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Depleted Uranium in Kosovo

Post-Conflict
Environmental
Assessment



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Depleted Uranium in Kosovo

**Post-Conflict
Environmental
Assessment**



Depleted Uranium in Kosovo

Post-Conflict Environmental Assessment

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Foreword

This report presents the findings of the first-ever international assessment of the environmental impact of depleted uranium (DU) when used in a real conflict situation. It has been carried out as part of the post-conflict assessments conducted by the United Nations Environment Programme (UNEP) in the Balkans.

The report builds on an earlier theoretical study by UNEP. In October 1999, as part of its assessment of the impact of the Kosovo conflict on the environment and human settlements, UNEP carried out a Desk Assessment study of the potential effects of the possible use of DU during the conflict. The study was limited by lack of information on the actual use of DU. In July 2000, however, the North Atlantic Treaty Organization (NATO) provided UNEP with the information required, enabling a field mission to be planned and conducted. The information included a map indicating the location of 112 separate strikes by DU ammunition, and a table showing the number of DU rounds used and the coordinates of the targeted areas.

During the field mission to Kosovo, from 5 – 19 November 2000, soil, water and other samples were collected from eleven sites where DU had reportedly been used during the conflict. Five separate laboratories then analysed these samples.

When the laboratory phase was finalised in early March, the analyses of the samples showed only low levels of radioactivity. Furthermore, the results suggested that there was no immediate cause for concern regarding toxicity. However, major scientific uncertainties persist over the long-term environmental impacts of DU, especially regarding groundwater.

Due to these scientific uncertainties, UNEP calls for precaution. There is a very clear need for action to be undertaken on the clean-up and decontamination of the polluted sites; for awareness-raising aimed at the local population; and for future monitoring.

Just as the Desk Assessment conducted in October 1999 advised precaution, the recommendations of this report have also been guided by this approach, with the objective of protecting the environment and human health.

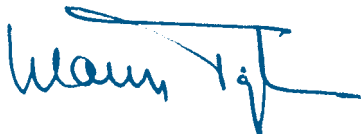
This difficult task was conducted effectively and efficiently, thanks to the close cooperation of several key partners, to whom I am very grateful. NATO provided information and excellent cooperation. The NATO Kosovo Force (KFOR) ensured the basic safety and security of mission staff, and provided other important logistical support. The United Nations Interim Administration Mission in Kosovo (UNMIK) contributed expertise to the team and assisted with field logistics. The International Atomic Energy Agency (IAEA) has been our partner in the initial desk assessment and the field mission, and has assisted with the laboratory analysis. The World Health Organization (WHO) is conducting a parallel desk assessment on the health impacts, and the together two reports should provide comprehensive information on the issues

surrounding DU. Several governments, including those of Finland, Italy and the United States, have provided in-kind contributions, and I am especially grateful to the Government of Switzerland, which has provided generous financial support for this assessment.

Above all, my gratitude is expressed to the team of dedicated experts that conducted this historic mission under the able and professional leadership of Pekka Haavisto. The team undertook demanding scientific field investigations at short notice to ensure of completion of the work before the onset of winter in Kosovo. The laboratory work was conducted at an astonishing pace so that results could be made available in record time to a public concerned about the potential risks of DU.

Throughout the exercise, special efforts have been made to ensure the objectivity and scientific credibility of the analysis, by drawing on an international team of experts and by using a range of different laboratories for the sample analysis. It is hoped that the data we have collected in the field will advance further analysis of this topic in related fields, such as the impacts of DU on human health.

UNEP now recommends, following its precautionary approach and to reduce uncertainties about the environmental impacts of DU in the longer term, that ways and means be explored for undertaking similar missions in other Balkan regions where DU was used in earlier conflicts.



Klaus Toepfer
United Nations Under-Secretary-General
Executive Director of the United Nations Environment Programme

Introduction

“Perhaps the most endangered natural resource in times of war is truth”, stated the introduction of the joint UNEP/UNCHS Balkans Task Force (BTF) report published in October 1999. For the safety of the local population and international workers in post-conflict situations it is essential to obtain truthful and correct information regarding the environmental situation and any possible connected health risks.

Depleted uranium (DU) was one the issues that confronted us during the environmental assessment work in the summer of 1999. As part of the BTF process, a special international group of experts – the ‘Depleted Uranium Desk Assessment Group’ – was established to assess the potential effects on human health and the environment arising from the possible use of DU. At the time the Group conducted its assessment, information on the use of depleted uranium during the Kosovo conflict was not available to the United Nations. The Group did, however, conduct a field mission in August 1999, during which it visited areas in and around the towns of Pristina, Klina and Pec that might have been struck by DU ordnance. The field mission did not find any evidence or indication of depleted uranium at the locations visited. In preparing precautionary recommendations, the Group concluded that it would not be meaningful to conduct further field searches for possible DU contamination without confirmation that DU had indeed been used in Kosovo and without data on the corresponding targeted areas.

Following a request made to NATO by the Secretary-General of the United Nations, Mr. Kofi Annan, in October 1999, NATO confirmed in February 2000 the use of DU during the Kosovo conflict and provided the United Nations with information consisting of a general map indicating the areas targeted and the total number of DU rounds fired. This information was not considered sufficient to justify a further field mission because of the absence of detailed site coordinates.

A request for additional information was made to NATO by the United Nations Secretary-General. In July 2000, NATO provided the United Nations with a detailed map indicating sites where DU munitions had been used. This was accompanied by a table of coordinates for each of 112 attacks during which DU ammunition had been used, together with the number of rounds used in each case, where this latter information was known.

This additional information was reviewed at a meeting convened by UNEP in Geneva in September 2000. The meeting was attended by members of the Depleted Uranium Desk Assessment Group, by representatives of NATO, as well as by the United Nations partners concerned with the issue: the International Atomic Energy Agency (IAEA), the United Nations High Commissioner for Refugees (UNHCR), the

► Map1: Sites identified as being targeted by ordnance containing DU



United Nations Interim Administration Mission in Kosovo (UNMIK), the United Nations Medical Service in Geneva, and the United Nations Department for Disarmament Affairs. The meeting recommended that UNEP, in close cooperation with relevant United Nations partner agencies and other interested parties, conduct a field study on sites in Kosovo that were struck by DU ordnance, as early as possible, preferably in autumn of that year.

A field mission was carried out from 5 – 19 November 2000, by a team composed of 14 experts from inter-governmental agencies, well-known institutions, and other interested parties. Additional cooperation was received from NATO, KFOR and UNMIK. During the mission, soil, water and other samples were collected and sent for analysis to five laboratories well reputed in matters of radiological or

toxicological analysis. The use of several laboratories allowed comparison of different methods for assessing impacts. Each laboratory was responsible for its own methodology and results.

UNEP alone, however, had responsibility for the selection of sites for sampling. UNEP chose sites that were most heavily targeted, as well as sites that were in or closest to inhabited areas. In selecting the sites, variation was also sought in the surrounding natural environment, soil types and biodiversity. Sampling in some areas was limited by the fact that the sites had not been cleared of mines and unexploded ordnance. Furthermore, the fact that the sampling was conducted one and a half years after the conflict presented a number of scientific challenges. Owing to better-than-expected weather conditions, however, eleven sites were visited rather than the initially planned number of six. Thus, sampling occurred at approximately 12% of the total number of DU-targeted sites listed by NATO, in two different KFOR sectors – the Italian sector MNB (W) and the German sector MNB (S).

► Map 2: KFOR sectors in Kosovo



Experience obtained in the field suggested that the site coordinates provided by NATO were accurate. Measurements taken during the August 1999 field mission – which had no information on the exact sites where DU had been used – did not detect any elevated levels of radiation. During the November 2000 field mission, no evidence was found of DU presence outside of the NATO-listed sites. UNEP field experience also supports the information provided by NATO on the type of DU ammunition used. There are no indications of the use of any other type of DU ammunition in Kosovo.

Nevertheless, even after one and a half years had elapsed since the conflict, the UNEP team found slightly radioactive material at many sites, including the penetrator and jacket parts of DU ammunition. On tarmac roads and areas covered with concrete that had been struck by DU ammunition, radioactivity was measurable in the immediate vicinity of the impact holes. The samples collected around the sites where DU ordnance had been used show that DU dust is also measurable near the targeted sites. Even if alarming environmental risks do not currently exist at these sites, UNEP recommends several precautionary measures – among others, marking the DU sites and decontaminating them when possible. In the areas most at risk of groundwater contamination, we recommend the monitoring of the water quality.



A penetrator found lying in the grass. Note the yellow coating on the penetrator. Planeje/Planeja.

Apart from concern over the possible impacts of DU on local populations and the field staff of international organisations, there has also been considerable concern expressed over the possible impacts of DU on military personnel. Three specific situations should be taken into account. First, the additional risks – beyond the obvious ones – of being at or very close to the site of an area under attack by DU. Clearly this circumstance could not have been investigated within the scope of the UNEP mission, some 18 months after the conflict had ended. Secondly, during the clean-up of targeted sites, loose contamination might pose a risk, thereby requiring protective measures – especially when entering partly destroyed armoured vehicles. No such vehicles were present at the sites visited by UNEP in November 2000 and it is therefore likely that military clean-up had already taken place. UNEP has no information of the removal or possible current locations of any DU-damaged vehicles from the visited sites.

The third situation concerns mine clearance at sites where DU has been used. There are significant parts of Kosovo that have yet to be de-mined and cleared of unexploded ordnance, including areas that were targeted with DU. De-mining is sometimes carried out by exploding the mines, which could lead to increased exposure to DU fragments and dust. However, there is a lack of information on the behaviour of DU (and related risks) in cases where penetrators are present in minefields being cleared by explosion.



The Turkish EOD testing a High-tech mine detector's ability to find a buried penetrator. Bellobrade/Belobrod.

The observations made at the sampling sites also provide the basis for extrapolation to other areas in Kosovo targeted by DU ordnance. Based on the findings of the report, a number of recommendations are made both for the areas where sampling occurred and for all sites in Kosovo where DU has been used.

DU is certainly not the main environmental problem in Kosovo at the present time. Nevertheless, it is an additional negative factor in the equation, and action should be taken to eliminate all possible risks to the environment. It is important that the military organisations, NATO and KFOR, continue to take part in the elimination of all DU-related risks, particularly as many of the DU sites remain a risk due to the presence of mines and other unexploded ordnance.

UNEP also recommends that ways and means be explored for undertaking similar missions in other Balkan regions where DU has been used. The first steps should be similar field studies at the few sites in Serbia and Montenegro struck by DU ordnance during the

Kosovo conflict, to ensure that the findings in Kosovo are also valid in other parts of the region. Secondly, a broad-based environmental assessment, including the issue of DU, should be carried out in Bosnia-Herzegovina, bearing in mind that a comprehensive post-conflict environmental assessment was never conducted there following the war in the 1990s.



German KFOR soldiers guarding the UNEP Mission team members.

Conducting post-conflict environmental assessment differs from ordinary environmental assessment in that the security aspect overshadows the whole work, due to unexploded ordnance and other serious security risks. I am therefore most grateful to KFOR, and especially its Multinational Brigades, West and South, for

their strong commitment to ensuring the protection of the members of the UNEP DU expert team during the mission.

UNEP wishes to acknowledge the cooperation of experts who participated in the field mission. At the conclusion of the mission, these experts, through their institutions, provided UNEP with the analyses of samples they had taken during the mission. The results of these analyses were used by UNEP as a basis to prepare the present report. However, the conclusions and recommendations reflect solely the views of UNEP.

While carrying out this exercise we have noted that there is a lack of information on the nature and effects of DU, as well as the associated risks. For this reason, I note with great pleasure that IAEA has announced that, together with relevant United Nations organisations such as WHO and UNEP, it will organise courses for scientific institutions, national and local authorities, international agencies and NGOs regarding the issue of depleted uranium.

The success of this scientific work is due to the commitment and expertise of colleagues both from the United Nations system, and from the academic world. I am most grateful for the outstanding efforts made by the DU experts from Bristol University – Department for Earth Sciences, the Finnish Radiation and Nuclear Safety Authority (STUK), the International Atomic Energy Agency (IAEA), the Italian Environmental Protection Agency (ANPA), the Swedish Radiation Protection Institute (SSI), the Swiss AC-Laboratorium Spiez, and the US Army Center for Health Promotion and Preventive Medicine (USACHPPM).

Pekka Haavisto
Chairman, UNEP Depleted Uranium Assessment Team
Geneva, 12 March 2001

Background

2.1 UNEP's role in post-conflict environmental assessment

In May 1999, the Joint UNEP/UNCHS (Habitat) 'Balkans Task Force' (BTF) was established with the aim of making an overall assessment of the consequences of the Kosovo conflict for the environment and human settlements, focusing in particular on the Federal Republic of Yugoslavia (Kosovo, Montenegro and Serbia). As part of this work, an international expert group on DU the 'Depleted Uranium Desk Assessment Group' was appointed to "assess the potential health and environmental impact of depleted uranium used in the Kosovo conflict". However, it should be noted that use of DU in Kosovo had not been officially confirmed at this time and no information was available on the locations of sites possibly targeted by DU. The work was carried out, inter alia by:

- collecting background information on the potential effects of DU on human health and/or the environment, the quantity and quality of depleted uranium used in the conflict, and the locations of affected sites;
- assessing, by means of a scenario-based desk study, the medium- and long-term potential health and environmental impacts of DU used in the Kosovo conflict;
- undertaking a fact-finding mission to Kosovo to make preparations for a possible future sampling campaign;
- analysing information in order to quantify problems 'on the ground' in potentially affected areas and to provide qualitative answers concerning the possible risks to human health and the environment.



