (50% equilibrium is reached after one half-life, or 80,000 years). Thus, no radium and radon (post-U-234 decay products) exist as a result of contamination of DU, and it will take thousands of years before any significant amounts are formed.

When radioactive elements decay, they emit alpha, beta or gamma radiation. Some of the elements in the uranium decay series emit alpha radiation, others beta and gamma radiation. The sum of the energy of the emitted alpha radiation per unit time of the isotopes in DU is 11% of the sum of the energy of all the emitted alpha radiation per unit time in the uranium-238 series in radioactive equilibrium. The energy of the beta radiation emitted from DU is about 42%, and the energy of gamma radiation about 1.4% of that in the uranium-238 series in equilibrium (Table 4.2).

Thus the main dose received from DU will come from alpha and beta radiation. However, as alpha and beta radiation has very limited range in tissue, the dust or particles of DU has to be inhaled or ingested to contribute to the received dose. In case of skin contamination through contact with solid pieces of DU, there will be some external beta radiation to the skin. At most, the dose will be about 2 millisievert per hour (mSv/h). The gamma radiation from DU particles and dust on the ground has a limited importance for the received dose.

Table 4.1. DU Composition

Depleted Uranium, DU (^{235}U 0.2%)

Chemical composition [1)]			**Specific activity**	**Bq/mg DU**
^{238}U	99.8000%		^{238}U	12.27
^{235}U	0.2000%		^{235}U	0.16
^{234}U	0.0010%		^{234}U	2.29
^{234}Th	Traces		^{234}Th	12.27
^{234} Pa	Traces		^{234}Pa	12.27
^{231}Th	Traces		^{231}Th	0.16
				Sum 39.42

Specific gravity theoretically 19.07 Melting point 1,132^{o}C

[1)] Reference, Browne et al. 1986

Table 4.2. 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
↓					
Thorium-230 ^{230Th}	α	7.54 10^4y	4.74	-	0.002
↓					
Radium-226 ^{226}Ra	α	1600 y	4.86	-	0.007
↓					
Radon-222 ^{222}Rn	α	3.824 d	5.59	-	-
↓					
Polonium-218 ^{218}Po	α 99+% β 0.02%	3.05 m	6.11	-	-
↓					
Lead-214 ^{214}Pb	β	26.8 m	-	0.291	0.284
↓					
Bismuth-214 ^{214}Bi	β 99+% α 0.04 %	19.9 m	-	0.648	1.46
↓					
Polonium-214 ^{214}Po	α	1.64 10^{-4}	7.83	-	-
↓					
Lead-210 ^{210}Pb	β	22.3 y			0.047
↓					
Bismuth-210 ^{210}Bi	β	5.01 d	-	0.389	
↓					
Polonium-210 ^{210}Po	α	138.4 d	5.40	-	-
↓					
Lead-206 ^{206}Pb	Stable				

Isotopes existing in depleted uranium

* Branched decay

Table 4.3. 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 10^6 y	4.47	0.048	0.154
↓					
Thorium-231 ^{231}Th	β	25.52 h	-	0.163	0.026
↓					
Protactinium 231 ^{231}Pa	β	3.28 10^4 y	5.04	0.063	0.048
↓					
Actinium-227 ^{227}Ac	α	21.77 y	6.91	0.016	-
↓					
* Thorium-227 ^{227Th} (98.6%) +	α	18.72 d	5.95	0.046	0.106
Francisum-223 ^{223}Fr (1.4%)	β	21.8 m		0.391	0.059
↓					
Radium-223 ^{223}Ra	α	11.43 d	5.75	0.075	0.133
↓					
Radon-219 ^{219}Rn	α	3.96 s	6.88	-	0.058
↓					
Polonium-215 ^{215}Po	α	1.78 10^{-3} s	7.52	-	-
↓					
Lead-211 ^{211}Pb	β	36.1 m	-	0.454	0.053
↓					
Bismuth-211 ^{211}Bi	α	2.14 m	6.68	-	0.047
↓					
* Polonium-211 ^{211}Po (0.28%)	α	0.516 s	7.59	-	-
Tallium-207 ^{207}Tl (99.7%)	β	4.77 m		0.493	
↓					
Lead-207 ^{217}Pb	β	Stable			

Isotopes existing in depleted uranium

* Branched decay

2. Chemical properties

Uranium occurs naturally in the +2, +3, +4, +5, and +6 valence states, but it is most commonly found in the hexavalent form. In nature, hexavalent uranium is commonly associated with oxygen as the uranyl ion, UO_2^{2+}. The different isotopes of uranium are chemically identical and thus exert the same chemical and toxicological effects. The discussion of the chemical effects of depleted uranium (DU) will therefore focus on uranium and uranium compounds.

Metallic DU reacts chemically in the same way as metallic uranium, which is considered to be a reactive material. It reacts readily with all the non-metallic elements and also forms numerous inter-metallic compounds. The general chemical character of uranium is that of a strong reducing agent, particularly in aqueous systems (Blasch et al. 1970).

In air at room temperature, solid uranium metal oxidises slowly. It first assumes a golden-yellow colour. As the oxidation proceeds, the film becomes darker, and at the end of 3 to 4 weeks, the metal appears black. The oxide films that form on uranium in air do not protect the metal from further chemical attack. Boiling water attacks solid uranium slowly. Hydrogen accelerates the corrosion because of hydride formation. In distilled water, the rate of reaction is at first less than in hydrogen-saturated water. Diluted (6N) sulphuric acid does not attack uranium; at the boiling point, the action is about that of boiling water alone. Uranium metal is attacked by concentrated hydrochloric acid remarkably fast. The rate is much slower in 1N acid than in 6N acid. Mixtures of hydrochloric acid and oxidising agents may be used to effect complete solution of uranium metal (Blasch et al. 1970).

Different uranium compounds differ in their chemical and physiological properties, and thus also in the toxicological effects they exert. Compounds such as uranyl chloride, uranyl nitrates and uranyl ethanoate are soluble uranium di-and trioxide (UO_2, UO_3) and triuranium octaoxide (U_3O_8) are sparingly soluble.

The reaction of uranium with water is complex. Initially it reacts to form uranium dioxide and hydrogen:

$$U + 2H_2O \rightarrow UO_2 + 2H_2$$

Upon oxidation, uranium metal forms UO_2. Typical oxidation rate for massive uranium metal is penetrations of 0.005 mm/day (0.19 mg/cm^2 per day) at 175 ^oC. Significant oxidation of UO_2 does not occur except at temperatures above 275 ^oC. The reaction is strongly influenced by the presence of impurities in the CO_2 especially water vapour (Bennellick 1966). Uranium oxides are sparingly soluble, but will in a moist environment gradually form hydrated oxides. Under such conditions, the addition of 0.75% titanium to DU metal appears to slow the oxidation rate by a factor of approximately 16 (Erikson 1990).

Microbial action can speed the corrosion of uranium. The corrosion rate is controlled by several variables, including the oxygen content, presence of water, size of metal particles, presence of protective coatings and the salinity of the water present. With respect to U.S. Department of Defense applications, the principal factor controlling corrosion is the size of the particles. Small particles of uranium metal, produced by abrasion and fragmentation, corrode rapidly. Large masses of uranium metal (such as ingots) corrode very slowly. The

important point is that eventually all uranium metal will oxidise to U^{4+} and U^{6+} (U.S. AEPI 1994).

DU, particularly as powder, is a pyrophore, which means that it can ignite spontaneously at temperatures of 600-700 ^{o}C. When DU burns, the high temperatures oxidise the uranium metal to a series of complex oxides, predominately triuranium octaoxide (U_3O_8), but also uranium dioxide (UO_2) and uranium trioxide (UO_3). Upon weathering, the nonoxidised small particles and surfaces of remaining uranium metal will also oxidise to those three uranium oxides over time (RAND 1999).

3. Uranium concentrations in the environment

Uranium is a radioactive element that occurs in all rocks and soils. The normal activity concentration of U-238 in the earth's crust is 5-125 becquerel per kilogram, Bq/kg, (0.5-10 ppm, 1 ppm = 1 gram/ton) and of U-235 0.2- 5 Bq/kg. The activity concentration of U-238 in some uranium-rich rock types such as alum shale is of the order of 600-5000 Bq/kg (50-400 ppm). The activity concentration in uranium ores of good quality (1-30% uranium) is 1.2 10^5-3.6 10^6 Bq/kg. The activity concentration of pure uranium metal in radioactive equilibrium with its immediate decay products is 50.23 10^6 Bq/kg.

The range of uranium activity concentration in water is for:

Fresh waters	1-90 mBq/l (0.1 –8 µg/l)
Groundwaters	<1- 140 mBq/l (UNSCEAR 1993)
Finnish values up to	150 Bq/l (12,400 µg/l) (UNSCEAR 1999)
Yugoslavian values	0.5-510 mBq/l (0.04 - 41 µg/l) (UNSCEAR 1993)
Seawater	40.5 mBq/l (3.3 µg/l).

In air, the total activity concentration of uranium is about 1 µBq/m^3 (UNSCEAR 1999).

Uranium in rocks and soils is normally in radioactive equilibrium with all its daughter products down to Pb-206 (Table 4.2). The overwhelming part of the radiation emitted from the nuclides in the U-238 series is emitted from the isotopes that follow after U-234. Compared with the sum of the energy of the emitted alpha radiation per transformation from all isotopes in the U-238 series, the isotopes that follow after U-234 emit about 89% of the alpha energy, about 58% of the beta radiation energy and about 98.6% of the gamma radiation energy (Table 4.2).

4. Environmental levels and human exposure

4.1. Inhalation of uranium

Reported levels of uranium in ambient air range from 0.02 nanograms per cubic meter (ng/m^3) to 0.076 ng/m^3. On the assumption of a daily respiratory volume of 20 m^3 and a mean ambient air concentration of 0.05 ng/m^3, the daily background intake of uranium from air would be about 1 ng. Tobacco smoke (two packages of cigarettes per day) contributes about 25 ng of inhaled uranium per day (WHO 1998).

4.2. Ingestion of uranium

The mean daily uranium intake from drinking water has been estimated to range from 0.8 to 2.1 µg per person per day (WHO 1998).

Uranium has been detected in a variety of foodstuffs. The highest concentrations are found in shellfish, and lower levels have been found in fresh vegetables, cereals and fish. Per capita, the average intake of uranium in food has been reported to range from 1.5-3 µg per person per day (WHO 1998). This means that combined average background ingestion (food and drinking water) for uranium can be estimated to range from 2.3-5.1 µg per person per day.

4.3. Overall exposure to natural radiation

Outdoors and indoors humans are exposed to ionizing cosmic radiation and gamma radiation emitted from potasium-40 and isotopes in the uranium and thorium series. The dose rate for exposure to terrestrial gamma radiation outdoors is normally 0.02-0.15 microsievert per hour, µSv/h, with a world average of 0.08 µSv/h. The outdoor dose rate in areas where the bedrock consists of, and the soil contains uranium and thorium rich granites is often 0.2-0.3 µSv/h, in areas with uranium-rich black shales 0.2-1 µSv/h. Even higher natural gamma radiation occurs in areas with carbonatites and heavy sands, where the gamma radiation locally in inhabited areas can be as high as 2-25 µSv/h. In houses made of stone material (bricks, concrete or blocks of stone) the normal dose rate is 0.08-0.25 µSv/h. Higher dose rates exists in buildings with walls and floors of stone material with higher than normal concentrations of natural radioactive elements, e.g. fly-ash or uranium-rich shales. For example, in Swedish houses that have walls of light-weight concrete made of alum shale, the indoor dose rate, depending on the uranium concentration in the type and quantity of material used, is 0.3-1.3 µSv/h.

A permanent exposure to gamma radiation at a dose rate of 0.2 µSv/h is equal to an effective dose of 1 millisievert per year (mSv/y). A person that stays permanently indoors in a house with indoor gamma radiation dose rate of 1 µSv/h would receive a dose of 5 mSv/y.

The mean dose received by the world population by natural ionizing radiation is 2.2 mSv/y (UNSCEAR 1999). Of this dose, 0.38 mSv/y is received from cosmic radiation, 0.48 mSv/y external terrestrial outdoor and indoor radiation, 0.006 mSv/y from inhalation of naturally-occurring radionuclides in air (radon and thoron excluded), 0.33 mSv/y from ingestion and 1.0 mSv/y from radon and thoron gas and their progeny in the inhaled air.

The dose burden from radon gas gives the greater part of the dose received from natural radiation. The European Commission recommended reference level for radon gas in dwellings, 400 Bq/m^3, corresponds to an effective dose of 8 mSv/y. In many buildings, the radon concentration is much higher than this. Dwellings with indoor radon concentrations of more than 50,000 Bq/m^3 are found.

Contamination of DU dust on the ground surface may be compared with the use of phosphate for agricultural purposes. Normally 30-150 kg of P_2O_5 is used per hectare and per year. A typical value for the activity concentration of the uranium in the phosphate is 4000 Bq/kg (UNSCEAR 1993). However, in the comparison one has to remember that the uranium in the phosphate is much more radioactive the DU because it contains all the decay products in the U-238 series which are absent in DU.

5. Dispersion characteristics for DU

Information available from the U.S.A. suggests that a combination of DU fragments and aerosols is produced during impact of a DU penetrator on a hard target. Rounds fired on soft ground (sand, silt or clay) will penetrate a meter or more into the ground. There is some discussion of the proportion of DU converted into aerosol form. The RAND report (1999) gives a range of 10–30%, with a maximum of 70%, and suggests that virtually all the aerosol is likely to be in the respirable range. U.S. experience (e.g. PNL-5928 1986) suggests that the respirable fraction is likely to be significantly lower if DU is released as a by-product of a fire— perhaps 0.1–33 % (RAND 1999). The main oxidation product is U_3O_8 (PNL-2944 1979) which is largely insoluble, suggesting that it may be treated as a compound with slow clearance from lungs (Type S in the EC BSS, 1996) for the purpose of assessing inhalation doses (RAND 1999 and PNL-5415 1985).