The fact-finding mission did not encounter elevated levels of radiation, either in and around the wreckage of destroyed military vehicles, or on/alongside roads. Based on these preliminary measurements, the team concluded that there was no evidence or indication of the presence of DU at the locations visited. However, it was also stressed that any further investigations could only be meaningful if and when confirmation was received of whether DU ammunition had been used and, if so, where. This was deemed essential for making additional measurements, for verifying provisional risk assessments, and for assessing the necessity of remedial or precautionary actions. Further information is contained in the report 'The potentials effects on human health

and the environment arising from possible use of depleted uranium during the 1999 Kosovo conflict. A preliminary assessment' (UNEP, 1999).

In July 2000, following approaches from the United Nations Secretary-General, NATO made available a detailed list of sites where DU had been used. UNEP then moved quickly to assemble a team of international experts to prepare a scientific mission to Kosovo. The mission itself took place from 5 – 19 November 2000.

2.2 Depleted uranium

What is depleted uranium?

Depleted uranium (DU) is a by-product of the process used to enrich natural uranium ore for use in nuclear reactors and in nuclear weapons. It is distinguished from natural uranium by differing concentrations of certain uranium isotopes. Natural uranium has a uranium-235 (abbreviated as U-235 or ^{235}U) content of 0.7%, whereas the content of U-235 in DU is depleted to about one-third of its original content (0.2 – 0.3%).



One penetrator (right) and two penetrators still fixed in their jackets. The left penetrator has partly moved from its position in the jacket. The length of the penetrator is 95 mm.

Like natural uranium, DU is an unstable, radioactive, heavy metal that emits ionizing alpha, beta and gamma radiation. Because of its radioactivity the amount of uranium in a given sample decreases continuously but the so-called half life (the period required for the amount of uranium to be reduced by 50%) is very long – 4.5 billion years in the case of the isotope uranium-238 (U-238 or ^{238}U). In practice, therefore, the level of radioactivity (which is measured in units per second known as ‘becquerels’ – Bq) does not change significantly over human lifetimes.

The UNEP studies in Kosovo showed that the material in the DU penetrators found there also contained traces of transuranic isotopes such as uranium-236 and plutonium-239/240 which are created during nuclear reactions. This indicates that at least part of the material in the penetrators had originated from the reprocessing of nuclear fuel. However, the amounts of these isotopes were very low and not significant in terms of the overall radioactivity of penetrators.

The applications of DU and its use during the Kosovo conflict

DU has been used for civil and military purposes for many years. The civil applications include use in radiation shielding and aircraft ballast. Because of its high density (19.0 g/cm³) and resistance, DU also has major military applications, particularly in defensive armouring for tanks and other vehicles. However, the properties of DU also make it ideal for offensive use in armour-piercing munitions. Both tanks and aircraft can fire depleted uranium munitions, with tanks firing larger calibre rounds (100 and 120 mm) and aircraft smaller calibre rounds (25 and 30 mm). During the Kosovo conflict, DU weapons were fired from NATO aircraft, and it has been reported that over 30,000 rounds of DU were used (UNEP, 2000).

Characteristics and behaviour of DU anti-armour rounds fired by A-10 aircraft

The type of DU round fired by NATO A-10 aircraft has a length of 173 mm and a diameter of 30 mm. Inside the round is a conical DU 'penetrator', 95 mm in length and with a diameter at the base of 16 mm. The weight of one penetrator is approximately 300 g. The penetrator is fixed in an aluminium 'jacket' (or 'casing') 60 mm long and 30 mm in width. When the penetrator hits an armoured vehicle, the penetrator continues through the armouring, but the jacket usually remains outside. The A-10 aircraft is equipped with one gatling gun capable of firing 3,900 rounds per minute. A typical burst of fire occurs for two to three seconds and involves 120 to 195 rounds. These hit the ground in a straight line, one to three metres apart, depending on the angle of the approach, and cover an area of about 500 m². The number of penetrators hitting a target varies with the type of target, but does not normally exceed 10% of the rounds fired (CHPPM, 2000).

Penetrators that hit either non-armoured targets, or miss targets, will generally remain intact, passing through the target and/or becoming buried in the ground. The depth depends on the angle of the round, the speed of the plane, the type of target and the nature of the ground surface. In clay soils, penetrators used by the A-10 attack aircraft may reach more than two metres depth. Conversely, penetrators hitting hard objects such as rocks and stones may ricochet and be found lying on the surface some distance from the targeted area.



Normally 10-35% (maximum of 70%) of the round becomes aerosol on impact with armour and the DU dust catches fire (Rand, 1999). Most of the dust particles are $< 5 \mu\text{m}$ in size, and spread according to wind direction. DU dust is black and a target that has been hit by DU ammunition can be recognised by the black dust cover in and around the target (U.S. AEPI, 1994). The DU dust formed during the penetration of armoured vehicles can be dispersed into the environment, contaminating the air and the ground. However, such contamination should be limited to within about 100 metres of the target (CHPPM, 2000). It is important to note that hits on non-armoured ('soft') targets do not generate significant contamination because the DU penetrators do not generate significant amounts of aerosols on impact.

Small penetrator fragments and DU dust are gradually transported into the upper soil layer by water, insects and worms. Wind, rainwater, or surface water flow may also redistribute the dust. Due to the varying chemical properties of different soils and rocks, the effects of buried penetrators on the environment will also vary. The mobilisation of DU in the soil profile and its possible contamination of groundwater will depend on a range of factors such as the chemistry and structure of the surrounding soil, rainfall and hydrology.

2.3 Assessing the risks

The concept of risk, its meaning and application are discussed in detail in Appendix I. The following is a summary, intended to equip readers with the necessary background for interpreting the findings, conclusions and recommendations presented in sections 4, 5 and 6 of this report.

‘Risk’ can either refer to the probability of occurrence of an event, or to the consequences of an event if it occurs. A third possibility is a combination of probability and consequence.

Irrespective of how the term is used, it is clear that scientific quantification of a given risk has to be expressed clearly and concisely, so that appropriate judgements and responses can be made.

The effects of being exposed to DU are both radiological (i.e. due to radiation) and chemical (i.e. as a result of biochemical effects in the human body). Corresponding health consequences may, depending upon the dose or intake, include cancer and malfunction of body organs, particularly the kidneys.

In order to avoid such consequences arising from day-to-day procedures in which radioactive and toxic materials are used, a range of applicable standards has been established. These include limits for exposure to radiation and toxic materials.

However, the existence of such limits and standards does not mean that at any point above these values there will automatically be severe adverse consequences such as serious illness. There are still wide safety margins built in before an unconditionally unacceptable threshold is reached.

One possible way of judging the consequences of events or circumstances where exposure to DU may have occurred is to compare findings, measurements or assessments with natural levels, and with given ‘safety’ limits or standards.

In this report the consequences are those that might be caused by intake of DU by ingestion or inhalation and by external exposure to radiation from DU.

The consequences of radiation may be expressed directly in terms of the radiation dose, which is measured in millisieverts (mSv) or microsieverts (μ Sv). Comparisons can be made with natural levels and with established limits and action levels.

With regard to chemical toxicity, the consequences are expressed in concentration or total intake and compared with given health standards.

In this way it should be possible to express the risk (consequence) as ‘insignificant’ or ‘significant’ bearing in mind the basis for the comparisons drawn. In this report, the consequences of radiation are considered insignificant for doses less than 1 mSv per year (or per infrequent event) and significant for doses higher than 1 mSv. In relation to chemical toxicity, consequences are treated as insignificant for concentrations or total intakes below applicable health standards, and significant for those above health standards.

In the discussions of site-by-site findings in section 7, judgements of risk are made on the basis of DU ground contamination measured. The relation between measurement results and risks are discussed in Appendix I. There is also a summary of risk assessments in relation to a given situation (known as the *Reference Case* and taken from the report of the 1999 UNEP DU Desk Assessment). This assumes ground surface contamination of 10 g DU/m². Some means of exposure lead to significant risks (consequences), others to insignificant risks. If the ground contamination is less than 0.1 – 1 g/m² the consequences are normally all insignificant.

In the present report, the risks considered and assessed – in terms of significance or insignificance of consequences for the environment and human health – are the following:

- If there is widespread measurable contamination of the ground surface by DU, there is a risk that some DU will become airborne through wind action and be subsequently inhaled by people. There is also a risk of contamination of food (fruit, vegetables, meat etc.) and drinking water.
- If there are localised points of concentrated contamination (referred to in this report as ‘contamination points’), there is a risk of contamination of hands and/or of direct ingestion of contaminated soil. There is also a risk of possible airborne contamination and contamination of drinking water.
- Solid pieces of DU lying on the ground surface – either complete penetrators, or fragments of them – can be picked up by someone completely unaware that they are handling uranium. Consequently, there is a risk of being exposed to external beta radiation and to internal radiation (i.e. from inside the body) if dust or fragments of DU enter the body.
- A large percentage of DU rounds that either hit soft targets, or missed the target completely, will have penetrated into the ground where they will corrode (to a widely varying degree, depending on site-specific environmental conditions) over time. As a result, there is a risk of future contamination of ground-water and nearby wells used to supply drinking water. There is also a risk that fragments of DU will be brought up to the surface during reconstruction of houses, roads etc.

UNEP mission to Kosovo

3.1 Mission objectives

Because one and a half years had elapsed since the Kosovo conflict, the overall aim of the UNEP mission was to examine the possible risks from any remaining DU contamination of ground, water and biota and from solid pieces of DU (i.e. intact or fragmented penetrators) still in the environment.

The key questions facing the mission were:

- What are the present levels of DU contamination in Kosovo?
- What are the corresponding radiological and chemical risks, both now and in the future?
- Is there any need for remedial measures or restrictions?
- If so, which measures are reasonable and realistic?

The operational objectives and scope of the mission were directed at answering these questions, bearing in mind the conclusions and recommendations of the October 1999 UNEP DU Desk Assessment, the possible constraints on the mission, and the need to conduct the mission in a way that was as scientifically sound as possible. These conditions and prerequisites are further developed in Appendix II.

The operational objectives and scope of the mission were as follows:

- To confirm the presence of DU at given locations;
- To determine how widespread was any contamination of soil, water, etc. at the sites visited;
- To determine the distribution of solid pieces of DU (penetrators, jackets, fragments) in the environment and associated localised points of concentrated contamination (or 'contamination points') at the sites visited;
- To judge the degree of dispersion on and below the ground surface and any possible contamination of groundwater at the sites visited;
- To assess the corresponding risks from DU;

- To judge the necessity of taking remedial actions;
- To gain experience with regard to the possibilities and limitations that need to be taken into account when planning and executing similar missions in the future;
- To draw conclusions and to recommend possible follow-up activities;
- To inform concerned parties.

3.2 Composition of the team

The team consisted of 14 experts representing their own competence and capacity but coming from two international organisations: UNEP and the International Atomic Energy Agency (IAEA); one military organisation: the United States Army Center for Health Promotion and Preventive Medicine (USACHPPM); and four national laboratories/authorities: AC-Laboratorium Spiez in Switzerland, National Environmental Protection Agency (ANPA) in Italy, University of Bristol – Department of Earth Sciences in the United Kingdom, and Swedish Radiation Protection Institute (SSI) in Sweden.



The Mission Team gathered outside our barracks in German camp at Prizeren.

The composition of the team was determined mainly by the need for a diversity of technical experience and competence in order to ensure a suitably qualified, scientific and wide-ranging examination of the DU problem. It was also necessary to

have members with appropriate positions of seniority for conducting negotiations with the military and administrative authorities during the mission.

For that purpose the team comprised the following functions and expertise:

- team leader
- scientific leader
- technical leader
- experts in the fields of
 - health and environmental effects of depleted uranium
 - radiation protection
 - equipment
 - measurement
 - sampling
 - laboratory work
 - military advice
 - safety and security
 - logistics
 - reporting
 - public relations

In practice, one person was often able to cover several functions and areas of expertise, so that a number of areas were dealt with by two or more experts.

3.3 Selection of sites

The final choice of which general areas should be investigated was made by UNEP, based mainly on information received from KFOR, together with the previously supplied NATO list of locations where DU had been used. Within each chosen study area, a more detailed selection of specific sites suitable for investigation was made in situ, based mainly on instructions from KFOR about the presence of mines and unexploded cluster bombs.

The criteria for selection of sites were that:

- use of DU in the area had been confirmed by NATO;
- the approximate number of DU rounds fired was known;
- DU penetrators and/or jackets had been found by KFOR;
- the sites taken together represented a range of environmental conditions and properties;
- the areas to be examined were safe from mines and unexploded ordnance.

► Map 3: UNEP Assessment Mission to Kosovo Visited Sites



The following 11 sites were visited during the mission (place names are given in Albanian and Serbian versions):

Site name	NATO reference number*	Site name	NATO reference number*
• Gjakove/Djakovica	28	• Rikavac	69
• Vranoc/Vranovac	100, 103	• Ceja	83
• Radonij/Radonjic	98	• Planeje/Planeja	60
• Irznici/Rznici	97	• Bellobrade/Belobrod	30, 35
• Pozhare/Pozar	88	• Kuke/Kukovce	64
		• Buzesh/Buzec	37

*The NATO reference numbers correspond to the list of DU-targeted sites provided to UNEP by NATO (see Appendix VIII for complete list).