Studies of the radiological contamination from impacted DU armour suggests that exposures are insignificant beyond 100 m (Fliszar et al 1989). Another study measured soil concentrations as a function of distance from detonation and found the highest surface contamination within 0–10 m of the detonation point. Levels at 50–200 m distance from detonation were less than 15 % of those at 10 m (Hanson and Miera 1977). In addition, a study of the environmental consequences of using DU rounds from A-10 aircraft for training purposes (NELLIS 1997) concluded that DU particles are gravitationally heavy and would settle quickly. These studies suggest that dispersion and deposition would be fairly localised.

The impact of past use of DU munitions at the US Nellis Air Force Range (NELLIS 1997) included a program of soil sampling which indicated that only 13 % of soil particles were smaller than 125 μm. It also concluded that particles larger than 100 μm are unlikely to be resuspended by the action of wind or the movement of vehicles and that only particles smaller than 20 μm in diameter were likely to remain airborne long enough to reach air samplers around the DU impact area. This indicates that, at least for the site considered, the potential for resuspension of particles remaining in the environment will be low.

Once the DU particles have settled, and rain has fallen, even the small particles will not easily be moved. Most of them will be adsorped on clay minerals and humus. There they will remain as surface fall-out and form hydrated uranium oxides. These will gradually be dissolved by percolating rainwater into U_2^{2+} ions and transported farther down into the soil or groundwater (see also Appendix 6).

The applicability of all this information to the overall situation in Kosovo is uncertain. Information on how DU has been and will be dispersed in Kosovo would be more solid if more site investigations are made.

On the other hand the report, ‘Assessment on the environmental impact of Military activities during the Yugoslavia conflict, June 1999’ prepared by the European Commission’s Regional Environmental Center for Central and Eastern Europe (REC 1999), reports that the Ministry of Environment in Macedonia has measured enhanced uranium concentrations in water and on air filters that could be caused by windblown DU dust. However, filter measurements performed in Northern Greece showed no excess uranium (Rapsomanikis et al. 1999) and the BTF DU Fact Finding Field Mission team to Kosovo, 16-19 August 1999 did not find any evidence of contamination of DU in the locations it visited and measured (see Appendix 7).

6. Exposure pathways for radionuclides in the environment

People may be exposed to radionuclides in the environment by irradiation from material external to the body, and from radionuclides taken into the body by inhalation and ingestion. The relative importance of these pathways depends upon the radionuclides concerned and their physical and chemical form.

6.1 External

The importance of the external exposure pathway is determined by the form and energy of radiation emitted during the decay process. The isotopes of uranium, and the daughter products present in depleted uranium (DU), decay in such a way that the primary route of external radiation exposure from DU in the environment would be from contact with the skin, resulting in a localised dose to the skin (from beta radiation emitted by Pa-234m, a radionuclide in the U-238 decay series). The U.K. Ministry of Defence (1999) has estimated that a piece of DU could give a dose to the skin of the order of 2 mSv/h. It is also possible to calculate the external dose rate from gamma radiation from DU contamination on the ground (not in contact with the skin) if the activity concentration (Bq/m^2) on the ground is known. However, the gamma radiation is unlikely to be significant for the dose.

6.2 Inhalation

Once DU as dust particles has been dispersed and deposited on the ground, DU may be resuspended by the action of the wind or by mechanical disturbances, such as the movement of vehicles. Resuspended DU particles may be inhaled either as separate DU particles or adsorped on clay particles or on humus. Only a fraction of the inhaled particles will be small enough to reach the deep lung, where exchanges with blood, and thus transfers to other parts of the body, occur. It is possible to make an estimate of the resulting dose from a known activity concentration of DU dust in the air (Bq/m^3), the inhalation rate (e.g. in m^3/a) and a dose coefficient (Sv/Bq) which may be obtained from the EC Basic Safety Standards (EC BSS 1996). Information available from the US Military suggests that dose coefficients for the insoluble oxides may be appropriate.

6.3 Ingestion

Two potential ingestion exposure routes may be considered; inadvertent ingestion of soil, and ingestion of radionuclides incorporated in the food chain. It is possible that radionuclides deposited on the ground, or on the surface of plants, may be incorporated into the edible portion of the plant and consumed directly by humans.

A proportion of radionuclides in the intakes by animals may be incorporated in meat or animal products consumed by humans. It is possible to make a screening assessment of the radiation dose arising from soil and food ingestion pathways if the activity concentrations in the soil and in food (Bq/kg) are known. In this case, the intake by humans (e.g. kg/y) and the dose coefficient (Sv/Bq) for ingestion of DU is also needed.

However, the uptake of uranium in plants is very limited and an animal can eat a lot of greatly contaminated soil before the meat achieves an unhealthy concentration of uranium. Thus, ingestion of DU in food is not expected to result in a significant radiation dose except during the first days after an attack, when there might be a contamination on the surface of vegetables etc. (see Appendix 8).

The transfer of radionuclides from deposits on soil and plants surfaces to other materials in the environment can be assessed if the activity concentration on the ground is known. So called 'transfer factors' are published in the literature, for example IAEA Technical Report Series No. 364 (IAEA 1994). It provides soil to plant transfer factors (Bq per dry weight crop/Bq per dry weight soil) for uranium. As an example, the values for grass and green vegetables are 0.023 and 0.0083 respectively.

The fraction of an animal's daily intake, which is transferred to meat and milk, may also be assessed. Thus, if the activity concentration of DU in pasture grass is known, or can be estimated, it is possible to make a rough estimate of the activity concentration in meat and milk from the daily intake (in kg/d) and the transfer coefficient for uranium (0.0003 d/kg) given in IAEA TRS 364. However, in the case of DU, the main source for the uranium ingested by the animals will be DU particles that are ingested with soil.

It is also possible that a fraction of the activity on the ground will be transported to ground water by the action of rainwater. This process is, however, highly dependent upon the soil and geological characteristics of the site, and it is difficult to make an exact assessment of this pathway without specific data (see Appendix 6).

7. Metabolism of uranium and DU

7.1. Ingestion

Although ubiquitous in the environment, uranium has no known metabolic function in animals and is regarded as a non-essential element. Absorption of uranium from the gastrointestinal tract depends on the solubility of the uranium compound, previous food consumption and concomitant exposure to oxidising agents. In general, absorption decreases with decreasing solubility of the compound. The average human gastrointestinal absorption of uranium is about 1-2% (ATSDR 1997, WHO 1998).

Clearance of systemically available uranium is rapid (generally <24hr). However, if the pH is low, the complex dissociates to a variable degree, and the uranyl ion may then bind to cellular proteins in the tubular wall of the kidney, which may then impair tubular function. Uranium might accumulate in the kidneys and the skeleton. The biological half-life of uranium in rat kidneys has been estimated to be approximately 15 days. Clearance from the skeleton is considerably slower; biological half-lives of 300 and 5000 days have been estimated, based on a two-compartment model (WHO 1998).

7.2. Inhalation

Absorption of inhaled uranium depends on the particle size and solubility. Particles larger than 10 µm in size generally get caught in the nose and throat, never entering the lungs. Particles smaller than 10 µm can get into the large upper branches just below the throat where they are caught and removed by the bronchial mucociliary mechanism and transported to the gastrointestinal tract by swallowing.

Particles smaller than 5 µm can get into the bronchial tubes, at the top of the lungs; particles smaller than 2.5 µm in diameter can get down to the deepest (alveolar) portions of the lungs (Dockery and Pope 1994, Seaton et. al. 1995). Following inhalation, soluble compounds (e.g. uranium hexafluoride, uranyl fluoride, and uranyl nitrate hexahydrate) are more likely to be absorbed.

Mean uranium absorption in humans, following inhalation exposure, was estimated at 0.8-0.9% (ATSDR 1997). Less soluble compounds (e.g. uranium tetrafluoride, uranium di- and trioxide, triuranium octaoxide) are more likely to remain in the lung.

8. Health effects

8.1 Health effects, radiological

8.1.1. To humans

When ionizing radiation passes through matter, it deposits energy in the material concerned. For example, if it passes through a cell nucleus that forms part of body tissue, ionisation and resulting chemical changes may occur which cause harmful biological effects. The clinical effects of such microscopic changes will depend upon the level of dose (a measure of the energy per unit mass of tissue) and the time over which that dose occurs. For example, a single dose of beta radiation of 5 gray (Gy), or more to the skin would cause reddening (erythema) within a week or so. If the same dose occurred over a longer time there would be more opportunity for the cells to repair and no such obvious immediate effect may occur.

However, such a dose is also assumed to give rise to an additional risk of cancer in later life. An important source of information on the relationship between dose received and the risk of cancer is from studies of the survivors of the atomic bombs dropped at Hiroshima and Nagasaki. This information is included in periodic reviews by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and by the International Commission on Radiological Protection (ICRP).

This information is based on high dose and dose rate exposures which need interpolation to be applied to the doses and dose rates normally encountered. For radiological protection purposes, it is assumed that there is a linear relationship between dose and risk such that any level of dose, additional to natural background levels, is assumed to carry with it a finite risk of cancer (ICRP suggest the use of a factor of 5% per sievert, Sv, for long term exposure).

Depleted uranium has a low specific activity (39.4 kBq/g) and may be considered as ‘only weakly radioactive’. Nevertheless, given the linear dose response relationship discussed

above, exposure to it must be considered as carrying a potential risk of cancer, although at a lower level than many other radioactive materials present in the environment from both natural and man-made sources.

8.1.2. To farm animals

High exposure to radioactive particles in the guts of grazing animals can cause beta-burns on the walls of the intestines and also tumours after 2-5 years. Sheep and pigs, which ingest a lot of soil, are especially vulnerable to exposure.

To cause injury, radioactivity has to be in the order of gigabecquerel (GBq) and at least of megabecquerel (MBq) in the particle. The dose from ingested DU is unlikely to be of any harm as the activity of DU is low. Pigs might be more vulnerable to surface DU contamination as they have an acid digestive system and may have a larger absorption of uranium, which may accumulate in the liver. However, in this case it is the toxic effect and not the radioactivity that may be harmful.

8.2. Health effects, chemical

8.2.1. To animals (general)

8.2.1.1. Ingestion

There are few reports on harmful effects on humans from intake of uranium. Few humans have had such a large intake of uranium that it may be harmful. Therefore, information on the possible health effects of uranium intake relies mainly on experiments with animals that have similar digestive systems as humans, e.g. rats, dogs, pigs, and monkeys, but not rabbits and ruminants. In the following section some examples are given of results from studies on animals.

Acute effects
Death has been reported following oral doses of uranyl ethanoate dihydrate (about 200 mg/kg of body weight) to rats and mice. The most common renal injury is damage to the proximal convoluted tubules (Domingo et al. 1987, Domingo 1995). There is evidence that tolerance may develop following repeated exposure to uranium, but this tolerance does not prevent chronic damage to the kidney, as the regenerated cells are quite different. Persistent changes in the proximal tubules have been reported to be associated with the kidney's ability to store uranium (McDonald-Taylor et al. 1997).

Short-term exposure
In short-term toxicity studies it was shown that the kidney is the target organ for uranium toxicity. Rats given drinking water containing uranyl nitrate hexahydrate for 90 days, showed treatment-related liver changes, but the most important effects were degenerative lesions in the renal proximal convoluted tubule. The Lowest Observed Adverse Effect Level (LOAEL) for these effects is about 0.1 mg uranium per kg of body weight, per day. For various endpoints and animal species ATSDR reported minimal effect levels in the range of 1-10 mg/kg per body weight (ATSDR 1997).

Long-term exposure
In an early series of experiments, very high doses (up to 20% in the diet) of a variety of soluble uranium compounds were fed to rats, dogs and rabbits for periods ranging from 30 days to 2 years. On the basis of very limited histological investigations, renal damage was reported in each species (WHO 1998). No effects were found in mice fed high levels of (insoluble) UO_2 or U_3O_8 in the diet (Maynard et al. 1953). For these studies noeffect levels for systemic toxicity ranging from about 10-50 mg/kg body weight have been reported (ATSDR 1997).

Reproductive and developmental toxicity
Mice given soluble uranium compounds (uranyl nitrate hexahydrate, uranyl acetate dehydrate) have shown exposure-related fetotoxicity, reduced fetal body weights, external and internal malformations, increased incidence of developmental variations, and decreased fertility. Based on both the maternal and fetotoxic effects, an overall LOAEL of 2.8 mg of uranium per kg of body weight per day could be considered (WHO 1998).

Mutagenicity
A dose-related decrease in the viability of the cells, a decrease in cell cycle kinetics, and increased frequencies of micronuclei, sister chromatid exchanges, and chromosomal aberrations have been observed in Chinese hamster ovary cells after ingestion of uranyl nitrate (Lin et al. 1993).

Carcinogenicity
No carcinogenic effects have been reported in animals ingesting soluble or insoluble uranium compounds (Wrenn et al. 1985).

8.2.1.2. Inhalation

Acute effects
Mortality was induced in rats and guinea pigs at high levels of uranium (about 25 to 35 g/m^3 uranium as uranium hexafluoride, UF_6). Besides renal damage, damage to the respiratory tract was also observed, probably due to HF, a hydrolysis product of UF_6 (ATSDR 1997).

Short-term exposure
In studies with exposure up to one year with several animal species and various uranium compounds (soluble and insoluble) no signs of pulmonary changes were observed in a concentration range of 0.05-10 mg/m^3. Conflicting hematological effects have been reported. In most studies no effect on blood parameters have been found, whereas some studies showed hematological effects at concentrations down to 0.13 mg uranium/m^3. Indications for hepatotoxicity were found in the same concentration range. In a number of animal species dose-dependent kidney lesions have been found with a variety of uranium compounds in a concentration range of 0.15-18 mg uranium/m^3 (ATSDR 1997).