3.4 Fieldwork, sampling and laboratory analysis

The mission used three complementary technical methods in conducting its investigations:

- field measurements of beta radiation;
- field measurements of gamma radiation;
- field sampling with subsequent laboratory analysis.



Checking a “contamination point” by measurements of gamma radiation with the Saphymo-SRAT S.P.P. 2 NFscintillometer (left) and the beta radiation by the Berthold Contamination Monitor LB 122 (right).

uranium isotope (U-238 etc.) per kilogram of sample (abbreviated as ‘mg U/kg sample’), with DU expressed as a percentage of total uranium concentration; or in terms of activity, Bq/kg.

The surveys of radiation in the environment were made using beta and gamma instruments held close to the ground, with the team members often employing the ‘line-up survey’ technique described in Appendix III. This involved team members walking several abreast at fixed distances from each other and sometimes along parallel transect lines. As a complement to these formal searches for DU, individual measurements were made. Although carried out in a more random way than the ‘line-up surveys’, likely search areas were selected by observing the assumed direction of attack and looking for signs of ammunition impacts. These individual surveys were often very effective. The results of field measurements of radioactivity are given as ‘counts per second’ – abbreviated as ‘cps’.

The results of laboratory samples (of soil, water, milk etc.) are given either in terms of weight, i.e. milligrams of



Taking notes on measurements and samples.

Each measurement taken was governed by uncertainties that had to be estimated. Besides the usual statistical uncertainties there are possible systematic errors in the field measurements caused by absorption of the radiation, and in laboratory work by varying technical conditions. In order to overcome differences between various laboratories inter-laboratory comparisons were made using IAEA standards. The results of these quality tests are presented in Appendix III.

Specific components of the measurement and sampling campaign included:

- field measurements using beta or gamma instruments held close to the ground to search for possible widespread contamination by DU and localised points of concentrated contamination ('contamination points');
- field measurements using a gamma instrument held close to the ground to find DU penetrators and jackets lying on or close to the surface;



"Line-up survey" at Rikavac.



Collecting soil samples at Ceja mountain.

- sampling of soil from around and beneath penetrators and contamination points, in order to study the migration of DU in soil;
- sampling of soil from the wider environment to search for possible widespread DU contamination (complement to the field measurements);

- sampling of water to search for possible DU contamination of water supplies;
- sampling of milk to identify possible DU contamination of food;
- sampling of biota (e.g. grass, roots, moss, bark and lichen) in order to check for the possible presence of DU as evidence of earlier or ongoing contamination.



Water sampling.

The number of samples taken in each site, the number of penetrators and jackets found, and the approximate number of DU rounds fired against the respective site are given in Table 1. The results of all the laboratory analyses are given in detail in Appendix X which also gives the geographical (UTM) coordinates of the locality where the respective sample was taken. The sampling sites can be found on the maps in section 7. The analytical methods used are described in Appendix III.

Table 3.1 Soil profile measurements around and below DU penetrator, Gjakove/Djakovica garrison

Site name	Soil	Water	Botanical	Milk	Smear test	Contamination points found	Penetrators found	Jackets found fired	DU round
Gjakove/Djakovica	71	2	2		7	30	1+1/2	0	300
Vranoc/Vranovac	11	12	2			0	0	0	2,320
Radoniq/Radonjic	68	2	1		2	9	1	1	655
Irznig/Rznic	40	8	11	1		5	0	0	532
Pozhare/Pozar	1	12	3	1		0	0	0	945
Rikavac	16	3	0			2	0	0	400
Ceja	24	0	14		4	1	2	4	290
Planeje/Planeja	9	3	2	1		1	2	1	970
Bellobrade/Belobrod	7	3	1			0	0	0	1,000
Kuke/Kukovce	2	0	1			0	1	0	500
Buzesh/Buzec	0	1	0			0	0	0	200
Totals	249	46	37	3	13	48	7+1/2	6	8,112

Notes on Table 3.1: the columns of figures represent the number of samples in each category from each site. The number of contamination points located, the numbers of penetrators and jackets found, and the approximate number of DU rounds fired against the site, are also shown.

'Contamination points' are those very localised areas, often holes in the road, which were identified as being DU-contaminated, but at which no penetrator or jacket was found. In addition, the soil underneath any penetrators and jackets located was most often shown to be contaminated. All penetrators and jackets were removed from the sites.

Findings

The findings at the 11 sites are summarised below, with the corresponding overall conclusions presented in section 5. The assessments of risk (where applicable) are based on the approach outlined in section 2.3 above and discussed in more detail in Appendix I.

(a) Widespread contamination

If a great number of penetrators hit hard targets and become aerosols on impact, there is a risk of people inhaling airborne DU dust if they are close to the target at the time of attack. As the aerosols disperse and fall out there will be a contamination of the ground that might be localised or widespread, depending on the properties of the aerosols and the meteorological conditions.

The UNEP team could not find significant contamination of the ground surface or the soil except at localised points of concentrated contamination ('contamination points' see (b) below) close to penetrator impact sites or penetrator holes. The level of DU detected decreased rapidly from contamination points, with the maximum distance at which contamination was still measurable being 10 – 50 m.

Non-measurable contamination of the ground means that any widespread DU contamination at the investigated areas is so small that it is not discernible from the natural uranium concentrations of the soil.

Assessment of risk

The corresponding radiological and chemical risks from all points of view are consequently insignificant.

(b) Localised points of concentrated contamination

At many of the investigated sites there were clear marks and/or holes caused by projectile impacts in asphalt roads and in concrete slabs or walls. The holes were sometimes contaminated with DU indicating that a penetrator had hit the surface and entered the ground or disappeared as a ricochet far away in the surrounding environment. Sometimes the holes were partly filled with sand or gravel, with the major part of the radioactivity attached to this material. Exceptionally, small fragments of a penetrator were found. When a penetrator (or jacket) was found on the surface of the ground, the soil below the penetrator was normally contaminated.



Sampling of a penetrator impact at Djakovica/Djakovica garrison.

The areal extent of contamination points was normally small, i.e. less than 20 x 20 cm. The relative concentration of DU at such a point could be high, up to 100% of the uranium content of a soil sample. The absolute concentration of DU in soil varied from a few mg DU/kg soil, up to about 18 g DU/kg soil. The major part of DU is U-238 and therefore this high concentration of DU meant U-238 showed concentrations about 10,000 times higher than normal. However, the total amount of DU is small and varies – depending on the amount of contaminated soil – from less than 1 mg DU up to 10 g DU. This last value corresponds to 4% of the weight of a penetrator.

The depth of contaminated soil below contamination points in the ground or on the road was normally in the range of 10 – 20 cm with declining activity concentration relative to increasing depth. This vertical distribution probably resulted from dissolution and dispersion of DU from the initial superficial contamination (or from the penetrator lying on the surface). For further information see point (c) below.

Assessment of risk

One risk related to contamination points is the possibility of some contaminated soil becoming airborne through wind action and being inhaled by people. Another risk could be that the DU from the contamination points eventually contaminates ground water and plants through leakage. However, in both these cases, the amount of DU at the contamination points is too low to cause any radiological and chemical problems at present or in the future. The corresponding risks are insignificant.

The only risk of any significance related to contamination points would be from the possibility that someone came into direct physical contact with the contamination point and thereby contaminated their hands or directly ingested contaminated sand/soil. However, even if gram quantities of soil are ingested, the resulting exposure is insignificant with regard to the radiation from ingested uranium ($<10 \mu\text{Sv}$). On the other hand, such exposure might be significant from the heavy metal toxicity point of view, meaning that the intake of uranium could be higher than health standards.

(c) Dispersion in ground

Several investigations were made on the vertical distribution of DU contamination in the ground caused by an initial superficial ground contamination or a penetrator lying on the surface. The major part of the contamination was normally found in the upper 10 – 20 cm. The most reasonable explanation is that this is an effect of vertical dispersion during the one and a half years that had elapsed since the military conflict in 1999. It is therefore also an indication of the corresponding behaviour of any initially widespread contamination which is no longer detectable. However, any widespread contamination must have been small (and insignificant from a health point of view), i.e. less than 0.1 g DU/m^2 , otherwise it would have been detected during the mission.



Line-up survey at the Rikavac site.

There are reasons to believe that the chemical and physical properties of DU make it more liable to dispersion in soil than is the case for natural uranium. The issue of DU dispersion into the ground is also of particular relevance in judging the risk of future contamination of groundwater and, ultimately, drinking water supplies. More detailed discussion of this point is contained in Appendix V. The possible consequences for groundwater arising from DU at contamination points or slightly more widespread ground contamination are insignificant, as indicated above. However, for penetrators left in or on the ground, there may be a risk, see (d) below.

(d) Penetrators

As outlined in section 2.2 above, and discussed in more detail in Appendix VII, the fate of a DU penetrator when fired is governed by a wide range of variable factors (e.g. type of target, resistance of surface substrate). Consequently, there are several possible explanations of why penetrators were found at some sites but not at others. Altogether, 7.5 penetrators were found during the mission, representing five of the 11 sites investigated. In six locations no penetrators were found although, according to NATO data, two of these locations had been attacked by the highest number of rounds used at any of the sites visited. In most cases, the penetrators were located either on the surface, or superficially covered by leaves and grass. They had been only slightly affected mechanically and were found on both rocky and soft, soil-covered ground.

Because of the security risks it was only possible to investigate in detail a small part of the sites visited by the mission. Consequently, it is likely that there are still unfound penetrators lying on the surface in other parts of the sites, as well as in other locations on the NATO list of DU targets.

The soil below the penetrators was contaminated by DU, as described under point (b) above.

On visual inspection, it appeared that the surface of penetrators was susceptible to oxidation. From smear tests on some of the penetrators, it was concluded that a part of the radioactivity is easily removed from the oxidised surface. However, the amount is very low, about $10^{-3}\%$ of the mass of the penetrator, i.e. a few mg. Even though the amount may be small, it illustrates one possible pathway for internal exposure by ingestion from contaminated hands.

Penetrators were also analysed with regard to their content of plutonium (Pu) and uranium-236 (U-236), see Appendix VII. It appears that in some cases the activity was too low to be measurable. In other cases, however, traces of the plutonium isotopes Pu-239 (and some Pu-240 which can not be separated from Pu-239 in the measurements) were found in four different penetrators. The amount of plutonium in the penetrators varied from less than 0.8 to 12.87 Bq/kg penetrator. U-236 was also

found in penetrators as well as in some of the soil samples, see section 7 of this report (site-by-site findings). The concentration of U-236 in DU is 0.003% of the U-238 concentration in terms of weight and 0.5% in terms of activity.

The presence of these radioactive elements in the DU indicates that at least some of the depleted uranium had come from material reprocessed from spent nuclear fuel or from the contamination of equipment in the processing plant during the reprocessing of spent nuclear fuel. However, the amount of plutonium and U-236 found in the DU penetrators was very low and did not have any significant impact on their overall radioactivity or the health risk.

Assessment of risk

Penetrators on the surface of the ground can be picked up by people. One possible consequence is contamination of the hands. As shown by the smear tests the amount of DU that will be removed is a few mg DU; 5 mg DU has been measured. Only a small part of that is expected to pass into the body and will give a very small radiation dose (of the order of 1 μ Sv). The possible intake is also small in terms of chemical toxicity health standards, at least in relation to annual tolerable intakes.

Another possible consequence is the external beta radiation on the skin if a person put the penetrator in his or her pocket or used it as an ornament on a neck chain. This could mean a continuous exposure of skin, leading to quite high local radiation doses (in excess of radiation safety guidelines) after some weeks of continuous exposure, even though there will not be any skin burns from radiation. The resulting gamma radiation exposure will be insignificant and, at most, of the same order of magnitude as natural radiation.

Penetrators on the surface and particularly those in the ground may dissolve in time and slowly contaminate the groundwater and the drinking water (see further discussion in Appendix V). As discussed in point (g) below, drinking water has a natural content of uranium. The normal natural concentration of uranium and the annual intake of natural uranium by water in the visited areas is low, 10^{-5} – 10^{-3} mg U/l water and 0.01 – 1 mg uranium/year, respectively, leading to radiation doses of less than 1 μ Sv/year.

When the number of penetrators shot against an area is of the order of 1,000 it means a substantial additional amount of uranium. The relative contribution depends on the size of the affected area. Assuming 1,000 m² only and that the water table is at 3 m depth and the natural uranium concentration is 1 mg uranium/kg soil, 1,000 penetrators in the ground would increase the uranium content by a factor 100. Nevertheless, the radiation doses will be very low but the resulting uranium concentration might exceed WHO health standards for drinking water.

However, this very much depends on local circumstances and the chemical and physical properties of the DU penetrators, soil and groundwater. There are too many uncertainties to predict the fate of the penetrators and even more uncertainties in predicting any possible water contamination in the future.

Penetrators currently hidden in the ground may be dug up during construction works in the future. Were this to occur there would be corresponding risks of external exposure from beta radiation and the risk of contamination of hands would occur as described above.

There are no risks of any significant increased uptake of DU in plants at present or in the future as a consequence of penetrators remaining in the environment, (compare point (b) above).

There is no risk of inhalation of possibly contaminated dust from penetrators; compare point (b) above.

The measured concentration of plutonium in DU was 12.87 Bq/kg DU at the most. This has to be compared with the activity of U-238 in DU which is 12,400,000 Bq/kg DU i.e. 1,000,000 times more. The radiation dose per Bq of Pu is much higher than per Bq of DU, particularly with regard to doses caused by inhalation, by a factor of 100 to 240, depending on the properties of the inhaled particles and the age of the person. By combining the relative activity and the dose factor, it is concluded that the Pu contained in the investigated penetrators is at least 5,000 times less hazardous than the DU itself.

Analysis of uranium-236 in the penetrators showed a concentration of 0.0028% of the total uranium. The content of U-236 in the penetrators is so small that the radiotoxicity is unchanged compared to DU without U-236.



(e) Jackets

A jacket is the part of the projectile that holds the penetrator. It stops at impact on a hard surface while the penetrator enters the target. All together, six jackets were found. The small number of jackets found is another indication that most of the penetrators missed hard targets and pene-

The jacket remained in the hole and the penetrator continued into the soil beneath the asphalt layer.

trated the ground with the jacket attached. The soil underneath a jacket was contaminated – as in the case of penetrators – to a depth of 15 – 20 cm, with the contamination levels being up to the same level as for penetrators.

Assessment of risk

The potential risks from jackets are much lower than those from penetrators because they are not made of DU and are only slightly contaminated with depleted uranium.

(f) Contamination of vehicles, houses etc.

No contamination of houses, vehicles or other objects was found.

Table 4.1 Total uranium concentration in water samples from Kosovo

Location	UNEP Code	ANPA [mg/kg]	BU [mg/kg]*	SSI [mg/kg]
Djakovica public water	124, 326		6.20E-04	5.99E-04
Radonjic lake water	045, 133	5.49E-04	6.00E-04	
Vranovac pond	128, 327		7.79E-05	2.38E-04
Vranovac farm 1 well	129, 328		2.15E-03	1.63E-03
Vranovac farm 2 well	035, 130, 336	1.62E-03	1.64E-03	1.60E-03
Vranovac next to school well	036, 131, 337	3.15E-04	3.24E-04	3.06E-04
Vranovac spring at farm 1	132, 335		8.28E-04	7.50E-04
Rznic farm 1 well	049, 126	4.38E-05	ND	
Rznic school well	050, 127, 329	4.52E-05	ND	2.52E-05
Rznic channel water	080, 125, 330	4.40E-04	4.70E-04	4.13E-04
Bandera farm 1 well	061, 134, 331	5.27E-05	ND	3.86E-05
Bandera farm 2 well	062, 135, 332	4.16E-05	ND	1.63E-05
Bandera farm 3 well	063, 136, 333	1.94E-04	1.30E-04	1.51E-04
Bandera river water	064, 137, 334	7.31E-05	4.17E-05	7.67E-05
Planeja well	077, 139, 338	2.17E-04	2.17E-04	2.67E-04
Belobrod/Opoja Co-op well	079, 140, 339	2.36E-05	ND	6.50E-06
Rikavac stream water	080, 138, 340	4.01E-04	3.56E-04	4.18E-04
Buzec co-op water	141		9.65E-05	

*The BU samples were filtered through 0.2 micron filters on site and acidified with nitric acid.

ND = Not Detected, below the detection limit.

Notes: Results of analyses on samples collected by ANPA, Bristol University and SSI Team Members. At each site one to three samples were collected from the same well or surface water body.

Information on which laboratory provided a particular result is contained in Appendices III and X.



Collecting a water sample from a well in Pozhare/Pozar village.

(g) Contamination of water

In all, 46 water samples were taken and analysed in laboratories. They were taken from 10 of the 11 sites, see table 3.1 above. All the water measurements are summarised in table 4.1 (see above).

The uranium concentration varies from $6.5 \cdot 10^{-6}$ to $2.15 \cdot 10^{-3}$ mg U/kg water. There are no signs of DU in water. As can be seen from table 4.1 the results of the various laboratories agree very well.

(h) Contamination of botanical material

At several sites, samples were taken of botanical material such as grass, roots, moss, bark and lichen, in order to search for possible DU uptake and to identify whether some types of botanical material could serve as good indicators of earlier or continuing airborne contamination. Because of difficulties in avoiding cross-contamination of uranium in soil, the results are not conclusive except with regard to lichen (and possibly bark), which appears to be an indicator of airborne DU contamination (see Appendix VI). This is not a new scientific finding. Lichen is known, for instance from studies on fallout of the atomic bomb tests in early 1960s, to be a good indicator of airborne contamination.

While many of the mission's observations suggested that very few penetrators had been aerosolised and mostly passed into the ground, additional research into bioindicators might provide additional data allowing more definite conclusions to be drawn on events immediately following a DU strike.



Milking a cow that was grazing in the target area at Irzniq/Rznic barracks.



Checking for contamination after finishing work.
Gjakove/Djakovica garrison.

(i) Milk

Milk samples were taken from three sites and from cows that grazed in potentially contaminated fields. None showed any DU contamination.

(j) Contamination checks on UNEP team members

After every visit to a site and before breaks for lunch in the field, all team members were measured for possible contamination by DU on the soles of their footwear, on gloves and on clothes. No contamination was found at any time.

Conclusions

Introductory notes:

(a) The conclusions and observations in this section refer to the UNEP mission to Kosovo from 5 – 19 November 2000, and to the 11 sites that were visited and investigated at that time. Because of the risks posed by mines and unexploded ordnance, the investigated sites were limited in extent when compared with the total area potentially affected by the use of DU in Kosovo. Nevertheless, the results from the 11 sites studied are at least indicative for other affected areas. The mission made a number of important new findings and acquired a variety of experience that will be of value in planning and implementing further work.

(b) A ‘significant’ radiological risk is one where the expected radiation dose would be > 1 mSv per event, or per year. A ‘significant’ toxicological risk means that the expected concentration or intake would exceed WHO health standards. ‘Insignificant’ radiological or toxicological risks are those where the corresponding dose or concentrations/intakes are < 1 mSv, or below WHO health standards, respectively.

(c) Based on the findings discussed above in section 4 (and on a site-by-site basis in section 7), the overall conclusions of the UNEP mission are as follows:

1. There was no detectable, widespread contamination of the ground surface by depleted uranium. This means that any widespread contamination is present in such low levels that it cannot be detected or differentiated from the natural uranium concentration found in rocks and soil. The corresponding radiological and toxicological risks are insignificant and even non-existent.
2. Detectable ground surface contamination by DU is limited to areas within a few metres of penetrators and localised points of concentrated contamination (‘contamination points’) caused by penetrator impacts. A number of contamination points were identified by the mission but most of these were found to be only slightly contaminated. The majority of the radioactivity was attached to the surrounding asphalt, concrete or soil, with some attached to the loose sand present in some penetrator holes. In many cases, the radioactivity was so low that it was hardly detectable.
3. There is no significant risk related to these contamination points in terms of possible contamination of air, water or plants. The only risk of any significance would be that someone touched the contamination point, thereby contaminating their hands (with a risk of subsequent transfer to the mouth), or directly ingested the contaminated soil. However, with reasonable assumptions on intake of soil, the

corresponding radiological risk would be insignificant, while from a toxicological point of view, the possible intake might be somewhat higher than the applicable health standards.

4. No DU-contaminated water, milk, objects, or buildings were found.
5. Seven and a half penetrators and six jackets were found during the two-week mission. The fact that no more were found, despite intensive searching, may imply that:
 - other penetrators are not on the surface but buried in the ground;
 - they are spread over a larger area than assumed;
 - they have already been picked up, for instance during military site clean-up or mine clearance.
6. There are probably still penetrators lying on the ground surface. If picked up they could contaminate hands. However, the probable intake into the body is small and both the radiological and toxicological risks are likely to be insignificant.
7. If a penetrator is put into the pocket or elsewhere close to the human body, there will be external beta radiation of the skin. That can lead to local radiation doses above safety standards after some weeks of continuous exposure. Even so, it is unlikely that there will be any adverse health effects from such an exposure.
8. Penetrators oxidise and the outermost layer of the surface of the penetrator can then be removed easily and thereby contaminate its surroundings. Some DU has dispersed into the ground beneath penetrators and jackets lying on the surface and is measurable to a depth of 10 – 20 cm.
9. It is probable that many penetrators and jackets are hidden at some metres depth in the ground. These penetrators and jackets as well as those on the ground surface, constitute a risk of future DU contamination of groundwater and drinking water. Heavy firing of DU in one area could increase the potential source of uranium contamination of groundwater by a factor of 10 to 100. While the radiation doses will be very low, the resulting uranium concentration might exceed WHO health standards for drinking water.
10. However, there are too many uncertainties to predict the future levels of groundwater contamination with any reliability. To reduce these uncertainties, it would be valuable to undertake a mission to areas where DU was used at an earlier time than in Kosovo, e.g. Bosnia-Herzegovina where buried or surface DU ordnance has persisted in the environment for 5 – 6 years.
11. Hidden penetrators and jackets may be dug up to the ground surface in the

future. The corresponding risks are then the same as for penetrators and jackets now lying on the surface.

12. The uranium isotope U-236 and the plutonium isotopes Pu-239/240 were present in the depleted uranium of those penetrators analysed in very small concentrations and do not pose a significant risk.
13. There are signs that some plant material, such as lichen, and possibly bark, may be good environmental indicators of DU. The preliminary results should be verified by additional analysis.
14. The sites visited by the UNEP mission represent some 12% of all sites attacked using DU ammunition during the Kosovo conflict. Based on the mission's findings, it is possible to make certain extrapolations for other DU-affected sites in Kosovo, but also for sites in Serbia (about 10% of sites targeted with DU) and Montenegro (amounting to approximately 2% of sites targeted with DU), where there are similar circumstances and environmental conditions, and which had been targeted by DU ammunition during the same conflict. However, further work would be needed to confirm the validity of such extrapolations.

Recommendations

These recommendations are valid for all sites in Kosovo where depleted uranium (DU) has been used. Similar precautionary action is also recommended to the authorities responsible for sites in Serbia and Montenegro that were also targeted with DU ammunition in spring 1999.

1. At all sites in Kosovo where DU has been used, the appropriate authorities should undertake visits with suitable measuring equipment to search for possible widespread ground contamination, the presence of penetrators and jackets on the ground and contamination points, as well as to assess the feasibility of clean-up and decontamination. NATO and KFOR should be fully involved in these tasks owing to the security risks posed by mines and unexploded ordnance.
2. The appropriate authorities should undertake the marking of all DU-affected sites, where and when appropriate, until the site is cleared from solid DU (penetrators and jackets) and loose contamination at contamination points.
3. At all sites, penetrators and jackets should be collected and disposed of safely, as determined by the responsible authorities.
4. Contamination points should be decontaminated where feasible and justified, particularly where they are close to inhabited areas. Contaminated material should be disposed of safely as determined by the responsible authorities. In some cases, contamination points could be covered by concrete or other durable material.
5. Within and adjacent to areas where DU has been used, groundwater used for drinking should be checked by the appropriate authorities for possible DU contamination. The type and frequency of checks would depend on local environmental, geological and hydrological conditions.
6. When analysing DU penetrators and samples, transuranic elements should also be taken into account, as appropriate.
7. Information should be provided to the local population on the precautions to be taken on finding material containing DU, possibly through ongoing mine-awareness activities.
8. The site-specific recommendations contained in section 7 of the report (and expanded in Appendix V) should be implemented as soon as the security situation allows.

9. Further scientific work should be carried out to reduce the scientific uncertainties related to the assessment of the environmental impacts of DU.

10. In order to reduce scientific uncertainty on the impact of DU on the environment, particularly over time, UNEP recommends that scientific work be undertaken in Bosnia-Herzegovina where DU ordnance has persisted in the environment for over five years. This could be part of an overall environmental assessment for Bosnia-Herzegovina.



Sign at Radoniq/Radonjic warning of depleted uranium.

Site-by-site findings

7.1 Introduction

This chapter summarises the results of the investigations made at the 11 sites visited in Kosovo. Maps showing the locations and coordinates of each site are given together with the results of sample analyses. The findings, and the conclusions derived from them, are given on a site-by-site basis. For ease of reference by the local authorities, local people and other interested parties, all the information relating to a particular site is presented in a ‘stand alone’ section and not grouped with potentially distracting information relating to other sites.

All results from the laboratory analyses are given in Appendix X. Each sample was allocated a unique UNEP reference code and this code is referred to, as far as practicable, in the discussion.

In the assessment of results and the corresponding conclusions about possible environmental contamination and consequential risks to people both now and in the future, there are comparisons with natural levels of radioactivity and with international limits and standards for radiological and chemical risks. There are also references to what is called the ‘Reference Case’. For further information, please consult Appendix I, ‘Risk Assessment’.

In both the tables and the text the concentrations of the various uranium isotopes are expressed as a measure of radioactivity (unit Bq per kg of sample), or as a measure of weight (unit mg per kg of sample). The relationship between these two measurements is given in Appendix IX.

One problematic issue discussed in this chapter is the possible future contamination of drinking water. Even though it is most unlikely that any problems will arise in the future as far as water is concerned, there are a number of uncertainties. As a consequence, particularly bearing in mind the desirability of taking a precautionary approach, certain actions are recommended. The necessity for, and modalities of, such actions are further discussed in Appendix V.