2 Long-term exposure
Chronic exposure of rats, dogs and monkeys to 5 mg/m^3 uranium as UO_2 did not reveal histological changes in the lung nor damage to the kidneys. Minimal fibrosis of bronchial lymph nodes was seen in dogs and monkeys. With soluble uranium compounds mild to severe renal tubular damage has been found in several species at concentrations of 0.2 mg/m^3 uranium or higher. The overall No Observed Adverse Effect Level (NOAEL) was established at 0.15 mg uranium/m^3 (ATSDR 1997).

8.2.2. To farm animals

Data on the effects of (depleted) uranium on farm animals are scarce. Current assessment is that deposition of mostly insoluble uranium compounds on the soil, and uptake of soil by grazing animals, are the most relevant factors. Uptake by plants can be considered negligible. For the sake of simplicity deposition on plants (grass) is neglected, unless data indicate otherwise.

Grazing cattle are estimated to consume about 500 g soil/animal/day. Assuming a body weight of 400 kg this corresponds to about 1.25 g/kg body weight. Goats are very selective grazers; they consume only the top of the grass leaves. Thus for goats soil intake can be considered to be negligible. No clear data on soil intake are available for sheep and pigs (VHI 1997). In general it is assumed that sheep ingest more soil (on a body weight base) than cattle because they graze lower. However, the amount of soil depends of type of soil and vegetation and grazing density. On average it is assumed that sheep ingest 2-4 times more soil than cattle. For a sheep of 50-70 kg this means an intake of about 125-500 g soil per day.
It can be assumed that pigs walking around freely ingest more soil on a body weight basis. If this is about twice as much as for cattle, then a 200 kg pig may also ingest 500 g soil per day.

For cattle and sheep Puls (1990) reported that minimal effects are associated with a daily uranium intake of 400 mg and 50 mg, respectively (corresponding to 1 mg/kg body weight for both species). This is in the same range as minimal effects for other species. More serious effects can be expected for a uranium intake in the range of 10-100 mg/kg body weight.

Thus, to prevent effects in cattle, the uranium concentration in ingested soil should be:
< 400 mgU/500 g soil, equivalent of < 800 mgU/kg soil.

If the worst case is taken for sheep, the uranium concentration in soil should be:
< 50 mgU/500 g soil, equivalent to < 100 mgU/kg soil.

8.2.3. To humans

8.2.3.1. Ingestion

Kidney disfunction is the main chemically induced effect of oral exposure to uranium in humans. In clinical studies in Canada, a trend towards increasing excretion of urinary P2-microglobulin, as indicator for an early tubular defect, and increasing concentration of uranium in well water was observed. It was suggested that the suspected tubular defect might well be rapidly reversible (Moss et al. 1983). In another study, there was a statistically significant association ($p = 0.03$) between increasing but normal levels of urine albumin and the uranium cumulative index (Mao et al. 1995).

The risk of health effects following oral exposure to DU depends on the amount of soluble uranium compounds formed during the military action. Soluble uranium compounds could have contaminated the soil, or migrated to surface or ground water. Using this water for drinking or irrigation could lead to human exposure. Therefore, for a chemical risk assessment, following oral exposure information on the possible amounts of soluble uranium compounds following the use of DU ammunition is essential. If these compounds could have been formed, exposure scenarios for direct and indirect exposure should be developed/used.

8.2.3.2. Inhalation

The pyrophoric nature of uranium is of special relevance to the assessment of health effects resulting from the use of depleted uranium (DU) ammunitions during the Balkan crisis. As a result of the high temperatures (about 1200 ^{o}C) created when a round containing DU impacts in a hard object, about 30% of the uranium is burnt and oxidised. Less than 1% of the formed uranium-oxide particles are smaller than 20 µm (BPNW 1985). The uranium compounds of concern for risk assessment are uranium metal and sparingly soluble (insoluble) depleted triuranium octaoxide (U_3O_8), uranium dioxide (UO_2), and uranium trioxide (UO_3). (RAND 1999).

Inhaled particles of uranium oxides that have a size of less than about 10 µm will predominantly remain in the lungs. Particles larger than 10 will be removed from the lungs by mucociliary and transported into the gastrointestinal tract, and will reach the intestine. Because the uranium oxides are very insoluble they will be poorly absorbed. This is reflected by results of human studies showing that workers accidentally exposed to high levels of uranium in air did not suffer renal damage (ATSDR 1997).

Human fatalities following accidental inhalation exposure to massive concentrations of UF_6 are most likely attributable to HF. No signs of pulmonary toxicity were found in uranium-processing workers exposed to insoluble uranium dust at levels of 0.5-2.5 mg/m3 for 5 years.

Several epidemiological studies found an increase in chromosomal aberrations or increased deaths from lung cancer in miners. However, it is difficult to attribute these effects to uranium because the miners were concurrently exposed to radon daughters, and other confounders, such as smoking, could have contributed to the increased risk for lung cancer (ATSDR 1997).

For a first approach to assess the potential chemical risks from inhalation exposure, estimated or measured concentrations of uranium could be compared with guidelines for occupational exposure set by the American Conference of Governmental Industrial Hygienists (ACGIH) and U.S. National Institute for Occupational Safety and Health (NIOSH): 0.2 mg/m^3 for chronic exposure and 0.6 mg/m^3 for short–term exposure. When these occupational guidelines are converted for continuous exposure of the general population (24 hr instead of 8 hr, 7 days/week instead of 5 days/week) the following values result:
- chronic 5/7 x 8/24 x 0.2 mg/m^3 = 0.05 mg uranium/m^3 (rounded figure)
- short term 5/7 x 8/24 x 0.6 mg/m^3 = 0.15 mg uranium/m^3 (rounded figure)

Both short-term (a couple of days to a couple of weeks) as well as long-term exposure should be considered, because deposited depleted uranium dust might be redispersed in air. With levels lower than the above-mentioned figures, there is/was no chemical health risk. In case of higher levels, it is difficult to assess the potential health risk for humans because dose response information for effects in humans is lacking.

Animal studies, however, point to concentrations showing no or minimal effects (particularly kidney damage) following short to chronic inhalation exposure in the range of 0.15 mg uranium/m^3. Assuming that humans are equally as sensitive as animals for uranium toxicity, this indicates that levels above 0.15 mg/m^3 might exert toxic effects in humans.

In general, however, it is expected that due to the insoluble nature of the dispersed uranium and uranium oxides (UO_2, UO_3, U_3O_8), these compounds will pose primarily a radiological, not chemical, toxicological risk following inhalation.

8.2.4. To humans consuming animal products

It has been reported by Puls (1990) that meat from cattle ingesting 200 g uranium per day (500 mg/kg body weight) is unfit for human consumption. Assuming that all this uranium stems from soil, and taking the soil ingestion figure mentioned above (500 g), this corresponds to a concentration of uranium in soil of 400 g/kg.

Compared to the uranium level in soil for the protection of cattle and sheep derived above, this figure seems extremely high!

Levels of uranium in meat and corresponding levels in soil could also be derived in a different way:

- The WHO established a Tolerable Daily Intake (TDI) of 0.6 micrograms per kg (µg/kg) body weight. For a 70 kg person this corresponds to a daily intake of 42 µg.
- Background intake is 5 µg uranium per day at most (see 4.2.2). This leaves 37 µg uranium per day as tolerable additional consumption from contaminated meat.
- GEMS Food (WHO) uses an estimated average daily meat consumption of about 150 g per person per day. This allows a uranium concentration of 37/150 = 0.25 µg/g (mg/kg).
- Assuming homogeneous distribution of uranium in cattle and a body weight of 400 kg, this leads to a total amount of uranium per animal of 400 x 0.25 = 100 mg.
- Assuming a maximum oral absorption of 1%, the corresponding ingested amount would be 10 g uranium.
- If this amount is consumed with 500 g of soil, the maximum permissible concentration of uranium in soil is 20 g/kg (as compared with 0.6-6 g/kg in the scenario case, see Appendix 8, assuming 1000 m^2 contaminated area, depth 10-1 mm, respectively)

The same calculation can be carried out for pigs, assumed to ingest twice the amount of soil (on a kg body weight basis). This gives a maximum permissible level of uranium in soil of 10 g/kg.

8.2.5. Conclusion on chemical toxicity

In general, it can be concluded that soluble uranium compounds do have a greater chemical toxicity than insoluble compounds. This toxicity results primarily in kidney damage. Depending on the degree of exposure, impairment of kidney function could occur after a few days. Often these effects will disappear after cessation of exposure, although kidney morphology will not return to normal.

9. Standards, regulations and guidelines

9.1. Chemical

The WHO derived a guideline for drinking-water quality of 2 µg of uranium per litre. This value is considered to be protective for sub-clinical renal effects reported in epidemiological studies (WHO 1998).

For oral exposure, a Tolerable Daily Intake (TDI) for uranium of 0.6 µg/kg body weight per day was established by the WHO (1998).

U.S. EPA 1991 has proposed 20 µg/liter as a limit for uranium in drinking water. (EPA, 1991).

The American Conference of Governmental Industrial Hygienists (ACGIH) adopted the maximum permissible concentration of 0.2 mg/m^3 for soluble and insoluble natural uranium. The short-term exposure limit to natural uranium in the air was set at 0.6 mg/m^3. (ACGIH 1993).

The U.S. National Institute for Occupational Safety and Health (NIOSH) recommends a limit of 0.2 mg/m^3 for insoluble uranium and 0.05 mg/m^3 for soluble uranium (time-weighted average) for chronic occupational exposure, and a short-term exposure limit of 0.6 mg/m^3 (NIOSH 1994).

The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) derived a Minimal Risk Level (MRL) for chronic inhalation exposure of 1 µg/m^3. For oral exposure, an intermediate MRL of 1 µg/kg body weight per day was established (ATSDR 1997).

9.2. Radiological

Radiation exposures are controlled on the basis of a system of radiation protection proposed by the ICRP. The objective of this system is to prevent the occurrence of acute effects (which may occur at high doses and dose rates) and to minimise the risk of cancer, which may be predicted at lower doses and dose rates. The doses and dose rates normally encountered are very much lower than those at which acute effects may occur. The primary potential health effect of concern, is the risk of cancer induction.

The system of radiation protection is based on the underlying assumption of a linear relationship between dose and the risk of cancer induction. Limits and reference levels for radiation exposures therefore do not reflect the borderline between what is safe and unsafe, but rather a balance of what may be tolerable and what is unacceptable.

For example, ICRP have recommended dose limits of 20 mSv per year for workers, and 1 mSv per year for members of the public. These limits relate to exposures from practices, which may be controlled prospectively, that is to say, the dose received due to the practice may be foreseen and measures taken in advance. The limits are not directly relevant to clean-up criteria for material already existing in the environment. Such criteria are currently under

development by ICRP and IAEA. These suggest that some form of remediation may be necessary if long-term exposures exceed around 10 mSv.

These and other levels, together with the global annual average dose from natural sources of 2.2 mSv, may provide a basis for judging predicted doses from exposures to DU in the environment.

Appendix 5

Military use of DU ammunition

At the time of writing (23 September 1999) no official NATO statement had been given to UNEP confirming or denying that DU weapons had been used in the Kosovo conflict. According to Reuters, Nairobi, UNEP director general Klaus Töpfer told a news conference on 12 August 1999 that "A NATO source in Brussels confirmed that depleted uranium had been used during the conflict, but only in cannons fitted to A-10 tankbuster planes and not to missiles. The use was limited and only in the last few weeks of the war" (Reuters, Nairobi 12 August 1999). New Scientist 5 June 1999 reported that "In a press meeting Washington DC on 3 May, Major General Charles Wald, vice director for strategic plans and policy for the US Joint Chiefs of Staff, confirmed that A10 Warthog aircraft had fired DU munitions against Serbian forces. The US Joint Chiefs' spokesman James Brook, told New Scientist that AV-8 Harriers and Abrams battle tanks in the Balkans also carried DU munitions. The Brittish Foreign Secretary, Robin Cook, has said that "no DU is 'in use' by the Brittish forces". In reply to a question from UNEP Balkan Task Force Chairman Pekka Haavisto, Mr. Y. Sillard, NATO Headquarter, wrote on 6 August 1999 "DU is used in A10 armor piercing ammunition. There may be spent DU rounds as well as vehicles disabled/destroyed by DU ammunition present in Kosovo". From these statements, the BTF Depleted Uranium Assessment Group assumes that DU has been used in Kosovo. However we have no conclusive proof. Such proof has to be given by an official statement from the NATO forces or by measurements performed on site in Kosovo. When questioned by the BTF DU fact-finding mission to Kosovo on 17-18 August 1999, the KFOR authorities said that information on the use of DU was classified.

Of the NATO forces, U.S., British and French have DU weapons in their arsenals. The U.S. A-10 Warthog attack plane is usually equipped with DU rounds. The British Harrier plane also uses DU rounds and French aircraft probably do so. That airplanes in Kosovo used DU is not confirmed.

The U.S. A-10 Warthog airplanes are designed to be used against tanks and other vehicles. In Kosovo, the Warthogs searched the theatre for targets. Most of the attacks were made against dummies. Information in the press claims that over 90% of the targets hit were dummies, and it was stated by a KFOR officer in Kosovo that many attacks were made against dummies. This implies that DU ammunition, if used, may be found in many places in Kosovo. However, it is less likely that this kind of ammunition has been used against buildings and industrial sites.

If DU ammunition was used, NATO airforces may have exact information on where it was used. When an attack begins a video records the event and the coordinates of the target are automatically stored.

The DU ammunition used by the A-10s is fired by the General Electric GAU-8/A 30 mm seven-barrel gattling gun. This is said to fire 3900 round per minute. The bullet has a length of 173 mm and a diameter of 30 mm (Figure 1). The bullet is covered by an aluminum case. Inside the bullet is a conical DU penetrator. Its length is 95 mm and the diameter at the base 16 mm. The weight is 292 g.