7.2 Gjakove/Djakovica garrison

Site description and general information

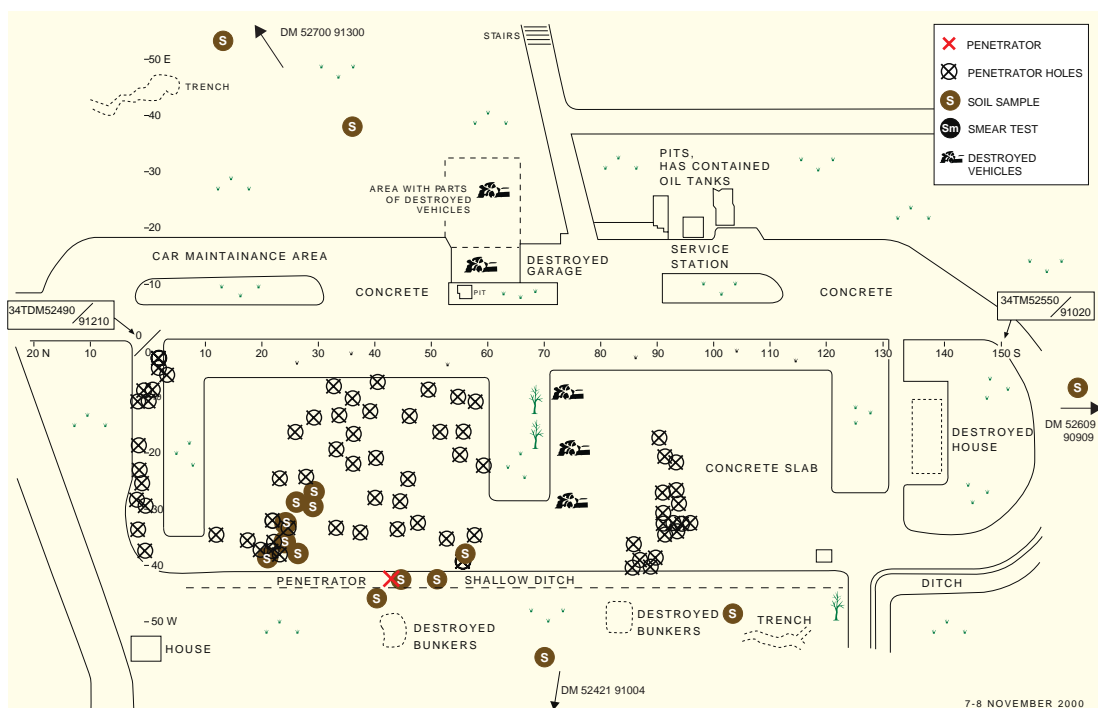
- Gjakove/Djakovica garrison (NATO reference no. 28).
- Coordinates: DM525 911.
- See map of general location in Kosovo and two sketch maps of site.
- Investigated by the UNEP mission on 7 and 8 November 2000.

The site is comprised of a former Yugoslavian army (VJ) garrison situated some 200 m south of Gjakove/Djakovica Old Town. The size of the garrison area is approximately 200 x 300 m. The garrison was attacked by NATO forces on 14 May 1999, probably in order to destroy the armoured vehicles situated there as well as to cause losses to other VJ facilities. The site was formerly used as a Serb garrison for military armoured vehicles and as an ammunition depot.

When the team visited the site it had been largely cleared of building remains, while destroyed vehicles had been piled together. This clean-up effort had been initiated under KFOR supervision and a stone crusher from a mine had been used to crush concrete and brick rubble. Pieces of metal were separated from the rubble using a strong magnet. The work was suspended when DU penetrators were found among the scrap metal.

At the time of the UNEP mission, the central part of the site was dominated by a large concrete platform (60 x 170 m). The surface of the platform showed clear

➤ Map 4: Gjakove/Djakovica garrison site



traces of more than 30 impact holes, which evidence suggests were caused by DU penetrators. The site also held a number of destroyed army vehicles and other military equipment. Although nearby buildings had also been hit, the nature of the impact holes, which indicated small calibre arms fire, together with the absence of any detectable DU, suggested that they had probably not been targeted by DU ammunition.

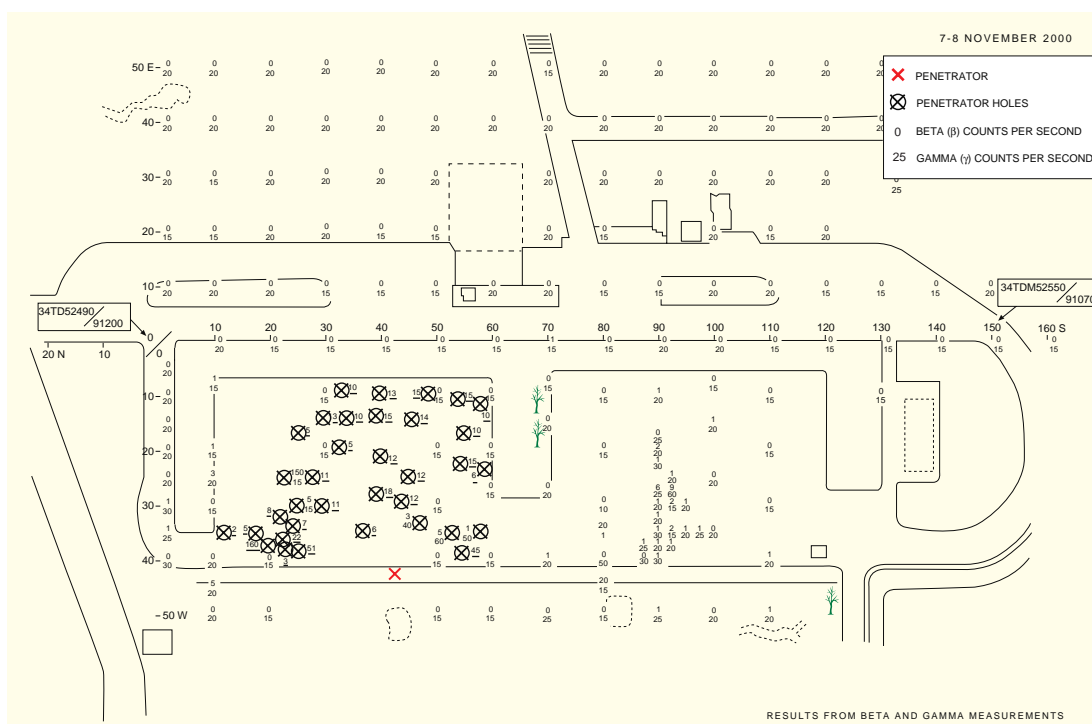
Information received from NATO indicated that a total of about 300 rounds had been fired at the area.

Gjakove/Djakovica Garrison is situated on flat land between the town and a river. To the north there is an upward slope towards the Old Town. The concrete platform is surrounded by grassland. At the time of the UNEP mission, cows and sheep were grazing in the area and children were playing. The ground consists of black clay silt. UNEP soil samples taken from outside the concrete platform showed low uranium content (0.8 – 3 mg/kg U) and low gamma radiation (0.05 – 0.1 μ Sv/h).

Summary of samples taken at Djakovica garrison:

- 71 soil and concrete samples
- 2 grass + roots samples
- 2 samples of public tap water from the same tap
- 7 smear tests
- 1 penetrator

► Map 5: Beta & Gamma radiation measurements
- Gjakove/Djakovica garrison



Field investigations

The beta/gamma radiation survey was made by ‘line-up survey’ (see Appendix III for a description of this technique) with 10 m between the lines ordered in an east-west direction along the concrete platform and extending about 10 m beyond the platform in all directions (see sketch map). These measurements were complemented by a number of measurements at specific places on the platform (all surface holes) and beyond it at various distances of up to 200 m.

Measurements were also taken from inside the destroyed vehicles and both the interior and exterior of destroyed buildings. Soil samples were taken where penetrators were found, and at some contaminated points on the slab and in the surrounding grassland, as well as from a park, UNEP 245 a and b, close to the old town. Two samples of public tap water, UNEP 124 and 326 were taken from a house north of the platform.

Furthermore, some experiments were made to study the effect of decontamination and the outcome of a smear test on the concrete platform.

Summary of results

■ General contamination

The beta/gamma instruments used showed no detectable DU either on the concrete platform or outside it, except where a few small patches of the slab were covered by a thin layer of sand, close to the two penetrators found (see below), and in the cavities on the surface of the concrete (see localised contamination, below).

■ Penetrators and jackets

Two penetrators were found: a complete penetrator just outside the concrete slab, and a half penetrator in one of the holes in the concrete. The complete penetrator was lodged in the top layer of the ground (at 5 cm depth) partly hidden by grass. No jackets were found.

■ Localised points of contamination

The measured activity of the localised points of contamination (‘contamination points’) varied from near background levels (1 cps) to 160 cps (beta radiation) corresponding to about 500 Bq (40 mg DU). The activity of the majority of the points sampled (30 all together) was within 10 ± 5 cps, corresponding to 30 ± 15 Bq (2 ± 1 mg DU).

The contamination points were in the form of small cavities in the concrete slab. These contained small amounts of sand, gravel and small stones in a layer varying in thickness from 0.5 to 2 cm. Measurements of initial activity were made in four such cavities, with portions of sand, gravel and stones then taken out for analysis. It was found that the major part (more than 90%) of the activity was bound to the sand, gravel and stones. The small part bound to the surface of the concrete was very tightly fixed, with smear tests showing no activity.



Sampling penetrator impacts in the concrete platform at the Djakovica/Djakovica garrison. The penetrator hits are marked by red spray paint.

The activity of DU contamination of sand/gravel/soil in three other holes varied between 11 and 36 kBq/kg (UNEP 019, 021, 022). With an assumed total of 10 - 100 g contaminated material, between 100 and 4,000 Bq or 10 to 300 mg of DU would be generated. All three holes together would therefore correspond to only 0.01 - 0.3% of the weight of a penetrator.

Samples of concrete fragments from around another hole probably caused by DU fire, and taken at 0 – 15 cm depth, showed DU activity of 16 kBq/kg or 1,326 mg DU/kg, corresponding to about 1 g of DU (UNEP 172). The contamination of the surface covered an area no more than 10 x 10 cm. The total activity would correspond to about 0.3% of the weight of a penetrator.

■ Soil samples

Soil samples taken from around and below a penetrator lodged in the ground a few metres west of the concrete platform contained DU contamination to a depth of about 20 cm. The samples were divided into two parts for analysis at two different laboratories. The activity ratio U-234/U – 238 is a measure of the concentration of DU. Values significantly lower than 1.0 indicate the presence of DU. The results from one of the laboratories are shown in table 7.1 below.

Table 7.1 Soil profile measurements around and below DU penetrator, Gjakove/Djakovica garrison

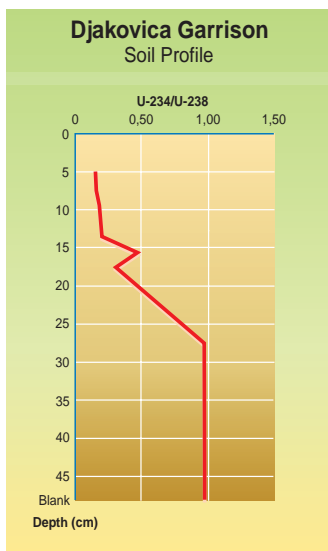
Sample number	Sample depth (cm)	U-238 (Bq/kg)	U-234 (Bq/kg)	U-235 (Bq/kg)	Utotal (mg/kg)	U-234/U-238
UNEP 017	0 – 5	225760±5538	30111±4740	3800±110	18253±2961	0.13
UNEP 001	5 – 7.5	45731±1121	6502±1543	750±22	3697±889	0.14
UNEP 002	7.5 – 9.5	684±93	103±11		59±10	0.15
UNEP 004	11.5 – 13.5	389±48	69±7	8±2	30±8	0.18
UNEP 005	13.5 – 15.5	90±24	40±14	4±2	8±5	0.44
UNEP 006	15.5 – 17.5	230±36	65±18	5.0±0.5	31±10	0.29
UNEP 011	25.5 – 27.5	30±4	29±3	3±1	3±1	0.94
UNEP 016	39.5 – 44.5	29±7	28±5	1.8±0.5	3±1	0.95
UNEP 018	Blank*	31±5	30±6	2.1±0.4	3±1	0.98

* = soil sample from Gjakove/Djakovica taken outside the attacked area.

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

The total activity of the DU contamination at and below the level of the penetrator was about 150 kBq, equivalent to 12 g of DU. This means that the penetrator had lost about 4% of its total mass (initially about 300 g) at the time of impact and subsequently (over a period of 1.5 years) by dissolution. The soil profile in terms of the ratio U-234/U-238 is shown in figure 7.1 below.

Figure 7.1 U-234/U-238 ratio in soil profile at site of DU penetrator, Gjakove/Djakovica garrison



The results from the other laboratory are shown below in table 7.2 and refers to samples UNEP 082 – 090. The high values in table 7.2 are caused by a DU fragment in the soil. Note: the laboratory did not take part in the quality control exercise (NAT-9).

Note: the 'Blank' sample was taken from outside the attacked area.

Table 7.2 U content of soil profile above, around and below DU penetrator, Gjakove/Djakovica garrison

Location of soil sample	Sample depth or radius from penetrator	mg U/kg sample	UNEP Code
Above penetrator	Surface covering	28	082
Around penetrator	10 – 20 cm radius	40,300	083
Below penetrator (samples taken from deeper than 14.5 cm showed normal levels of U and are not listed here)	0 – 2.5 cm depth	2,640	084
	2.5–4.5 cm depth	29	085
	4.5–6.5 cm depth	8.9	086
	6.5–8.5 cm depth	51	087
	8.5–10.5 cm depth	51	088
	10.5–12.5 cm depth	17	089
	12.5–14.5 cm depth	4.1	090

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise, and, if so, whether it passed, is contained in Appendices III and X.

The uranium concentration of all samples taken from 14.5 cm down to 40 cm depth was normal, i.e. 1.7 – 3.4 mg U/kg sample, with an average of 2.4 mg U/kg sample. The total amount of the DU contamination around and below the penetrator was about 40 g.

Two other samples, one of surface soil (0 – 5 cm) and one slightly deeper (5–15 cm), taken two metres away from the position where a penetrator was found, clearly showed DU contamination of the soil (UNEP 162, 163). The surface layer was contaminated with 4.6 mg DU/kg soil, while the lower sample contained 0.8 mg DU/kg soil. The contamination by DU in the surface layer accounted for 75% of the total amount of uranium present in the sample. The corresponding figure for the deeper sample is 32%. The concentration of DU in the soil two metres from the penetrator was found to be three orders of magnitude less than around the penetrator itself.

Two further soil samples taken from a grass area within the concrete platform showed surface (0 – 5 cm) contamination of 1.5 mg DU/kg soil and sub-surface (5 – 15 cm) contamination of 0.02 mg DU/kg soil. DU made up 51.9% of the total amount of uranium (mg) in the surface sample and 1.2% in the lower sample (UNEP 164, 165).

Samples were also taken systematically at distances of up to several hundred metres from the concrete platform. No detectable DU contamination was found further than five metres from the platform, i.e. any contamination was below 0.1 g/m² (1% of the Reference Case, non-covered surface).

■ U-236

In a surface layer (0 – 5 cm) sample taken two metres away from the position where a penetrator was found, U-236 analysis showed a value of 116 ng/kg soil, which corresponds to 0.28 Bq/kg (UNEP 162). The U-238 concentration of the same sample was 6.07 mg/kg soil, equivalent to 75 Bq/kg. The ratio U-238/U-236 by weight is therefore 52,000 and by activity 270. Considering that only part of the total U-238 is

accounted for by DU (6.07 – 1.5 mg/kg), with 1.5 mg/kg being the normal natural uranium concentration, the ratio by weight will be $4.5 \text{ mg}/116 \text{ ng} = 39,000$ and by activity $56 \text{ Bq/kg} / 0.28 \text{ Bq/kg} = 200$.

In the surface sample (0 – 5 cm) taken from the area of grass inside the concrete platform, the U-236 concentration was 40.6 ng/kg soil, which equates to 0.1 Bq/kg (UNEP 164). The U-238 concentration of the same sample was 2.8 mg/kg soil, corresponding to 35 Bq/kg soil. The ratio U-238/U-236 by weight is therefore 69,000 and by activity 360. Considering again that DU is only responsible for part of the U-238 recorded (2.8 – 1.5 mg/kg) the ratio by weight will be $1.3 \text{ mg}/40.6 \text{ ng} = 32,000$ and by activity $16 \text{ Bq/kg} / 0.1 \text{ Bq/kg} = 170$.

Measurements on a fragment of penetrator gave a ratio U-238/U-236 by weight of 34,000 and by activity 170 (UNEP 172).

The sample of concrete from an impact hole in the concrete platform contained 1,326 mg U-238/kg sample, equivalent to 16,400 Bq/kg, and 36,140 ng U-236/kg sample, corresponding to 87 Bq/kg. The ratio U-238/U-236 by weight is therefore 37,000 and by activity 190 (UNEP 172).

For a summary and average see Table 7.3.

Table 7.3 U-238/U-236 ratio by weight and by activity, Gjakove/Djakovica garrison

Sample type	U-238 concentration		U-236 concentration		U-238/U-236	
	[mg/kg soil]	[Bq/kg]	[ng/kg] soil	[Bq/kg]	By weight	By activity
Surface layer, 0 – 5 cm, 2 m from a penetrator	6.07	75	116	0.28	52,000 39,000*	270 200*
Surface layer in the grass area	2.8	35	40.6	0.1	69,000 32,000*	360 170*
Penetrator					34,000	170
Concrete from a hole	1,326 mg/ /kg sample	16,400	36,140	87	37,000	190
Average					36,000	190

* These values represent the DU part of the sample. The averages also only represent the DU components.

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

■ Smear tests

Vehicles: in the smear tests carried out on vehicles with bullet holes suggesting they had been hit by DU penetrators, the activity values of U-238 and U-235 were both lower than the minimum detectable levels. These results suggest that either DU ammunition did not in fact hit these vehicles, that the DU ammunition easily penetrated these thin-skinned vehicles leaving minimal, non-detectable levels of contamination, or that the DU dust had been removed from the vehicle surfaces by rainfall and wind (UNEP 023, 029).

■ Drinking water

Two samples of public water were taken from a nearby house just to the north of the concrete platform. No excess activity was found and there was no indication of the presence of DU (i.e. the ratio U-238/U-235 was normal). The agreement of analyses performed at two different laboratories (UK and Sweden) was good, with values of 0.6 and 0.60 $\mu\text{g/l}$ respectively (UNEP 124, 326).

Site-specific conclusions

■ Measurements

- Penetrators, jackets and surface contamination:

Only one and a half penetrators were found from the 300 rounds reportedly fired. The intended targets were probably the military vehicles located on the concrete platform and in the immediate vicinity. Some penetrators had been found and removed from the site during earlier clean-up work.

A proportion of the DU penetrators would have become aerosolised during the attack and dispersed on and around the platform. However, no evidence of DU contamination was found more than a few metres from either the penetrators located, or the holes left by other penetrators. Very little was found on the platform itself, except in the penetrator cavities which had measurable quantities of DU reaching a total of just 0.1 – 1 g. Assuming that at least 100 penetrators became aerosolised on impact, about 30 kg of DU would have been deposited in the surrounding environment. 0.1 – 1 g is clearly a very small amount in comparison with 30 kg spread over 1,000 m² (the approximate size of the concrete platform and its immediate vicinity). Furthermore, 30 kg is three times the Reference Case and would be easily detected by direct external measurements and/or by laboratory measurements of soil samples. There could be several possible explanations:

(a) The DU dust was initially dispersed over a much wider area than the targeted site of about 1,000 m², and activity was therefore not detectable by field measurement. In order for this to be the case, a dispersal area of at least 300,000 m² would be needed in order to reduce the surface contamination to a level barely detectable by field beta measurement, and assuming that DU dust was lying on the surface. An area of 30,000 m² would be required if the DU was slightly covered by soil. Non-detectable activity means that the surface contamination is less than 0.1g DU/m² (1% of the Reference Case, non-covered area) and less than 1g DU/m² (10% of the Reference Case, covered area).

For these figures to be attained, wind dispersion would need to be over an area 1 – 10 km in length and 30 - 300 m wide with an even fallout across the whole

of this surface. This is not a probable scenario when compared with experience from experimental studies (UNEP DU Desk Assessment Report, October 1999). However, very windy conditions could certainly have contributed to wider dispersal than the target area itself.

(b) The great majority of penetrators either missed the target or hit a 'soft' target. Therefore they did not shatter, but entered the ground on and around the concrete platform. The large number of holes in the concrete, many of them slightly contaminated, suggests that this could be the case. No holes were found outside the concreted area but their presence cannot be excluded since the softer substrate would make holes more difficult to detect.

(c) Another possibility is that there was a ricochet effect, a conclusion that is based on studies of the characteristics of the holes in the concrete platform, and the pattern and angle of impacts.

In conclusion, the most probable scenario is that 300 rounds were fired, but that most of them hit soft targets or missed the target area and then entered the ground or disappeared as ricochets some distance from the concrete platform. A few penetrators were aerosolised, temporarily contaminating the surface of the platform until washed away by rainfall. Some contamination remains on the platform, attached to sand whilst other contamination has collected in holes as result of rain and wind action, again mainly attached to sand. The DU is not attached to the surface of the concrete itself except in the deeper parts of holes which have either been hit by penetrators and/or gathered DU leaked from the overlying sand.

Many penetrators might also have been cleared from the site during initial clean-up operations.

■ Residual risks

Because there was no detectable contamination of the ground beyond the edge of the concrete platform, except in the immediate vicinity of where a penetrator was found, the contamination in this area is probably less than 0.1g DU/m² (1% of the Reference Case). The residual radiological and chemical risks of DU exposure, either by inhalation of contaminated dust in the air or by ingestion of contaminated food, is insignificant.

There may still be some penetrators (and jackets) on the ground at, close to, or relatively far from the target area. If these were picked up by people, there would be a potential risk of external radiation exposure, which might be significant. There may also be some risk of contamination of hands and subsequent ingestion. Corresponding radiation exposure is insignificant but from a heavy metal toxicity point of view the exposure may be significant.

Because of localised ground contamination close to the penetrator, there may be some risk of internal contamination by ingestion of soil or contamination of hands. While such exposure would be insignificant with regard to radiation ($<10 \mu\text{Sv}$) it could be significant from a toxicological point of view.

Many penetrators may remain hidden in the ground and therefore vulnerable to solution and ultimate dispersal into the groundwater. Hence, there is a possibility that the drinking water from some nearby wells could become contaminated in the future.

The concrete platform is still subject to a degree of contamination contained in the bullet holes and in loose sand lying on the surface. Most contamination was removed by the UNEP team as a consequence of sampling, but around 0.1 – 1g DU remains as contamination. Some of it is bound tightly to the concrete, with the rest attached to sand or similar substrates. The possible potential risks are related to inhalation of dusty air caused by wind blowing across the platform, or ingestion of contaminated sand. The total amount of contaminated sand may be of the order of 100 g spread over the concrete surface, which would result in 1 – 10 mg DU/g sand or dust. That could be expected to lead to insignificant radiation doses less than 10 mSv effective dose after spending two hours in dusty air (compare the Reference Case, 6 mg DU/g dust). The toxicological risks are also insignificant. After a few hours all sand should have blown away and thereafter constitute an even smaller risk.

Alternatively, the sand does not blow away and there is no inhalation dose but there is a risk of ingestion. The only possible way to ingest the DU is by ingesting the contaminated sand itself. Ingestion of 1g sand would be a realistic maximum for a human being (compare the Reference Case). If that happens, the exposure is insignificant as regards radiation ($<10 \mu\text{Sv}$) but could be significant from a toxicological point of view.

■ Need for mitigation

There is no risk of high radiation doses or serious heavy metal toxicity now or in the future.

However, it is advisable to inform people about the possible presence of penetrators and jackets in the environment, and that all penetrators or jackets found should be dealt with by the local authorities or by KFOR. They should not be kept in homes or by children.

The village receives piped water, but any nearby wells used for drinking water should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

As a matter of prudence the concrete platform could easily be cleared of loose contamination by using a vacuum cleaner. The collected dust should be disposed of safely as determined by the responsible authorities. Alternatively, the existing platform can be covered with a layer of new concrete.

7.3 Vranoc/Vranovac hill

Site description and general information

- Vranoc/Vranovac hill (NATO reference nos. 100 and 103).
- Coordinates: DN528 123.
- See map of general location in Kosovo and two sketch maps of site.
- Investigated by the UNEP mission on 9 and 12 November 2000.



Searching the slope of the Vranoc/Vranovac Hill for contamination.

Vranoc/Vranovac hill forms part of a series of sandy ridges ('eskers') which run eastward from the mountains to the west. The ridge of the hill rises about 30 – 40 m above the surrounding country and is approximately 200 – 300 m wide and 1 km long. On top of the hill is a flat area used by the Serbian army for 12 anti-aircraft artillery positions. A road and farmhouses lying beneath the south side of the hill were partly destroyed by bombing. Along the northern side of the road, against the hillside, there are several excavations used for protecting tanks and other military vehicles. The village of Vranoc/Vranovac is situated on the western part of the ridge. The site was targeted twice by NATO forces on 8 June 1999. According to information received from NATO, about 2,320 rounds were fired.

The soil consists of fine to medium grained sand. Soil samples taken by the UNEP team from the top of the hill and from one of the farm houses on the southern

side of the ridge showed low uranium concentrations (1-3 mg/kg U). The gamma radiation readings were also low, being nowhere higher than 0.1 $\mu\text{Sv/h}$. Water samples were collected from five sites, as detailed below.