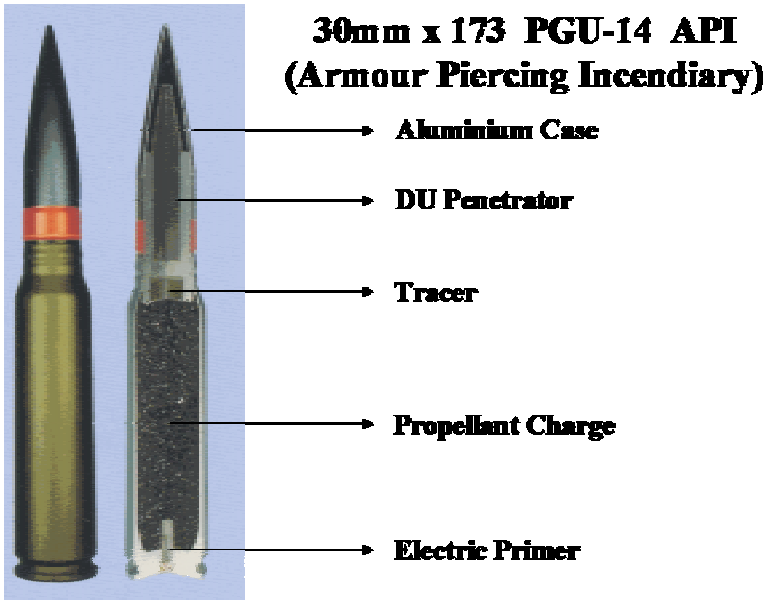

Figure 1. Amour penetrating round used by the U.S. A-10 Warthog attack airplanes.

DU ammunition is loaded together with standard ammunition. Usually, every fifth or six round is a DU bullet (NELLIS 1997).

According to weapons experts at the Swedish Research Institute of National Defense, the A-10s are very accurate. During one attack, 50-100 rounds are fired. These will be spread within an area approximately 10 m wide and 50 m long. This means that 10 to 20 DU bullets will hit this area. The total amount of uranium in this area will be in the order of 3-6 kg of DU. If three attack planes work together against a target, the amount of DU in the area hit might be 9-18 kg. There can of course be more than one target in the same area.

When a DU-bullet impacts on a hard object, it is crushed into fragments and dust. Normally 10-35% (maximum of 70%) of the bullet becomes aerosol on impact or when the DU dust catches fire (RAND 1999). Most of the dust particles are < 5 µm in size, and spread according to wind direction. DU dust is black and a target that has been hit by DU ammunition can be recognized by the black dust cover in and around the target (U.S. AEPI 1994).

If the area attacked consists of rocks and stony soil, most of the DU will be crushed and aerosolized, and thus there will be a fall-out of DU dust. However if the bullets hit sand or clay, they will continue down into the soil and to a large extent be intact. Around the targets in The Nellis Air Force Range, which have been used as training targets for a long period, most of the DU dust is reported to be deposited within a distance of 100 m from the target (NELLIS 1997).

There are some suggestions that DU was used in rockets and missiles. During the visit to Kosovo by the BTF Fact Finding Group, it was mentioned that DU might have been used as counterweights in cruise missiles. In the Gulf War, DU also was used in tank ammunition. NATO tanks were never used in combat in Kosovo, but it might be possible that DU rounds were fired from tanks across the borders from Macedonia and Albania. To work on the basis of correct information on the possible use of DU in the Kosovo conflict it is necessary to receive data from NATO.

Appendix 6

Environmental long-term behaviour and effects of DU

1. Deposition on ground

Because it has not been able to perform direct studies in Kosovo on the dispersion of DU the evaluation of the possible environmental long-term behaviour and effects of DU contamination is based on information in literature and on judgement of this information. The main part of the reports on the behaviour of DU in nature deals with the situation at U.S. test and training areas for the use of DU ammunition and armour. However, the situations in these test areas are not wholly relevant for the situation in Kosovo, as the amount of DU used in these tests is in the order of 70-150 tons per area. In Kosovo, the amount of DU used in one target area is assumed to be 10 kg. (This is an estimate based on available information after the Gulf conflict. It has not been confirmed by NATO, KFOR or by BTF visits to areas where DU ammunition may have been used).

Depleted uranium will behave as any other uranium in the environment, with the exception that the 0.75% titanium added to DU metal may slow the oxidation rate by a factor of approximately 16 (Ebinger 1990).

After an attack, at which DU ammunition has been used, DU will be deposited on the ground surface as DU metal in pieces, fine fragments and dust, and if the DU has caught fire as dust of uranium oxides. Most of the penetrators that impact on soft ground (e.g. sand or clay) will probably intact penetrate more than 50 cm into the ground and remain there for long time. Penetrators that hit armoured vehicles or stones in hard ground will be crushed at the impact. Bigger fragments and pieces of DU will remain intact on the ground surface. The fine fragments and dust gradually will be transported down into the upper soil layer by water, insects and worms. Wind, rainwater or water that flows on the ground surfaces may also redistribute the fine DU dust. A part of the fine dust particles will adsorp on soil particles, mainly on clay particles and organic matter, and thus be less mobile.

Due to the different chemical properties of different soils and rocks, the effects of DU on the environment varies. Penetrators that hit clay will remain unaffected and will not affect the surrounding soil and groundwater. If they impact on quartz sand they will weather relatively fast and may contaminate the ground water. If the impact is in residual soils, penetrators and DU dust will weather more or less easily, depending on the type of bed-rock . If a soil consists of weathered granite or acid volcanic rock, the environment will be acid and the weathering may be fast. On the other hand, if the underlying rock is limestone, a basic igneous rock or a basic volcanic rock, the DU may remain free of weathering. Acid rain will speed up the weathering.

Large pieces of DU can be collected if they can be located. Otherwise, the only way DU is removed is by gradual leaching by rain and melting snow. The migration of depleted uranium into the soil is slow, and in a test area in Florida that had been used since 1955, the uranium concentration in the upper 5 cm of soil was as much as 30 times higher than at 5-10 cm depth

(Wayne et al. 1976). Consequently, it will take many years, maybe several hundred years, before DU contamination disappears.

2. Chemical process of the transport of DU in ground

Because uranium metal is termochemically unstable relative to more oxidized forms of uranium, U(IV) and U(VI) it will react to form oxides when in contact with the earth's atmosphere. The primary oxidation products are hyperstoichiometric U(IV) oxides of the form UO_{2+x} where $O < x < 0.4$. Further oxidation to mixed U(IV) and U(VI) oxides may occur (Ebinger et al. 1990)

Uranium that is leached from fragments and dust particles of DU will be transported in the soil or bedrock as U_2^{2+} ions in precipitating water. Under oxidizing conditions, most of the dissolved uranium ions are in the form of soluble unary ions that can move through the environment and living organisms. Under reducing conditions, most uranium is solid or insoluble.

The potential for the migration of uranium depends on the chemistry of local soils and pore waters as well as on the oxidation products of the DU. The mobility of dissolved uranium products will depend on the Eh, pH and the presence of complexing ligands in local groundwaters. Uranium (VI) is more mobile than U(IV) because of aqueous complexation reactions involving ligands commonly found in natural waters; carbonate and phosphate are considered the most important of these. The transport of dissolved uranium can also be effected by attenuation reactions that reduce uranium concentration in ground water and surface waters. These reactions include ion exchange and specific adsorption of uranium on organic matter, clay minerals, and ferric oxides and oxyhydroxides commonly present in soil.

Dissolved U(VI) exists in solution as the uranyl ion (UO_2^{2+}), and form complexes with OH^-, CO_3^{2-}, F-, PO_4^{3-}, SO_4^{2-} and organic ligands. The uranyl ion is complexed primarily by fluorid between pH less the 4, and it is strongly complexed by phosphate between pH values of 4 and 7.5. At higher pH, dissolved uranium is present predominately as uranyl carbonate complex.

Reactions between local soils and groundwater may affect the concentration of U transported through a soil profile. These reactions include precipitation of secondary uranium minerals, ion exchange of U on clay minerals, and specific-ion adsorption of U on mineral surfaces. All these types of mass-transfer reactions could decrease the concentration of U in groundwater migrating through a soil profile.

Erikson et al. (1990) has studied the weathering of DU penetrators. They found that DU penetrators principally corrode into hydrated U(VI) oxides that were very soluble in water. Erikson further found that when native soils were acidic, they could attenuate uranium species, probably through adsorption reactions. They also studied the sorption capacities of different soils and found that soils with high carbonate had the lowest capacity, probably due to the formation of very soluble uranyl carbonate such as UO_2CO_3, $UO_2(CO_3)_2^{2-}$ and $UO_2(CO_3)_3^{4-}$. Under aerobic conditions, iron can play a key role in controlling the movement through soil. Uranium will bind to many iron minerals. Uranium adsorps to humic matter in the soil. Uptake (complexation) by organic compounds will slow the migration of uranium through soil by several orders of magnitude, so that it becomes essentially immobile.

In humid environments the lifetime of the 1 kg of uranium metal disrupted to 1 g pieces will be about 410 years. For an intact DU penetrator used as tank ammunition and having a mass of 1.345 kg the estimated lifetime would be around 2100 years. In either case, within a matter of hours the amount of UO_2 available to be leached by rainwater exceeds several milligrams. Under some environmental conditions, the solubility of UO_2 in water is of the order of a few micrograms of U per liter of water (Erikson et al. 1990).

For aqueous conditions, such as exist in surface waters, corrosion rates tend to be higher than at atmospheric oxidation rates.

3. Leakage to the groundwater

Dissolved uranium in the precipitating water will move through the soil down to the groundwater. Whether the effect of DU on the groundwater has any significance for unhealthy contamination of the water depends on the how much uranium is added to the groundwater, the size of the groundwater reservoir and the rate of flow through the reservoir. Soils usually have a porosity of 30-45%. That implies that below the groundwater table there is 300-400 litres of water per cubic meter of soil. The thickness of the water-bearing soil layer between the groundwater table and the basement may vary from a few centimeters to many meters. The rate of horizontal water flow through the soil is usually 1 -100 centimeters per day in normal soil and 0.01 centimeters per day in clays. However, the flow rate will increase if water is pumped from the groundwater reservoir. Thus the contamination of the groundwater by uranium leached from DU will depend on the amount of uranium leached, the precipitation, the volume of the water reservoir, the flow and water and volume pumped from the water reservoir.

As previously described in Appendix 4 the normal uranium concentration in groundwater is 0.1-12 µg/l.

In the scenario on contamination of the groundwater in Appendix 8, it is assumed that 40 m^3 are pumped annually from a well in an attacked area, that the precipitation is 500 mm per year, the thickness of the aquifer is three meters, and the amount of dissolved uranium transported from contamination on the ground is 1 kg per year. The assumptions are conservative. The assumed pumped water volume is small, and the amount of uranium that is assumed to be transported from the ground surface to the ground water aquifer is large.

However, even at these unlikely conditions the uranium concentration in the groundwater will not be higher than 1 mg/l. It is not likely that DU leached to the groundwater reservoir will result in intakes of more than 1.5 g uranium per year at a water consumption of 1.5 liters per day. An intake of 1.5 g uranium corresponds to a dose of 1 mSv per year. However, if surface waters run directly into a well without passing filtering soil the uranium concentration in the well water might be contaminated with undesired concentration of uranium.

The transport of uranium from DU on the ground surface to the groundwater will continue many years. However, in an attacked area no effects on the environment are likely due to contaminated groundwater.

4. Uptake by animals

The long-term perspective of uptake and effects of uranium on grazing farm animals is described in Appendix 4. Few investigations have been reported on the effects on small animals and evertebrates, which live in DU contaminated soil. Wayne et al. (1976) report that small burrowing animals trapped at the Florida test site contained a maximum of 210 ppm uranium in the gastrointestinal tract contents, 24 ppm in the pelt and 4 ppm in the remaining carcass.

5. Uptake by plants

Plants have a limited uptake of uranium and are generally not affected by high uranium concentrations in the soil. They are also much more resistant to radiation than animals.

In a U.S. study of the effects on plants growing at a test site for DU, the observed concentration ratios were 0.02-0.13 (Wayne et al.1976). The uranium levels in roots were much higher, the ratio plant U to soil U being 0.28-5.26. At least part of this variability was caused by several small particles of soil and presumably, uranium adhering to roots. Furthermore, uranium colloids would not be seen but may well have been absorbed on the root surfaces. This may imply that humans eating root vegetables that have grown in heavily contaminated areas may get a significant intake of uranium. More research is needed to investigate and evaluate this risk.

Appendix 7

Report from the Fact Finding Mission to Kosovo, 16 – 19 August 1999

The purpose of the travel to Kosovo was to conduct a fact finding mission in the context of the aims and objectives of the UNEP/Balkans Task Force (BTF) and specifically to make a preliminary assessment of the existing radiological situation in a few selected locations. The information gathered would then be used to determine whether there was a need for the expanded field study (sampling and measurements campaign) proposed by BTF related to depleted uranium (DU) in the environment.

The mission team was composed of Marceil Yeater (UNEP/Habitat BTF – Balkans Task Force, Geneva), Gustav Akerblom (Swedish Radiation Protection Institute, Stockholm), Kerry Burns and Peter Stegnar (IAEA, Vienna). The team worked in Kosovo (Pristina and its vicinity, Klina) from 16 to 19 August and returned from Pristina on 19 August 1999.

The team performed some preliminary measurements, such as, of absorbed dose rates in the air and surface alpha and beta contamination levels around the destroyed vehicles, at and along the roads the team travelled, and in Pristina around the damaged/destroyed Police Station and Post Office (checked partly inside as well). In addition to the measurements, two sets of swipe samples were taken from the surfaces of the destroyed tanks for subsequent isotopic analysis. These samples were taken for the purposes of establishing “background“ levels since the tanks were not attacked using DU weapons.

There were no elevated levels of radiation measured in the vicinity of the destroyed vehicles in Klina. No elevated levels of radiation were found at or along the roads the mission team travelled, or at the Pristina Police Station and Post Office. Based on the preliminary measurements the team did not find any evidence (indication) of the presence of DU at the locations visited.

The measurement results (from the in-situ measurements) are shown in TABLE 1.

Each of the two sets of swipe samples consisted of four individual swipes: one control sample prepared by wiping the freshly gloved hands of the sampling team prior to taking any samples; and three swipes taken from different points on the vehicle where shell impact or a dark surface deposit was evident. The swipes were returned to the IAEA Laboratories in Seibersdorf where they were analysed for uranium content by γ-ray spectrometry and X-ray fluorescence spectrometry.

No uranium was detected in any of the swipes by either technique. TABLE 2 presents the limit of detection for uranium for each swipe sample for both techniques. The detection limit for uranium is inferior by γ-ray spectrometry because of the small amount of material on one swipe. For either technique, the detection limits among the swipes do not differ significantly because each swipe was measured for the same period of time using the same sample geometry which generates essentially a constant background. For γ-ray spectrometric measurements, each sample was measured for a period of 28800 seconds on a HPGe γ-ray spectrometer (70% relative efficiency) at a source to detector distance of approximately 3

mm. For X-ray fluorescence spectrometry, each sample was measured for a period of 28800 seconds using an 80 mm 2 Si(Li) detector and a Cd-109 excitation source.

TABLE 1: Environmental Radioactivity Measurements in Kosovo

Location	Position	Absorption dose rate in air (microGy/h)	Beta surface contamination (Bq/cm^2)	Comment
Pristina – Police Station		0.07 – 0.1 outside	0.1 – 0.2	Natural background values
Pristina – Post Office		0.08 – 0.1 outside up to 0.12 inside	0.1 – 0.2	Natural background values
Klina – at the attacked site	N $42^0$36'33.8" E $20^0$34'32.4"	0.08 – 0.1	0.1 – 0.2	Natural background values
Peja – municipal waste dump site	N $42^0$39'22.4" E $20^0$19'10.2"	0.08 – 0.1 at the dump site, 0.15 – 0.2 on the asphalt road	0.1– 0.2 up to 0.5 on asphalt road	Presence of K-40
Mirusha village, a tank destroyed by KLA	N $42^0$29'33.3" E $20^0$43'34.5"	0.08- 0.1		Natural background values
Orlate village, army vehicle destroyed by NATO	N $42^0$33'9.5" E $20^0$49'59.2"	0.08 - 0.11		Natural background values

TABLE 2: Uranium Concentration (reported as the limit of detection in μg) for Two Sets of Swipe Samples Taken from Two Military Tanks near Klina, Kosovo

Sample Identification	**Uranium Concentration (μg)**	
	γ-ray Spectrometry	**X-ray Fluorescence**
CL-00495 Control	< 80	< 3
CL-00495 Swipe 1	< 80	< 3
CL-00495 Swipe 2	< 80	< 3
CL-00495 Swipe 3	< 80	< 3
CL-00496 Control	< 80	< 3
CL-00496 Swipe 1	< 80	< 3
CL-00496 Swipe 2	< 80	< 3
CL-00496 Swipe 3	< 80	< 3

Appendix 8

Potential health and environmental impact of using depleted uranium in ammunition

1. The conditions

In the case of the Balkan war there are no official documents provided that support or deny assumptions on the use of depleted uranium (DU) and the measurements made in limited areas did not give any indications of DU in the environment.
However, these two non-indicative facts do not rule out the possibility that DU has been used in the conflict. Therefore it is of interest to get some idea of possible effects as assessed on a theoretical basis using scenarios with realistic and/or conservative assumptions.

The best way to estimate the health consequences of environmental contamination of DU is measurements in the environment combined with data and facts on amounts of DU used, the conditions during the use of DU, exposed people etc.
However, because measurements, at least primarily, will not be made at all places where there might be DU contamination in the environment, it is necessary in the final analysis of the consequences to make extrapolations and assumptions based on models and scenarios.
In the calculations on radiation doses the dose factors given in Appendix 10 are used.
The following analysis would also be helpful in forthcoming assessments based on possible real observations.

The Terms of Reference include also consideration of possible contamination of the Adriatic Sea caused by dumped ammunition. This study does not consider that problem because there is information that precludes such dumping. Furthermore, the environmental problem from such a dumping is considered to be negligible.

2. The assumptions

The scenario includes a number of assumptions that are relevant for the calculations on possible consequences for human health and the environment. The assumptions are made on the basis of best available information with some conservatism built in and the references are found in the other appendices of this report.

2.1. Amount of DU.

DU only used by aircraft.
At each attack to a target 50-100 bullets are fired from an aircraft.
3 aircraft may attack the same target.
1 of five bullets contains DU.
Content of DU in a bullet is 300g.

Total amount of DU in an attack is accordingly 10-30 kg. 10 kg is used.
Only DU from enrichment processes is used, the activity composition is given in Appendix 4.

2.2. Affected areas

Initially all DU is assumed to be deposited on the ground in the target area assumed to be 20x50 = 1000 m^2
In the long term perspective a minor part of the DU dust might be dispersed over larger areas.

2.3. Events

50 % of the rounds are aerosolized.
Size is < 10 μm
50 % are penetrating or missing the target and hit the ground
Aerosols are respirable
DU dust is settled initially within 1000 m^2 (20x50m)

2.4. Impact on health and the environment

The impact on health is caused by inhalation of DU dust (metal and oxides), by ingestion of contaminated food and water and contaminated hands, by contaminated wounds and embedded fragments and by external radiation from pieces of DU.

Chemical impact: deterministic above thresholds which are assumed to be:
-air concentration 10 mg m^{-3} (no sign of pulmonary disease of U miners exposed to 0.5-2.5 mgm^{-3} of uranium dust for 5 years, for animals acute effects have been observed above 10 mg m^{-3} and no effects whatever for short or long term exposure in 0.15 mg U m^{-3}).
-water concentration 2 mg l^{-1} (short term exposure of rats)
-acute toxicity (lethality) in animals 100 mg/kg body weight, bw.
As regards long term effects see *limits* below

Radiological impact: somatic effects (cancer) without threshold (probability = 5 10^{-2} per Sv effective dose) and deterministic effects above the thresholds which are assumed to be
1 Sv for effective dose (death)
5 Gy for organ dose (organ death, skin burn)
For animals the same values are assumed.

2.5. Comparison values

In order to make a first preliminary judgement of possible consequences comparisons are made with a number of “reference” values for uranium. They are related to
-natural levels
-limits and standards
-impact values (see point 2.4 above)
-action and non-action levels (radiological)

2.5.1 Natural values (from UNSCEAR reports):

-activity of U-238 is 12.3 Bq mg^{-1}
-body burden 30 μg uranium (99.8% is U-238 by weight. 360 mBq each of U-238 and U-234 assumed to be in equilibrium)
-effective dose 5 μSv per year caused by only U-238 + U-234 (in equilibrium and each contributing about 50%) in the body
-total effective dose 160 μSv per year caused by all uranium daughters in the body from ingestion and inhalation (except radon daughters inhaled). The main part is from Pb/Po-210 ingested

-concentration in air 1 μBq m^{-3} each of U-238 and 234 (8 10^{-5}μg m^{-3}, 99.8% U-238 by weight)
-inhaled 7 mBq per year each of U-238 and 234 (~0.6 μg uranium, 99.8 % U-238 by weight)
-effective dose caused by inhaled uranium
0.3 μSv per year if all uranium daughters (except radon and its daughters) are in equilibrium
5.9 μSv per year from uranium and its daughters as they are in air (major part caused by Pb/Po –210)
0.06 μSv per year from U-238 solely and 0.07 μSv per year from U-234 solely

-normal dust load 50 μg m^{-3}
-natural uranium in soil 36 Bq kg^{-1} of each U-238 and U-234 (3 mg per kg)
-uranium in dust as in soil i.e. 1.8 μBq m^{-3} air of each U-238 and U-234

-ingested by food 5.2 Bq per year (0.4 mg uranium per year, the major part U-238 by weight) of each U-238 and U-234
-drinking water concentration 1 Bq m^{-3} (0.08 mg uranium m^{-3}) of each of U-238 and U-234
-intake by water 0.5 Bq per year (0.04 mg uranium per year, 500 l water per year) of each U-238 an U-234
-effective dose caused by ingested (by food and water) uranium 0.25 μSv per year from each of U-238 and U-234
Therefore: 36 Bq/kg soil (each of U-238 and 234) leads to a total annual intake by food and water of 5.7 Bq of each of U-238 and U-234 which leads to an effective dose of 0.25 μSv per year from each of U-238 and U-234

-the same concentration of uranium in soil leads to (with the level of equilibrium of short-lived daughters existing in ground) an external absorbed dose rate in air of 17 nGy per hour or 0.02 mSv per year (adjusted for indoor occupancy factor 0.8 and 0.7 Sv/Gy for conversion coefficient from absorbed dose in air to effective dose received by adults)

2.5.2 Limits

Chemical
-natural uranium with daughters in air 0.2 mg m^{-3} (US-value for workers) insoluble uranium and 0.05 mg m^{-3} soluble for long term exposure and 0.6 for short term exposure. Corresponding value for the public would be 0.15 mg m^{-3}.
-proposed (by EPA) drinking water standard for naturally occurring uranium 20 μg/l
-tolerable daily intake (WHO) of natural uranium 0.6 μg/kg body weight (bw) per day

Radiological
-intake of depleted uranium corresponding to 1 mSv:
by ingestion 1.5 g
by inhalation 10 mg

2.5.3. Impact values *(see point 2.4. above)*

Action and non-action values (radiological)
-no concern <10 μSv per year
-planning dose limit for a given source 0.1 mSv per year effective dose to the public i.e. the practice shall be planned to give doses (far) below that value
-dose limit for the public from all man made sources excluding medical and natural sources 1 mSv per year effective dose
-dose limit for the public for exposure of the skin 50 mSv per year
-action levels for radon in houses 10 mSv per year

-dose limit for worker 20 mSv per year effective dose as an average over 5 years
-dose limit for workers in a single year 50 mSv per year effective dose
-dose limit for workers for exposure of the skin 500 mSv per year
-actions probably justified after a nuclear accident or an existing unsatisfactory "de facto" situation if doses 10-100 mSv are prevented
- if expected doses are > 100 mSv countermeasures to prevent these doses are mostly always justified

3. The scenario and its consequences

3.1. The scenario

It is assumed that an attack includes 3 aircraft and the total DU used in the attack is 10 kg. The target is one or several vehicles and the area affected by the subsequent DU contamination is 1000 m^2. The impact of DU on soldiers and civilians in the vehicles and on the affected area during the attack is not considered specifically. The chemical and radiological impact during the attack is probably small as compared with the consequences of explosions and fire. However, the survivors may have been seriously exposed to depleted uranium on the top of the consequences of explosion and fire.

Most of the dust that is caused by explosions and fire is assumed to settle on the ground within the area of 1000 m^2. However, it is assumed that someone very close to the target instantaneously exposed for a short time to the dust cloud, that probably has a very high density, 100 mg m^{-3} is assumed.

After some time people may enter the area which be cultivated. By entering the area people cause suspension and breathe contaminated air, are contaminated by touching subjects in the area, are externally exposed from solid DU pieces of the ammunition on or in the ground that are picked up.

Some of the DU will be dissolved in water in ground and contaminate the groundwater which serves a well nearby.
Some animal will graze in the area, be contaminated and eventually be used as meat and contaminate people.
By dispersion a small part of the DU dust will in the long time perspective be spread over larger areas.

3.2 The consequences

3.2.1. Picked up solid pieces of DU.

The only realistic way of exposure is by external β-radiation. The γ-radiation is very weak and the α-radiation can not penetrate the dead skin layer. The surface radiation dose rate is about 2 mSv h^{-1}. If the piece of DU is put in the pocket the β-radiation is somewhat reduced, 50% is assumed. The exposed skin area will be quite small.
By keeping the piece of DU in the pocket for several weeks in the same position it might be possible that the skin dose will exceed values corresponding to the limit for the public and the workers. *It is out of question there will be any deterministic effects (skin burns) even though the skin dose might be high.*

3.2.2. Rounds that passed or missed the target and can contaminate the ground and groundwater.

The bullet will hit a ground of clay, sand or stones (solid ground) or a mixture. The extreme cases are intact impact (in clay) and complete disruption (on stones). *In the first case there is a risk of pick up and external radiation,* see 3.2.1. *In the second case there is a local surface contamination* and the possible consequences are those described below.

3.2.3. Instantaneous inhalation of DU dust after an attack.

The dust concentration outside the target immediately after an attack is probably very high. It is reasonable to assume that the dust is a mixture of DU and other toxic and non-toxic materials. 10 % DU is assumed and an instantaneous intake by breathing of more than 1g dust is unendurable. That means a maximum intake of 100 mg of DU which might lead to *acute chemical toxicity and a total effective radiation dose caused by inhalation of less than 10 mSv.* However, these dust concentrations can only appear immediately after an attack and close to the target.

3.2.4. Inhalation of resuspended DU

By wind, walking in the area, digging etc. dust from ground may be air born and be inhaled. All DU is assumed to be present in the form of small particles (<10 μm) and to be in the form of insoluble oxides (Type S), which are cleared from the lungs only slowly.
DU is mixed with soil on the ground and for the purpose of assessment it is assumed that a 1 mm thick soil layer includes all DU and takes part in the dust load.