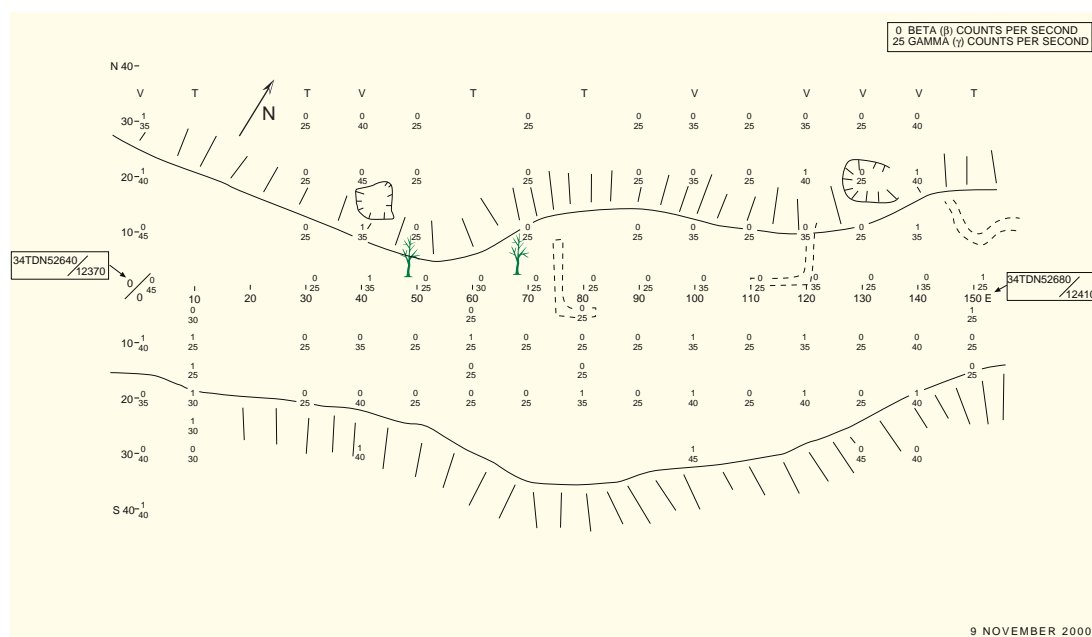
Summary of samples taken at Vranoc/Vranovac:

- 11 soil samples
- 2 botanical samples (1 lichen and 1 mushroom)
- 12 water samples:
 - 2 from an excavated pond used for cattle on the northern side of the ridge
 - 2 from a well in the yard of farm 1 situated at the foot of the southern side of the hill
 - 2 from a natural spring along the roadside opposite farm 1
 - 3 from a well in the yard of farm 2
 - 3 from a well at a house next to Vranoc/Vranovac school

Field investigations

The beta/gamma radiation survey was made by 'line-up survey' covering an area of 150 x 70 m of the hill top (see sketch map). The remainder of the hill top (total length about 1 km) was surveyed through measurements carried out at random.

► Map 6: Beta & Gamma radiation measurements - Vranoc/Vranovac

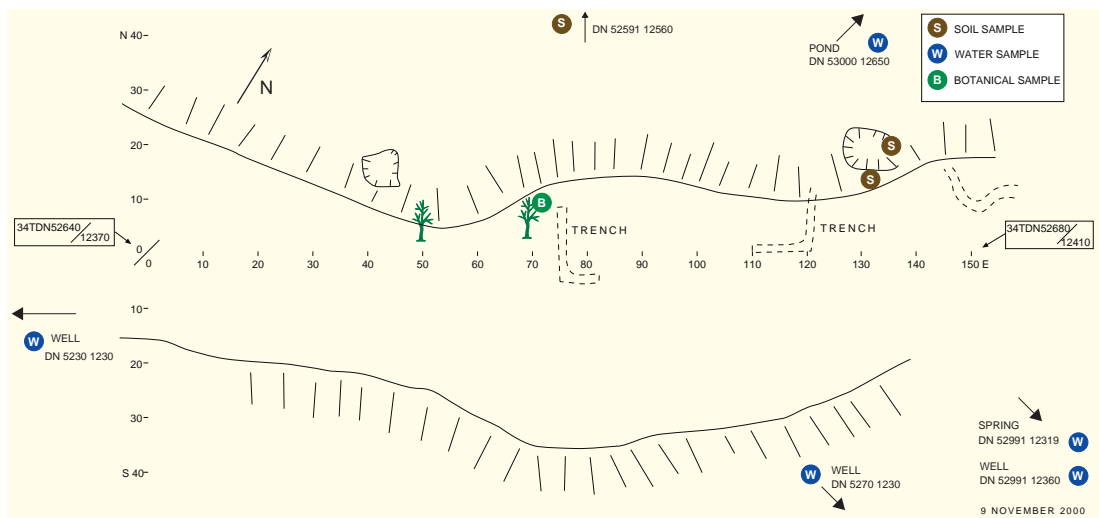


Measurements were taken from a number of holes and ditches and a few soil samples were taken from the top of the hill. Some holes were dug using a spade (to a depth of 50 cm) to search for penetrators or DU contamination. Samples of lichen from a tree and a mushroom from the ground were taken on top of the hill.

On the southern side of the hill the inside of a bombed-out farmhouse was measured. A ‘line-up survey’ was conducted over an area of approximately 50m perpendicular to the road by 400 m along the southern side of the road, starting above the farmhouse and continuing in the direction of the village. Further random surveys were made along the hillside towards the village and the school house.

12 water samples including drinking water, were also collected: UNEP 128 and 327, from a pond used to supply cattle with drinking water, and alongside the road on the north side of the hill; UNEP 035, 129, 328, 130 and 336 from wells belonging to two farmhouses on the southern side of the hill; UNEP 036, 131 and 337, from a well close to the village school; and UNEP 132, 335, from a natural spring at the foot of the hill.

► Map 7: Vranoc/Vranovac site



Summary of results

■ Penetrators and jackets

No penetrators or jackets were found.

■ General contamination

The beta and gamma surveys did not indicate any DU contamination of the area.

■ Localised points of contamination

No localised points of contamination (‘contamination points’) found.

■ Soil samples

None of the soil samples taken showed any measurable DU activity. The natural uranium content was very homogenous at depths of 0 – 15 cm.

■ Drinking water

None of the drinking water samples taken showed any measurable DU activity.

■ Botanical samples

The lichen sample (UNEP 033) showed clear indications of DU contamination, although the activity concentration was low, at less than 0.1 mg U/kg. The mushroom sample (UNEP 034) did not show any measurable activity of DU.

Site-specific conclusions

■ Measurements

- Penetrators, jackets and surface contamination:

In spite of the information provided by NATO that 2,320 rounds had been fired at this locality, no penetrators were found and there were no signs of penetrator or jacket fragments, or even of penetrator hits. Nor were there any indications of contamination of the ground, water or buildings. However, the result of measurements carried out on the lichen sample indicate exposure to air contaminated by DU, presumably caused by the shattering of DU penetrators.

Of the 2,320 rounds reportedly fired, some would have hit the target and aerosolised, some would have hit the target and passed through into the ground, and others would have missed the target and entered the ground. It is also possible that some penetrators ricocheted and came to rest hundreds (or even thousands) of metres away from the top of the hill.

As there was no activity detectable either from field measurements or from soil sampling, any remaining surface contamination is less than 1g DU/m² (10% of the Reference Case) and probably less than 0.1g DU/m² (1% of the Reference Case). The area over which the DU would need to have been dispersed in order to reach these low values can be calculated.

If all the 2,320 penetrators were converted to aerosols on impact, about 700 kg DU would have been released into the environment. The area required to distribute 700 kg DU at a density of 0.1g DU/m² would be 7,000,000 m², or more than 10 times the area of the hill. If the targeted area was 700 m wide, the dispersion area would need to be about 10 km in length to correspond to the assumed surface contamination level. Since quite windy conditions may occur on top of the hill, this scenario is plausible, assuming that all the DU was shattered into small parti-

cles and dispersed by a strong wind.

A more likely scenario is that most penetrators either hit soft targets, or missed the targets completely, and entered into the substrate of the hillside, where they cannot be detected by field measurements or soil sampling.

■ Residual risks

In the case of the less probable scenario of dispersion over a very large area, the corresponding residual risk of DU exposure by inhaling contaminated dust or ingesting contaminated food is insignificant.

The more probable scenario, that most of the penetrators are buried in the ground means that there is a possibility of future drinking water contamination if groundwater from the hill enters the drinking water supply. By way of comparison, the total amount of uranium naturally contained in the hill is of the same order of magnitude as that contained in 2,320 penetrators, $4 \cdot 10^{10}$ Bq and 10^{10} Bq respectively. From this it can be concluded that drinking water would not be seriously affected. However, the penetrators are concentrated sources and it is difficult to foresee if that would result in lower or higher concentrations than those assumed.

There may still be some penetrators and jackets on the ground at, close to, or relatively far from the target area (those further away probably resulting from ricochets). If these were picked up by people, there would be a potential risk of external radiation exposure, which might be significant. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure may be significant.

Because of localised ground contamination close to the penetrator, there may be some risk of internal contamination by ingestion of soil or contamination of hands. While such exposure would be insignificant with regard to radiation ($<10 \mu\text{Sv}$) it could be significant from a toxicological point of view.

■ Need for mitigation

There is no risk of high radiation doses or serious heavy metal toxicity now or in the future.

However, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators or jackets found should be dealt with by the local authorities or by KFOR. They should not be kept in homes or by children.

The drinking water in nearby wells should be kept under some surveillance by taking samples at appropriate intervals for uranium testing.

7.4 Radoniq/Radonjick lake

Site description and general information

- Radoniq/Radonjick lake (NATO reference no. 98).
- Coordinates: DN534 026
- See map of general location in Kosovo and sketch map of site.
- Investigated by the UNEP mission on 10 November 2000.

The investigated site is located at the large dam on the southern shore of Radoniq/Radonjicko lake. The lake is an artificial reservoir providing drinking water to a population of approximately 200,000 (i.e. most of the southern part of Kosovo) including the towns of Prizren and Gjakove/Djakovica. Several artillery positions and perhaps also tank positions were dug into the slope of a nearby ridge, just south-west of the dam. A severely damaged radio station is located on top of the ridge. According to NATO information, the area was targeted by 655 rounds on 7 June 1999. Prior to the UNEP mission, Italian army experts and KFOR Explosive Ordnance Disposal (EOD) personnel had found penetrators and jackets at the site during clearance of mines and unexploded ordnance. The size of the site is approximately 250 x 500 m.

Most of the area on the top of the ridge consists of rocky outcrops covered by a thin layer of stony and sandy red/brown soil. Basaltic volcanic lavas form the bedrock. The soil cover is thicker on the sloping sides of the ridge. Soil samples taken by the UNEP team showed very low, to low, concentrations of uranium (0.5 – 2 mg/kg U). The gamma radiation was around 0.05 μ Sv/h.

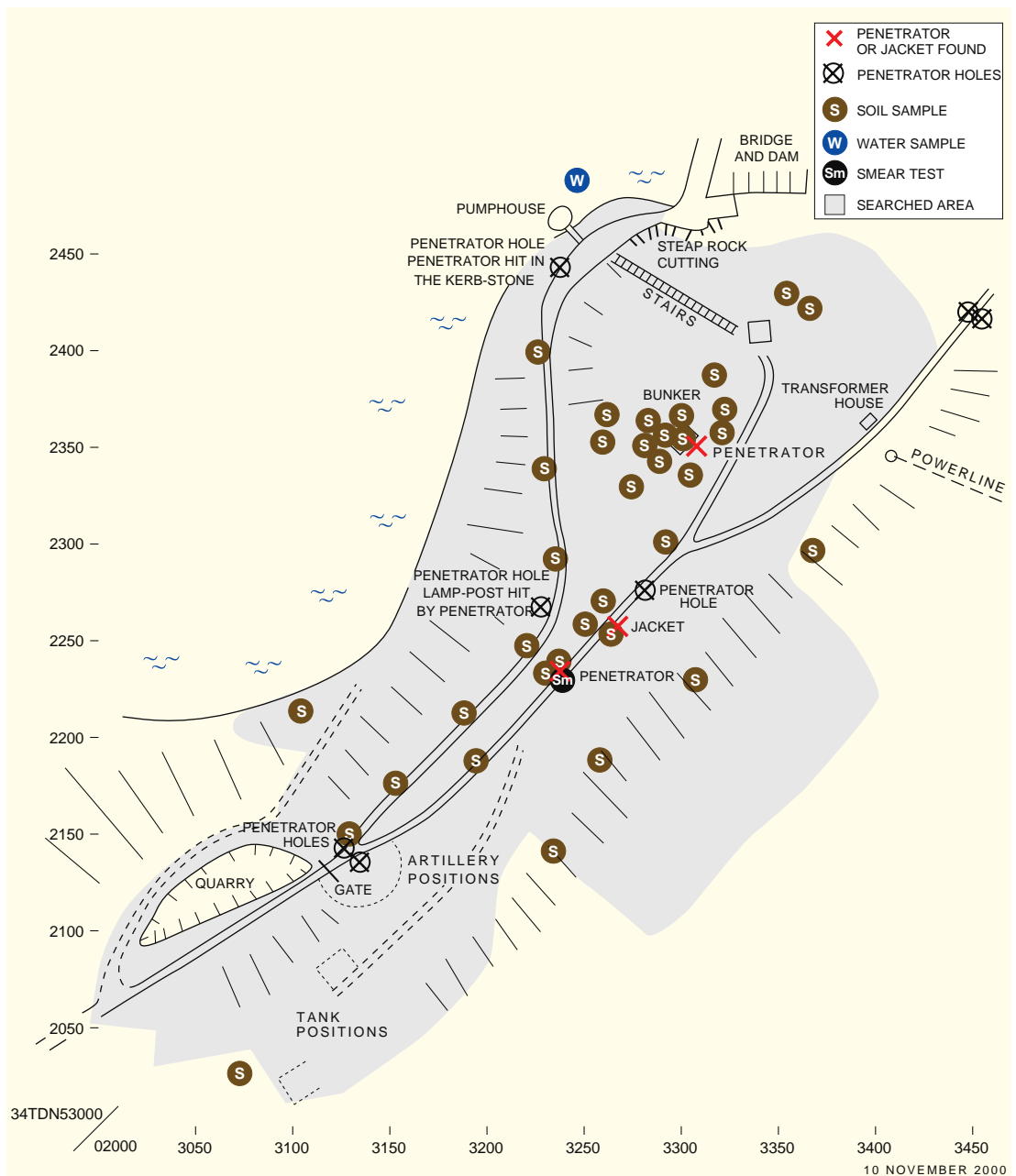


At Radoniq/Radonjic Lake the road to the dam had been hit by cluster bombs and DU penetrators.