10 kg DU is spread over 1000 m^2 containing 1 m^3 of soil weight 1500 kg down to 1 mm, i.e. the DU concentration of the dust will be 6 μg DU/ mg dust.
Normal dust concentration is 50 μg m^{-3} in air outdoors and very dusty 5 mg m^{-3} which leads to 0.3 μgm^{-3} and 30 μgm^{-3} respectively of DU in air. *From chemical point of view these levels are lower or within the range of given hygiene standards for chronic exposure.*

Assume *a stay in the area longing for 2 hours* and breathing rate of 1 m^3 per hour. That *would lead to* an intake of 0.6-60 μg of DU corresponding to *an effective dose of 0.07-7 μSv.*
Even *a continuous stay night and day for a year under the most dusty conditions would not lead to more than a few tens mSv or less. Normal dusty conditions would lead to 100 times less.*
A safety margin is the possibility that only a minor part is resuspendable. From studies on particle sizes of aerosols of DU almost 90 % of the particles were larger than 125 μm and not resuspendable and significant resuspension can only be expected for particles less than 20 μm.

An unsafe factor is that the area might be less than 1000 m^2 e.g. 100 m^2. In that case the individual dose for a 2 hours stay might be 10 times higher i.e. 0.7-70 μSv. On annual basis an assumption on a smaller area decreases the probability that anyone would stay in the same narrow wind direction all the year which reduces the resulting annual dose correspondingly to about the same annual dose as above.

A question that often meets special interest is the risk of inhaling particles (hot particles) giving rise to acute wounds in the lung because of very intensive radiation. This might be a problem with inhaled particles which have a high specific activity but the specific activity of depleted uranium (DU) is very low. Furthermore, it has not been shown that hot particles would cause a greater risk of a lung disease than the same activity distributed normally in the lung.

3.2.5. Ingestion of DU

Ingestion may occur by getting soil in the mouth (children), by eating contaminated vegetables, from hands coming in contact with contaminated skin and cloths, from contaminated water and from meat of contaminated animals.

1. Soil in the mouth.

The concentration of DU in soil is assumed to be 6 μg DU/mg soil. 1 g of soil is assumed to be ingested at maximum leading to an intake of 6 mg DU corresponding to an *effective dose of 4 μSv. Acute chemical toxic effects from uranium may occur if the amounts are about 10 times higher* which is the case if the area is 10 times smaller.

2. Contaminated vegetables.

The first days-weeks after the attack and before any rain there may be a surface contamination of leafy vegetables. The area contamination is assumed to be 10 kg DU over 1000 m^2 i.e.
10 000 mg m^{-2}. Normal intake of leafy vegetables is about 60 kg per year i.e. 1 kg per week corresponding to about 1 m^2 of land depending on type of vegetables etc. Assume 1 kg will be

the actual intake during the critical time after an attack. Normal hygienic routines by washing the vegetables will decontaminate them substantially and leaving only a few per cent left, some 100 mg DU. *That amount is absolutely significant from chemical risk point of view.*
The resulting radiation dose will be of the order of 0.1 mSv.
An unsafe factor is that the contamination might be spread over a less area, say 100 m^2, which makes the problem even worse.
An uncertainty factor is possible later surface contamination of vegetables caused by resuspended DU dust. However, this is believed to be a second order problem.

3. Contaminated hands.

Hands can be contaminated by touching contaminated subjects, clothes etc and part of it can be ingested during meals etc. However, as the intake is more depending on bad hygiene than intentional, as was the case in example 1 above, the amount is assumed to be 10-100 times less and correspondingly the doses i.e. *no acute chemical effect or significant dose are expected.*

4. Open wounds.

If an open wound is contaminated by DU dust the unprotected tissue near by will be irradiated by α- and β-radiation with a dose rate <50 mSv h^{-1} that hardly will give any acute deterministic effects. Possible contamination of the blood is difficult to predict. In any case the *harmful effect of contaminated wounds should not be underestimated.*

5. Contaminated water

By rain DU deposited on the ground may be transferred downwards eventually to the ground water that serves a well near by. The soil depth between the ground water table and the surface of the bedrock is assumed to be 3 m, the contaminated area 1000 m^2, total amount of DU 10 kg, leakage of DU 10 % per year of deposited amount of DU, the water content of the ground 30 % and the outtake from the well 40 m^3 per year.
The available water volume for dilution of the leakage of DU is accordingly 900 m^3 and the concentration will be 1 g DU per m^3. During a year the rainfall is approximately 0.5 m leading to a total of 500 m^3 over the area of interest, which means there is a more or less complete renewal of the water column. The concentration of DU in the well will therefore not increase with time.
A concentration of 1 g DU per m^3 (1 mg per l water) is much above hygiene standards for chronic exposure. At this level chemical toxic effects cannot be excluded.
The annual radiation dose caused by consumption of that water will be about 1 mSv.

6. Contaminated food.

Food other than vegetables may be contaminated indirectly by animals eating surface contaminated plants and soil then being meat for consumption or milk producer (cows) and in the long time perspective by uptake in the plants by the roots and by animal eating the plants.

In the first case the uptake by the animal may be substantial, corresponding to a grazing area of 10-100 m^2 per day i.e. 100-1000 g DU per day, which is *definitely unhealthy for the animal. People eating the meat and drinking the milk from these cows will probably be exposed to a much higher intake than "the Tolerable Daily Intake (TDI)". The radiation doses will be less than 0.1 mSv per day consumption of that meat or milk.* So, both for animals and humans there are health risks. These might be serious for animals after a few days of exposure. Although, the underlying assumptions are very conservative for this particular case it can be concluded that grazing animals should be kept away from (potentially) contaminated areas.

As regards *the long term contamination of plants and meat caused by root uptake* the following relationship can be used:
36 Bq/kg soil of U-238 leads to a total intake by food and water of 5.7 Bq of U-238 per year which results in an effective dose of 0.25 μSv per year. The contribution from U-234 is about the same. In DU the relative activity of U-234 is only 20 % of that in equilibrium and the resulting dose from DU in ground with 36 Bq/kg soil of U-238 and 7 Bq/kg soil of U-234 (corresponding to 3 mg uranium / kg soil) will accordingly be 0.25+0.05 = 0.3 μSv per year.

10 kg DU spread over 1000 m^2 and distributed in a 10 cm deep layer to be available for the roots corresponds to a concentration of 70 mg DU / kg soil if the density of soil is
1500 kg / m^3. That *will result in an effective dose by ingestion of 7 μSv per year.* This will allow more than 100 times more effective root uptake for DU than natural uranium before the doses begin to be significant.
If the DU is distributed over a smaller area it does not influence the result much because of dilution of the animal´s meal by grazing in other uncontaminated areas.

Based on this scenario for "root uptake" it is likely that there is no chemical risk for humans consuming vegetables. For grazing animals there seems to be no apparent chemical risk. However, if the upper soil layer should be contaminated at a higher level than assumed (distributed in thinner layer than 10 cm) and because ingestion of soil is an important factor for DU intake by grazing animals, health risks for grazing animals and consequently for humans consuming animal products can not be excluded in the situation of long term exposure.

3.2.6. External radiation

The same deposition is assumed i.e. 70 mg DU / kg soil over 1000 m^2. Natural uranium
(3 mg/kg soil) in the level of equilibrium it exists in soil gives 17 nGy per hour or an effected dose of 0.02 mSv per year (corrected for indoor occupancy 0.8 and conversion factor Sv/Gy of 0.7). The γ-radiation from DU is only 0.8 % of that of natural uranium. Therefore the resulting dose from 10 kg DU on 1000 m^2 would be 0.02/3x70x0.008 mSv per year = *4 μSv per year*.
A safety margin is that *even if the affected area is 10-100 times smaller the dose is still under 1 mSv per year with good margin.*

3.2.7. Activity spread over large areas

Only a smaller part of the deposited DU will resuspend and disperse and the affected area will be much larger. These two factors lead to *much lower individual exposures than in the target area.*

Appendix 9

Near future problems

The following paragraphs give some introductory remarks and reflections on the near future problems of measurements, decontamination and waste management and disposal and the need for further analyses of the problems and for development of principles and methods for solution of the problems. The recommendations given are tentative.

1. Measurements

1.1. The need

In Kosovo it would be necessary to find and bound the areas that are contaminated by DU and to determine the concentration of DU. Following paragraphs discuss the methods, instruments and analyzes that may be used and their limitation.

A boundary condition for measurements is that such contamination of DU can be detected that corresponds to significant exposures. At several months after the conflict the critical exposure pathways might be by external radiation from solid pieces that are picked up, by intake of contaminated soil by children and by consumption of drinking water from some nearby well. In order to prevent significant exposures by these pathways it would be necessary to be able to find solid pieces of DU and detect an area contamination of at least 1 g DU/m^2.

1.2. The methods

If black dust covers or partly covers an attacked object and the ground around it the object may have been hit by ammunition containing DU. However, to be sure that an object or the ground has been hit by DU one has to measure the radiation in the area or to take soil samples to be analyzed in a laboratory.

Depleted uranium emits alpha radiation, relatively strong beta-radiation (E_{max}= 2.29 Mev from Pa-234m) and some weak gamma radiation. Field-measurements others than from ground level do not seem possible or practicable.

The sensitivity of the measurement depends on the instrument used and what is measured. Measurements of alpha radiation in the field directly on the ground surface will suffer from many uncertainties mainly depending on self-absorption of the alpha particles in dust, humidity etc. Spot measurements may be possible.

Measurements of gamma radiation suffer from low sensitivity and a disturbing natural background and the limit of discernibility may be unacceptably high and it is unlikely that

simple instruments that measure the gamma radiation will be able to detect DU contamination of the order of 10 $g/m^{2.}$

Measurement of beta radiation may be more successful and allow detection of at least one order of magnitude less activity than what is possible at measuring of the gamma radiation with conventional instruments. It is probably possible to detect DU contamination of about 1 g/m^2.

In case of laboratory measurements samples taken should be representative for the area or spot where they were collected and the laboratory analysis should make it possible to judge the significance of the risk there.

1.3. The instruments

For measurements different types of instruments may be used. Instruments that measure the total gamma radiation can be used to detect penetrators or pieces of them. However, the instrument must have high sensitivity as the gamma radiation emitted from DU is weak compared to that from the natural radioactive elements that already exist in the ground; uranium, thorium and potassium.

Scintillometers are sensitive instruments for measurement of gamma radiation. Such instruments are designed for geological and geophysical surveys and have a short time constant and are suitable for finding pieces of DU. In the field they can be used for searching after DU pieces while walking over an area. However even these sensitive instruments have a limited capability to detect a layer of DU dust deposited on the ground. The concentration of the DU dust has to be in the order of 200 times the concentration natural uranium in the ground, if the gamma radiation emitted from the DU should be higher than that emitted from natural uranium, thorium and potassium-40 in the underlying soil or bedrock.

Instruments sensitive to beta radiation are *Proportional counters* and *Geiger-Mueller counters*. They measure both the gamma and beta radiation. As the beta radiation emitted at the decay of protactinium-234m is strong (about 50 % of all the beta radiation energy emitted in the whole uranium-238 series) this fact is favorable for the detection of DU. However, the concentration of DU has to be in the order of ten times the natural uranium concentration in the ground, as these types of instruments also measure the beta and gamma radiation emitted from decays in the uranium and thorium series and from potassium-40. Beta radiation has also quite a limited range, less than 0.5 cm in soil. This implies that only DU fragments and dust particles in the upper soil-layer can be detected and it is also in this layer the DU dust is expected to be found the first year(s). Beta-counters are good for spot measurements.

Alpha-meters are proportional counters sensitive to alpha radiation. They can be used to measure the alpha radiation emitted by the decays of uranium-238, -235 and -234 in the DU. To be able to detect alpha radiation from a dust cover of DU the dust must lay on the surface of the ground, as the range of the alpha particles in air only is a few millimeters. The alpha-meters are used for spot measurements.

Sensitive *gamma ray spectrometers* that use Ge(Li) detectors can be used in the field to distinguish between natural uranium in the soil and contamination of depleted uranium and to

analyse the concentration of DU. However, such measurements take long time and the instruments have to be cooled by liquid nitrogen.

Soil samples can be used to investigate if an area has been contaminated by DU. The samples have to be analysed at laboratories. Several different methods are used.

The more investigations of DU can rely on measurements of radiation in the field the better, as measurements in the field always is faster and cheaper than analyses of samples at laboratories. However, the radiation from the DU might be too week to detect with field instruments and this might make it difficult to determine small contamination of an area and from that decide on the need to bound the affected area.

2. Decontamination

If, when and how contaminated areas should be cleaned up should be decided case by case on the basis of justification, optimization and individual protection. If contamination is easily detectable and perhaps also visible it would certainly be justified assuming that involved workers are properly protected and methods have been developed to effectively decontaminate the area. However, there is a need to prepare special instructions that are applicable to the situation in Kosovo. These should also consider the need of protection of those taking part in the decontamination work as well as the problem of taking care of the waste afterwards (see below).

A couple of U.S. reports write on decommissioning of test sites for DU ammunition (e.g. Winchner et al 1992 and Khan 1993). The methods used for separation of DU in sand are screening to recover pieces and larger fragments of DU, heavy media separators, gravity and centrifugal concentration, magnetic separation, washing sand with water and leaching of uranium. The density separation achieved a high degree of separation, as much as 14-fold reduction in DU content but still fell short of achieving the 1.3 Bq/g requirement for unrestricted disposal. With the use of leaching processes the uranium concentration will reach levels under this limit (Khan 1993).

In Kosovo collecting of pieces of DU by detecting them with sensitive scintillometers can be a useful way to clear an attacked area from larger DU pieces. In some cases it may be possible to remove the topsoil and dispose of it. A method that will considerably lower the risk for inhalation and ingestion of DU particles is to cultivate the soil, for example by plowing. These ideas and all other aspects have to be developed and adjusted to the situations in the attacked areas.

3. Waste disposal

3.1. The problem

At the places, where depleted uranium (DU) has been used, uranium dust and pieces of DU are assumed to be found within a rather limited area, the target area. When the contaminated areas are identified, measured and decontaminated there will be an amount of waste containing DU diluted with soil and others like contaminated clothes, tools, instruments etc.

Probably the volumes are not huge but because of the radioactivity the waste would be considered as potentially dangerous and need special treatment. Furthermore, solid pieces of DU should be taken care of by official bodies like the police or some other authority and then be stored as radioactive material or radioactive waste until further instructions are given.

Normally radioactive waste is generated in connection with some civil, beneficial and justified use of radioactive material and the waste has to be taken care of in an optimised way according to well specified regulations.
But in the case of DU used for military purposes there are quite different conditions which put the problems into other perspectives.

3.2. The principles

Even though there are quite different conditions after a military conflict some guidance can nevertheless be obtained from principles on waste management and disposal applied in normal conditions.

As regard radioactive waste there is a well-developed system in most countries for waste management and disposal based on internationally accepted principles. However, even if these basic principles are the same in most countries, namely the International Commission on Radiological Protection (ICRP) recommendations and EU´s and the International Atomic Energy Agency (IAEA)´s basic safety standards for the protection of workers and the public completed with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management there are differences in the practical applications concerning methods and applied limits for different types of waste and disposal options.

An agreed general principle is that increasing activity of the waste requires safer disposal option. Other influencing factors are kind of radiation, radionuclide and half-life. That means that potentially least dangerous waste can be exempted or cleared from ordinary radiation protection requirements and can be handled and disposed of as ordinary non-radioactive waste. Next steps may be shallow land burial, rock repository and finally deep geological disposal for the most dangerous waste (high level waste and spent fuel).

Considering the management and disposal of depleted uranium as waste there are no generally accepted standards and there are few examples of national applications. An example is given in Appendix11. The problem is not only technical. Depending on the national legislation uranium in manageable quantities may not be considered as waste but as nuclear material with an economic value with special requirements as regards licensing, control and safeguard.

In comparison with the reference levels that exist for different types of radioactive waste, uranium in any form as a long-lived alpha radiation emitter would not be expected to be waste that could be exempted or cleared but should be taken care of as potentially dangerous waste. However, exemptions/clearance occur. That depends on the fact that uranium because of its long half-life has a very low specific activity and can easily be diluted to harmless concentrations. For example, uranium from leaching processes can in small amounts (of the order of 100 kg per year) and low concentrations (a few hundred ppm) be disposed of in a municipal refuse dump or landfill for non-radioactive waste. The estimated risks are very low

and the only way of exposure (might occur after a considerable time) is by consumption of fish from a nearby lake or water from a well.

As to the chemical toxicity aspects, there may be special regulations that specify what is to be considered as dangerous and not dangerous waste. In the latter case the waste is taken care of in municipal refuse dumps and in the former case in special facilities for dangerous waste. In case of uranium in larger amounts it would be considered as dangerous waste from chemical point of view.

3.3. Tentative solutions of the problems with depleted uranium as waste in Kosovo

If depleted uranium has been used in the Kosovo conflict and the countermeasures in attacked areas have led to manageable amounts of waste, concerned authorities should decide firstly
-who is responsible to take care of the waste
secondly, the one(s) responsible should,
-prepare and issue instructions on the management and disposal of the waste based on the following tentative principles:

1. collected dust mixed with soil etc. is brought to a municipal refuse dump.
2. collected solid pieces of depleted uranium are taken care of by responsible authorities and stored pending later decisions on disposal or other solution.

These tentative recommendations have to be analyzed more in detail before applied and implemented.

Appendix 10

Dose conversion factors for depleted uranium (DU).

1. Chemical composition and specific activity of DU

Table A. Depleted Uranium, DU (^{235}U 0.2%)

Chemical composition			**Specific activity**	**Bq/mg DU**
^{238}U	99.8000%		^{238}U	12.27
^{235}U	0.2000%		^{235}U	0.16
^{234}U	0.0010%		^{234}U	2.29
^{234}Th	Traces		^{234}Th	12.27
^{234}Pa	Traces		^{234}Pa	12.27
^{231}Th	Traces		^{231}Th	0.16
				Sum 39.42

Specific gravity theoretically 19.07
Melting point 1,132^{o}C
Only the uranium isotopes are emitting alpha-radiation and contribute significantly to the radiation dose in case of internal contamination.

2. Committed effective dose per unit intake (Sv/Bq) of various uranium isotopes via ingestion and inhalation for members of the public.

From
Council Directive 96/29/EURATOM OF 13 May 1996 laying down the basic safety standards for the protection of workers and the general public against the dangers arising from ionizing radiation.
Official Journal of the European Communities, No L 159, Vol. 39. 26.9.96

h(g) = the committed effective dose per unit-intake or unit-inhalation (Sv Bq^{-1}) for ingested or inhaled uranium by an individual in the group of age.

f_1 = gut transfer factor (i.e. the fraction of an element directly absorbed from the gut to body fluids) for intake by ingestion or inhalation.

Type F = denotes fast clearance from lung
Type M = denotes moderate clearance from lung
Type S = denotes slow clearance from lung

*Table B. Committed effective dose per unit intake via **ingestion** (Sv Bq^{-1}) for members of the **public***

Uranium-238

Half-life	**Age ≤ 1a**		**Age**	**1-2 a**	**2-7 a**	**7-12 a**	**12-17 a**	**> 17 a**
	f_1 for g≤ 1 a	h(g)	f_1	h(g)	H(g)	h(g)	h(g)	h(g)
4.47 10^9a	0.040	3.4 10^{-7}	0.020	1.2 10^{-7}	8.0 10^{-8}	6.8 10^{-8}	6.7 10^{-8}	4.5 10^{-8}

Uranium-234

Half-life	**Age ≤ 1a**		**Age**	**1-2 a**	**2-7 a**	**7-12 a**	**12-17 a**	**> 17 a**
	f_1 for g≤ 1 a	h(g)	f_1	h(g)	H(g)	h(g)	h(g)	h(g)
2.44 10^5a	0.040	3.7 10^{-7}	0.020	1.3 10^{-7}	8.8 10^{-8}	7.4 10^{-8}	7.4 10^{-8}	4.9 10^{-8}

Uranium-235

Half-life	**Age ≤ 1a**		**Age**	**1-2 a**	**2-7 a**	**7-12 a**	**12-17 a**	**> 17 a**
	f_1 for g≤ 1 a	h(g)	f_1	h(g)	H(g)	h(g)	h(g)	h(g)
7.04 10^8a	0.040	3.5 10^{-7}	0.020	1.3 10^{-7}	8.5 10^{-8}	7.1 10^{-8}	7.0 10^{-8}	4.7 10^{-8}

*Table C. Committed effective dose per unit intake via **inhalation** (Sv Bq^{-1}) for members of the **public***

Uranium-238 Half-life 4.47 10^9

Type	**Age ≤ 1a**		**Age**	**1-2 a**	**2-7 a**	**7-12 a**	**12-17 a**	**> 17 a**
	f_1	h(g)	f_1	h(g)	H(g)	h(g)	h(g)	h(g)
F	0.040	1.9 10^{-6}	0.020	1.3 10^{-6}	8.2 10^{-7}	7.3 10^{-7}	7.4 10^{-7}	5.0 10^{-7}
M	0.040	1.2 10^{-5}	0.020	9.4 10^{-6}	5.9 10^{-6}	4.0 10^{-6}	3.4 10^{-6}	2.9 10^{-6}
S	0.020	2.9 10^{-5}	0.002	2.5 10^{-5}	1,6 10^{-5}	1.0 10^{-5}	8.7 10^{-6}	8.0 10^{-6}

Uranium-234 Half-life 2.44 10^5

Type	**Age ≤ 1a**		**Age**	**1-2 a**	**2-7 a**	**7-12 a**	**12-17 a**	**> 17 a**
	f_1	h(g)	f_1	h(g)	H(g)	h(g)	h(g)	h(g)
F	0.040	2.1 10^{-6}	0.020	1.4 10^{-6}	9.0 10^{-7}	8.0 10^{-7}	8.2 10^{-7}	5.6 10^{-7}
M	0.040	1.5 10^{-5}	0.020	1.1 10^{-5}	7.0 10^{-6}	4.8 10^{-6}	4.2 10^{-6}	3.5 10^{-6}
S	0.020	3.3 10^{-5}	0.002	2.9 10^{-5}	1,9 10^{-5}	1.2 10^{-5}	1.0 10^{-5}	9.4 10^{-6}

Uranium-235 Half-life 7.04 10^8

Type	**Age ≤ 1a**		**Age**	**1-2 a**	**2-7 a**	**7-12 a**	**12-17 a**	**> 17 a**
	f_1	h(g)	f_1	h(g)	H(g)	h(g)	h(g)	h(g)
F	0.040	2.0 10^{-6}	0.020	1.3 10^{-6}	8.5 10^{-7}	7.5 10^{-7}	7.7 10^{-7}	5.2 10^{-7}
M	0.040	1.3 10^{-5}	0.020	1.0 10^{-5}	6.3 10^{-6}	4.3 10^{-6}	3.7 10^{-6}	3.1 10^{-6}
S	0.020	3.0 10^{-5}	0.002	2.6 10^{-5}	1.7 10^{-5}	1.1 10^{-5}	9.2 10^{-6}	8.5 10^{-6}

*Table D. Effective dose coefficients (Sv Bq^{-1}) for **workers***

Uranium-238

	Inhalation			**Ingestion**	
Type	f_1	$h(g)_{1\mu m}$	$h(g)_{5\mu m}$	f_1	h(g)
F	0.020	4,9 10^{-7}	5.8 10^{-7}	0.020	4.4 10^{-8}
M	0.020	2.6 10^{-6}	1.6 10^{-6}	0.002	7.6 10^{-9}
S	0.002	7.3 10^{-6}	5.7 10^{-6}		

Uranium-234

	Inhalation			Ingestion	
Type	f_1	$h(g)_{1\mu m}$	$h(g)_{5\mu m}$	f_1	h(g)
F	0.020	5.5 10^{-7}	6.4 10^{-7}	0.020	4.9 10^{-8}
M	0.020	3.1 10^{-6}	2.1 10^{-6}	0.002	8.3 10^{-9}
S	0.002	8.5 10^{-6}	6.8 10^{-6}		

Uranium-235

	Inhalation			**Ingestion**	
Type	f_1	$h(g)_{1\mu m}$	$h(g)_{5\mu m}$	f_1	h(g)
F	0.020	5.1 10^{-7}	6.0 10^{-7}	0.020	4.6 10^{-8}
M	0.020	2.8 10^{-6}	1.8 10^{-6}	0.002	8.3 10^{-9}
S	0.002	7.7 10^{-6}	6.1 10^{-6}		

Table E. Compounds and f_1 values used for the calculation of ingestion dose coefficients:

Uranium	0.020	Unspecified compounds
	0.002	Most tetravalent compounds, e.g., UO_2, U_3O_8, UF_4

Table F. Compounds, lung absorption types and f_1 values for the calculation of inhalation dose coefficients:

Adsorption type	**f_1**	**Compound**
F	0.020	Most hexavalent compounds, e.g., UF_6, UO_2F_2 and $UO_2(NO_3)_2$
M	0.020	Less soluble compounds, e.g., UO_3, UF_4, UCl_4 and most other hexavalent compounds
S	0.002	Highly insoluble compounds, e.g., UO_2 and U_3O_8

Comments

As seen from the tables the dose factors for infants and new born (< 1 a) are about a factor 4 higher than for adults (> 17 a) in case of inhalation and even more in case of ingestion.
However, the volume of air breathed and mass of food and water consumed per unit of time are much smaller for infants and new born than for adults (ICRP Report No. 23 Report of the Task Group on Reference Man 1974). Therefore with a given concentration (Bqm^{-3} or Bqg^{-1}) the intake of adults and infants are not so different.
Furthermore, in case of inhalation of insoluble uranium aerosols the biological half-life for a substantial part of the initial lung burden is very long, of the order of years. Table G is an example of lung clearance after an intake of 100 Bq U-234 as 5 µ S-particles to an adult.

Table G. Lung clearance and integrated effective dose as a function of time

Time after intake of 100 Bq U-234, days	Remaining U-234 activity in the lung, Bq	Received effective dose, Sv
2	8.6	$2.7\ 10^{-5}$
10	7.8	$1.1\ 10^{-4}$
100	4.6	$4.0\ 10^{-4}$
1000	1.9	$6.9\ 10^{-4}$
10.000	0.12	$9.2\ 10^{-4}$

Assuming the same clearance rate for children it is concluded that the major part of the dose is received when the child has grown up. Furthermore, in case of long time exposure the child is a child only a limited time.

Conclusion.
On the basis of the circumstances given above it is assumed that the uptake and resulting doses are those given for adults, type S-absorption (the most conservative), only.

3. Chosen committed effective dose per unit intake ($Sv\ Bq^{-1}$) of various uranium isotopes and of depleted uranium ($Sv\ mg^{-1}$).

Table H. Committed effective dose per unit of intake ($Sv\ Bq^{-1}$)

Isotope	Ingestion $Sv\ Bq^{-1}$	Inhalation $Sv\ Bq^{-1}$
U-238	$4.5\ 10^{-8}$	$8.0\ 10^{-6}$
U-234	$4.9\ 10^{-8}$	$9.4\ 10^{-6}$
U-235	$4.7\ 10^{-8}$	$8.5\ 10^{-6}$

Table I. Committed effective dose per unit of intake of depleted uranium ($Sv\ mg^{-1}$)

Mode of intake	SV per mg intake of DU
Ingestion	$6.7\ 10^{-7}$
Inhalation	$1.2\ 10^{-4}$

Appendix 11

U.S. regulations on waste disposal

The Clean Air Act (CAA) classifies all substances containing radionuclides as hazardous substances (40 Code of Federal Regulations, CFR, 61; 42 U.S. Code, USC, 7412). Any substance classified as hazardous under CAA is also classified as hazardous under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 USC 9601). However, CERCLA excludes DU from its requirements if the release of DU into the environment occurs in compliance with a valid Nuclear Regulatory Commission (NRC) permit, license, regulations or order. Furthermore, RCRA excludes DU in its definition of solid waste. Disposal of DU is controlled by the Low-Level Radioactive Waste Policy Act (LLRWPA) and its amendments and by NRC regulations (10 CFR 612; 10 CFR 20). In the United States, the Army must manage expended DU ammunition and vehicles contaminated with DU according to LLRWPA. This act allows states to create regional compacts for low-level radioactive waste (LLRW) disposal. The Army must dispose of LLRW at either a federal disposal facility or a state compact facility. (U.S. AEPI 1994)

"The US Nuclear Regulatory Commission (NRC) allows the Army to bury low concentrations of DU with no restrictions on burial method. Under this option DU must meet EPA standards. In addition, the waste must not expose the public to more than 1 millirad per year (0.01 mSv/y) of radiation to the lungs or 3 millirads per year (0.03 mSv/y) to the bone from inhalation and ingestion for any foreseeable use of material or property. In addition, the concentrations must be low enough that no individual will receive an external dose in excess of 10 micro-roentgen (0.1 µSv/h) above background. These standards are compatible with guidelines recommended by EPA (42 FR 60956-60959; 46 FR 2556-2563).

Alternatively, NRC allows the Army to dispose of low concentrations of DU by burying them under prescribed conditions so that no subsequent land use restrictions and no continuing NRC licensing of the material are required. The concentration of DU must be low enough that no member of the public will receive more than 1 millirad per year to the lungs, 3 millirad per year to the bone, or 10 µR/h (0.10 µSv/h) above background if they avoid excavation in the burial ground (46 FR 52061-63)". (U.S. AEPI 1994).

References

ACGIH: Threshold limiting values for chemical substances and physical agents and biological exposure indices. 1993. Technical Affairs Office ACGIH. Cincinnati. Ohio. USA. 1993.

ARDEC: (1991a): "Summation of ARDEC test data pertaining to the oxidation of depleted uranium during battlefield conditions;" U.S. Army Armament Research, Development, and Engineering Centre (ARDEC); 8 March 1991, p. 2. *Health and Environmental Consequences of Depleted Uranium use in the U.S. Army;* U.S. Army Environmental Policy Institute; June 1995, p. 78. (Cited in Fahay 1999).

ARDEC (1991b): Summation of ARDEC test data pertaining to the oxidation of depleted uranium during battlefield conditions. U.S. Army Armament Research. Development, and Engineering Center (ARDEC). 8 March 1991; p. 2. (Cited in Fahay 1999).

AEPI: Health and environmental consequences of depleted uranium use in the U.S. Army. Technical Report. U.S. Army Environmental Policy Institute, June 1995.

ATSDR: Toxicological profile for uranium, draft for public comment. Research Triangle Institute for Agency for Toxic Substances and Disease Registry. Atlanta. USA. 1997.

Bennellick E. J.: A review of the toxicology and potential hazards of natural depleted and enriched uranium. United Kingdom Atomic Energy Authority. Health and Safety Branch. Report AHSB (RP) R 58. 1966.

Bertell R.: Gulf War veterans and depleted uranium. (Cited in Laka Foundation, 1999).

Blasch E B., Stuckenbroeker G., Lusky R.: The use of uranium as a shielding material. Nuclear Engineering and Design. Vol. 13 pp. 146-182. North-Holland Publishing Company. 1970.

BPNW: Potential behavior of depleted uranium penetrators under shipping and bulk storage accident conditions. Batelle Pacific Northwest Laboratory. Richland, WA, USA. 1985.

CADU a: Campaign Against Depleted Uranium (CADU) News, Issue 1. CADU, One World Centre, 6 Mount Street, Manchester, M2 5NS, 1999.

CADU b: Campaign Against Depleted Uranium (CADU): Briefing Pack, April 1999. Published by CADU, One World Centre, 6 Mount Street, Manchester, M2 5NS, 1999.

Dockery D. W. and Pope C. A. III: Acute respiratory effects of particulate air pollution. Annual Review of Public Health, Vol. 15 (1994), pp 107-132. 1994.

Domingo J. L.: Chemical toxicity of uranium. Toxicology and ecotoxicology news, 2(3), pp. 74-78. 1995.

Domingo J. L., Llobet J. M., Thomas J. M: Acute toxicity of uranium in rats and mice. Bulletin for Environmental Contamination and Toxicology, 39, pp. 168-174. 1987.

Ebinger M. H. et al.: Long-term fate of depleted uranium at Aberdeen and Yuma Proving Grounds. Final report, Phase 1: Geochemical Transport and Modeling. Los Alamos National Laboratory, LA-11790. 1990.

EC BSS: Council Directive 96/29/EURATOM OF 13 May 1996 laying down the basic safety standards for the protection of workers and the general public against the dangers arising from ionizing radiation. Official Journal of the European Communities, No L 159, Vol. 39. 26.9.96. 1996.

Erikson R. L. et al.: A review of the environmental behavior of uranium derived from depleted uranium alloy penetrators: Pacific Northwest Laboratory, Richland, Washington. PNL-7213. 1990.

Fahay D.: Depleted uranium weapons: lessons from the 1991 Gulf War. (Cited in Laka Foundation. 1999).

Fliszar R. W. et al.: Radiological contamination from impact abrams heavy armor. Ballistics Research Laboratory Technical Report BRL-TR-3068. 1989.

Gabriel films and BBC (U.K.): Desert Storms deadly bullet. Shown November 8th in the U.S.A. 1997, (Cited in Fahay 1999).

Gunther S-H. : The Gulf War Syndrome, a parallel to Chernobyl: Documentation of the aftermath's of the Gulf War. Presented at Roundtable Conference Opinion on Depleted Uranium and Cancers in Iraq, 1 Whitehall Place, London. July 1999.

Hanson, W. C. and Miera F. R.: Continued studies of long-term ecological effects of exposure to uranium. Los Alamos Scientific Laboratory. LA-6742. Los Alamos. 1977.

IAEA: Handbook of parameter values for the prediction of radionuclide transfers in temperate environments. IAEA Technical reports series, No.364. 1994.

ICRP 1983: Radionuclide transformations. Energy an intensity of emissions. Annals of the ICRP. ICRP publication 38. Vol. 11-13. 1983. Pergamon Press. 1983.

ITN TV: Riding the Storm, U.K. Shown January 3rd, 1996 in the U.K. 1996. (Cited in Fahay 1999).

Jamal G.: Gulf War Syndrome – a model for the complexity of biological and environmental interaction with human health. Adverse Drug React. Toxicol Rev. 17 (1), pp. 1-17. 1999.

Kahn A. A.: Separation of depleted uranium fragments from gun test catchment, Vol. IV. Bench-scale tests of separating depleted uranium from sand, Vol. IV of IV. Oak Ridge National Laboratory, Tennessee. Report ORNL/TM-111.41. 1993.

Kammas M.: Committee for pollution Impact by Aggressive Bombing (CPIAB). Environmental and Health Consequences of the Use of Radiological Weapons (Depleted Uranium) on Iraq in Um-Al-Ma'arek 1991-1999. Presented at Roundtable Conference Opinion on Depleted Uranium and Cancers in Iraq. 1 Whitehall Place, London. July 1999.

Laka Foundation: Depleted uranium: A post-war disaster for environment and health. Laka Foundation. Amsterdam, The Netherlands. May 1999.

Lancet: Does Iraq's depleted uranium pose a health risk? By K. Birchard. The Lancet 351 (Feb 28), p. 657 1998.

Lin R. H. et al.: Cytogenetic toxicity of uranyl nitrate in Chinese hamster ovary cells. Mutation Research, 319, pp. 197-203. 1993.

Mao Y. et al.: Inorganic components of drinking water and microalbuminuria. Environmental Research, 71, pp. 135-140. 1995.

Maynard E. A, Down W. L., Hodge H. C.: Oral toxicity of uranium compounds, in Voegtlin C. and Hodge H. C., eds.: Pharmacology and Toxicology of Uranium Compounds. New York. McGraw-Hill. USA. 1953.

McDiarmid: Transcript of March 25. 1998 VA/DoD teleconference on the DU program. 1998. (Cited in Fahay 1999).

McDonald-Taylor C. K., Singh A., Gilman A.:Uranyl nitrate-induced proximal tubule alterations in rabbits: a quantitative analysis. Journal of toxicologic pathology. Vol. 25(4), pp 381-389. 1997.

Moss MA et al.: Uranium in drinking water - report on clinical studies in Nova Scotia. In: Brown SS, Savory J, eds. Chemical toxicology and clinical chemistry of metals. London. Academic Press, pp. 149-152. 1983.

NELLIS: Resumption of use of depleted uranium rounds at Nellis Air Force Range, Target 63-10. U.S. Army Corps of Engineers, Nebraska. Draft June 1997.

NIOSH: Pocket guide to chemical hazards. US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. 1994.

NRC: Airborne particles National Research Council. National Academy of Sciences (Baltimore, Md: University Park Press, 1979), pp. 108-110. 1979.

PNL-2944. Gilchrist, Glissmyer, J.A., Mishima J.: Characterization of Airborne Uranium from Test Firings of XM774 Ammunition. Pacific Northwest Laboratory. PNL-2944. Richland, WA, 1979.

PNL-5415. Mishima J., Parkhurst M. A., Scherpels R. L., Hadlock D. E.:Potential Behavior of Depleted Uranium Penetrators under Shipping and Bulk Storage Accident Conditions. Pacific Northwest Laboratory . PNL-5415. Richland, WA. 1985.

PNL-5928. Haggard D. L., Hooker C.D., Parkhurst M. A., Sigalla L. A., Herrington W. M., Mishima J., Scherpelz R. I., Hadlock D.E.: Hazard Classification Test If 120 mm APFSDS-T, M829 Cartridge: Metal Shipping Container. Pacific Northwest Laboratory. PNL-5928. Richland, Washington. 1986.

Puls R.: Mineral levels in animal health. Diagnostic data. Sherpa int. Clearbrook, BC, Canada. 1990.

RAND. Harley N. H., Foulkes E. C., Hilborne L. H., Hudson A., Anthony C. R.: A review of the scientific literature as it pertains to Gulf war illnesses. RAND. Washington, USA. 1999.

Rao S.S. and Bhat T.B.: Depleted uranium penetrators – hazards and safety. Defense Science Journal 47 (1), pp. 97-105. 1997.

Rapsomanikis S. et al.: A pollution episode of organic semi-volatile compounds from the war-zone of Kosovo, detected in Xanthi Greece. Environmental Engineering Department, Demokritos University of Thrace, Xanthi, Greece. http://www.duth.gr/cosovo/pollution.html. 1999.

REC, Regional Environmental Center for Central and Eastern Europe: Assessment on the environmental impact of military activities during the Yugoslavia conflict, June 1999, Report prepared for the European Commission DG-XI – Environment, Nuclear Safety and Civil Protection. REC. June 1999.

Seaton A. et al: Particulate air pollution and acute health effects. The Lancet Vol. 345 (January 21, 1995), pp. 176-178. 1995.

Special Oversight Board: Presidential Special Oversight Board for Department of Defense Investigations of Gulf War Chemical and Biological Incidents. Interim Report. August 20th 1999. 1401 Boulevard, Suite 401, Arlington, VA 22209. 1999.

U.K. Ministry of Defense: Testing for the presence of depleted uranium in U.K. veterans of the Gulf War conflict: the current situation. http://www:mod.uk/policy/gulfwar/info/dutesting.htm. 24 May 1999.

UNSCEAR, 1993: United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly, with scientific annexes. New York. United Nations 54. ISBN 92-1-142200-0. 1993.

UNSCEAR, 1999: Exposures from natural radiation sources. United Nations Scientific Committee on the Effects of Atomic Radiation. Forty-eight session of UNSCEAR Vienna, 12 to 16 April 1996. Preliminary report. Draft. 1999.

U.S. Army Pamphlet 700-XX: Handling procedures for equipment contaminated with depleted uranium or radioactive commodities. Logistics. Headquarters. Department of the Army. Washington, DC, XX XXX 199X, Unclassified instruction in preparation.

U.S. AEPI: Health and environmental consequences of depleted uranium use by the U.S. Army. Technical report, June 1995. Army Environmental Policy Institute. Champaign, Illinois. 1994.

U.S. Department of Defense: Environmental Exposure Report: Depleted Uranium in the Gulf War. Office of the Special Assistant for Gulf War Illness. U.S. Department of Defense. July 31 1998, p. 157. (Cited in Fahay 1999).

U.S. EPA: Review of RSC analysis. Report prepared by Wade Miller Associates, Inc. for the U.S. Environmental Protection Agency. 9 May 1991.

U.S. EPA: Proposed drinking water standards. U.S. Environmental Protection Agency. 1991.

Wayne C. H. et al.: Long-term Ecological Effects of Exposure to Uranium. Los Alamos Scientific Laboratory. UC-11. 1976.

VHI: Veterinary Environmental Guide. Veterinary Health Inspectorate. The Netherlands.1997.

Winchner R. P., Kahn A. A. and Holegler J. M.: Separation of depleted uranium fragments from gun test catchment, Vol. II: Catchment system and separations methods. Oak Ridge National Laboratory, Tennessee. ESL-TR-91-29. 1993.

WHO: Guidelines for drinking water Quality. 2nd edition. Addendum to Volume 2: Health criteria and other supporting information. Geneva, Switzerland. 1998.

Wrenn M. E. et al.: Metabolism of ingested U and Ra. Health Physics, 48, pp. 601-633. 1985.