Summary of samples taken at Radoniq/Radonjick lake site:

- 68 soil samples
- 1 botanical sample
- 2 smear samples
- 2 water samples
- 1 jacket

► Map 8: Radoniq/Radonjick lake site



Field investigations

The investigations started with measurements in the wrong area. However, the correct area was identified after finding penetrator holes in the asphalt, and discussing locations with the military personnel escorting the UNEP mission. The beta/gamma radiation survey was made by ‘line-up survey’ (see Appendix III, for details) complemented by a number of individual measurements taken at random, though guided by visual observation of possible impact locations.

The measurements and sampling were carried out on both sides of the road to the dam. A large number of soil samples were taken, as well as two water samples from the adjacent lake, which – as mentioned earlier – serves as the drinking water storage reservoir for a large part of Kosovo.

Additional special investigations were conducted on and around a wall hit by a penetrator and on the soil below and close to a penetrator.

Summary of results

■ Penetrators and jackets

One penetrator and one jacket were found close to the road about 150 m north east of the gate (see sketch map).

At another locality, between the western side of the road and the lake, about 100 m south of the pumping station, there was an apparent indication by the gamma detector of a penetrator hidden in the soft soil. However, in spite of many digging attempts to more than one metre in depth it was not possible to find anything. Either the reading was ‘false’ having been caused by high natural uranium/thorium levels or it was a true indication of a buried penetrator. The first possibility illustrates one of the pitfalls of searching for DU, while the second possibility shows the difficulties of locating the exact position of a penetrator when it is hidden in the ground.

■ General contamination

With the beta instrument used there was no detectable DU on either side of the roads or between the roads, except at the so-called ‘contamination points’, i.e. marks left by penetrator impacts. These were found on the roads and in some concrete constructions, see below. The only other detection of any ground contamination was from soil samples taken close to a penetrator or from a penetrator impact site. The results are given below under ‘Activity profiles close to penetrator on ground’ and ‘A bunker wall hit by a penetrator’.

In addition to these observations there was one finding of DU contamination (20% of total uranium) in soil and roots, 1 – 5 cm depth, at a point close to the gate (see

sketch map), and few metres from a penetrator hole in the road; another finding of weak DU contamination (6%) in a sample of soil, roots and grass, 0 – 1 cm depth, taken 50 m north east of the gate on the northern side of the road; and one finding of DU contamination (40-50%) in soil, 0 – 5 cm depth, 100 m north east of the gate, between the two roads.

There were no other findings and indications of ground contamination of DU.

■ Localised points of contamination

In total, nine contaminated holes were found, some of them only slightly contaminated (less than 10 cps or less than 300 Bq of DU, 25 mg DU, assuming 90% absorption). Soil samples were taken from two holes caused by the impact of penetrators on concrete and on asphalt, UNEP 037 and 038. The samples contained about 2 g U/kg soil and 0.3 g U/kg soil respectively and most of the uranium (U), 80-100%, was DU. One hole was specially investigated, see below.

■ Special studies

(a) Activity profiles close to penetrator on ground.

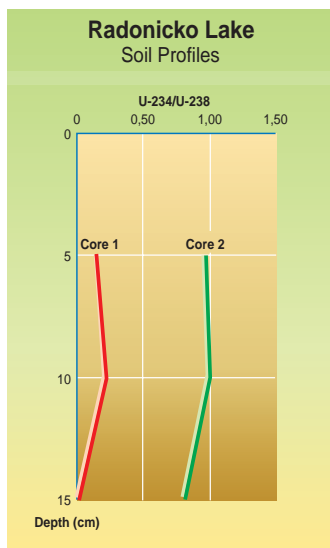
Two soil profiles were sampled. Soil samples were collected using a stainless steel core sampler (15 x 15 cm frame). The first core (core 1) was taken from just underneath the penetrator found lying on the surface of the ground down to a depth of 10 cm. The core was subdivided into two samples each 5 cm thick. The second soil core (core 2) was sampled to a depth of 15 cm, close to the road where a penetrator hole was observed. The core was taken 155 cm away from the penetrator hole, in the direction in which the rounds were probably fired. The core was subdivided into three samples, each 5 cm thick. The radiochemical results are reported in table 7.4.

Table 7.4 Soil profiles from samples taken at Radonjick lake

Sample number	Core number	Sample depth [cm]	U-238 [Bq/kg]	U-234 [Bq/kg]	U-235 [Bq/kg]	Utot [mg/kg]	U-234/U-238
UNEP 039	2	0 – 5	21±11	20±10	1.0±0.6	3±2	0.95
UNEP 040	2	5 – 10	14±3	14±3	0.9±0.6	1±1	0.97
UNEP 041	2	10 – 15	16±3	13±2	1.2±0.5	1.5±0.8	0.77
UNEP 042	1	0 – 5	3060±523	396±50			0.13
UNEP 043	1	5 – 10	434±169	74±23	6±2	46±27	0.17

The distribution of U-234/U-238 activity ratios within the soil profiles is shown in Figure 7.2.

Figure 7.2 Distribution of U-234/U-238 activity ratios in soil profiles at Radonjick lake



It is concluded from table 7.4 and figure 7.2 that DU is present to a level of almost 100% in both samples from core 1 (i.e. from immediately below the penetrator) but not in any significant amount in samples from core 2 (1.5 m away from a penetrator hole). The activity concentration decreases by a factor of five to seven between 0 – 5 cm depth and 5 – 10 cm depth below the penetrator.

(b) A bunker wall hit by a penetrator.

Another study was aimed at investigating in more detail the contamination by DU in the area close to a bunker in which a concrete wall had been hit by a penetrator.

The result of the analyses from around the bunker are shown in Tables 7.5 and 7.6. All samples were soil samples taken at 0 – 5 cm depth, except for sample UNEP 190 which was a sample of concrete taken from a 10 cm deep hole in the bunker.

Table 7.5 Isotopic compositions in samples from bunker

UNEP Sample no.	²³⁸ U		²³⁵ U		²³⁶ U	
	[mg/kg]	k %	[µg/kg]	k %	[ng/kg]	k %
176	100,2	1,34	206	1,43	2715	10,4
177	21,7	3,51	50,9	3,54	545	11,0
178	1,81	1,59	11,26	1,71	-	-
179	1,70	2,70	11,03	3,29	-	-
180	1,85	2,25	11,36	2,30	-	-
181	2,30	1,43	15,14	1,50	-	-
182	2,29	3,88	15,29	3,90	-	-
183	1,51	2,17	10,79	2,21	-	-
184	1,84	5,20	8,00	6,00	-	-
185	1,14	1,48	8,22	1,53	-	-
186	59,6	5,70	122	5,73	1630	12,2
187	1,32	24,7	8,44	28,6	-	-
188	1,66	33,2	8,16	39,0	24,7	36,3
189	1,61	1,29	11,62	1,35	-	-
191	1,00	3,04	7,09	3,06	-	-
192	0,78	4,24	5,61	4,35	-	-
193	1,24	1,58	8,94	1,63	-	-
194	1,10	3,11	7,96	3,16	-	-
195	2,69	4,31	17,97	5,70	-	-

Note: - indicated that the U-236 concentration was below the detection limit.

Information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

Table 7.6 Isotopic ratio U-235/U-238 and the percentage DU of the total uranium amount

UNEP	Isotopic Ratio	% DU of Total Uranium	RSD %
176	0,002058	99,0	0,3
177	0,002344	93,5	0,2
178	0,006239	19,1	3,0
179	0,006339	14,3	13,1
180	0,006159	20,6	1,8
181	0,006599	12,2	0,4
182	0,006678	10,7	1,2
183	0,007143	1,9	7,9
184	0,007267	<1	-
185	0,007242	<1	-
186	0,002048	99,2	0,3
187 a	0,005736 ¹⁾	28,7	0,2
187 b	0,007058 ¹⁾	3,5	0,3
187 c	0,006323 ¹⁾	17,5	0,4
187 d	0,006918 ¹⁾	6,2	0,3
188	0,004917	44,3	35,6
189	0,007239	<1	-
191	0,007095	2,8	5,3
192	0,007235	<1	-
193	0,007242	<1	-
194	0,007240	<1	-
195	0,006692	10,5	37,2

Notes: RSD = Relative Standard Deviation

Information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

The samples UNEP 176 and 177 are those taken from the bunker floor below the impact of the penetrator into the wall. These samples were contaminated with DU in the range of 93.5% – 99% which represents 20.3 – 99.2 mg DU/kg depending on the sample collected.

The soil sample UNEP 178 was taken 1.5 m away from the impact site but still within the same concrete bunker. Contamination of 19.1% DU, equivalent to 0.35 mg DU/kg was found in this sample.

The samples UNEP 179 and 180 were taken from in front of the bunker and to the right (when looking out from the bunker) at distances of 5 and 10 metres. Analysis showed contamination by DU of 0.24 mg DU/kg and 0.38 mg DU/kg.

The samples UNEP 181 and 182 were taken in front of the bunker and straight ahead at distances of 5 and 10 metres. They showed contamination by DU of 0.28 mg DU/kg and 0.25 mg DU/kg, respectively.

The samples UNEP 183 and 185 were taken to the left of the bunker (when looking out from the bunker) at distances of 5, 10 and 15 metres. They showed contamination by DU of 0.03 mg DU/kg, 0.12 mg DU/kg and no contamination.

The sample UNEP 186 was taken 5 metres behind the bunker in the direction that the attack could have taken place. Contamination of 99.2% DU or 59 mg DU/kg soil was found.

The samples UNEP 187 and 188 were also taken on the plateau behind the bunker, at road level, and within a radius of 30 metres around samples UNEP 202 – 211. Both samples were found to be contaminated by DU with respective results of 0.4 mg DU/kg and 0.7 mg DU/kg.

The sample UNEP 189 was taken far away from the impact area behind the remaining house at the top of the hill side and can be considered as showing natural background sample without contamination.

■ Discussion of special study results

The DU contamination in the area of the bunker is mainly located directly beyond the impact site.

In front of the bunker in an area of 30 x 10 metres DU contamination was found to be in the range of 0.03 – 0.38 mg DU/kg soil (compared with the natural uranium level of 1.2 mg/kg).

Initially surprising was the high value of 59 mg DU/kg found 5 metres behind the bunker. This area was apparently constructed of large blocks of concrete covered with about 10 cm of stony soil. Samples UNEP 186 – 188 were taken in the direction in which the attack had taken place. It can be expected that during the attack DU penetrators also hit the plateau behind the bunker and, by chance, sample UNEP 186 was taken very close to a position where a penetrator hit the ground. This scenario can be confirmed with the data from the samples 187 and 188 showing DU contamination of 0.4 mg DU/kg and 0.7 mg DU/kg soil respectively.

Sample UNEP 186 with its 59 mg DU/kg can be considered as a contamination point resulting from a penetrator having hit the sub-surface concrete platform. Except for localised points of contamination, an area of about 30 x 50 metres is contaminated by DU in the range of 0.4 – 0.7 mg DU/kg soil. This contamination lies within the range of the natural uranium level for that site.

That the levels of contamination behind the bunker seemed to be a little higher than those in front might be the result of more penetrators having hit the plateau, or be a consequence of the wind direction during attack having matched the trajectory of attack, thus depositing DU dust in that direction. Based on the data presented here, contamination sufficient to warrant the term ‘contamination point’ is limited to a few square centimetres, with DU levels lying in the range of a few mg DU/kg soil up to about 100 mg DU/kg. About two metres away from this contamination point the level of contamination drops to below 1 mg DU/kg soil. Values of about 0.5 ± 0.2 mg DU/kg soil were measured, decreasing rapidly with further distance.

Sample UNEP 195 was taken far away from the hilltop site, close to the lake and in front of the dam controlling the lake level. This sample was expected to show background activity only but this was not the case. Due to DU contamination of 0.28 mg DU/kg soil it can be concluded that DU penetrators also hit the concrete wall of the dam. In addition, the natural uranium level in the soil close to the lake was found to be about 2.4 mg/kg soil, a factor of two higher than the hill top.

■ U-236

U-236 was measurable in four samples. Its quantity is relatively constant, $2.6 \cdot 10^{-5}$ times the U-238 concentration in case of pure DU, and consequently only about half of that for a sample with 50% DU, UNEP 188. In all the other samples the DU concentration was too low for U-236 to be measurable.

■ Smear tests

The one smear test was made on a penetrator. The amount of activity that was easily smeared away was about 5 mg of DU, sample UNEP 044.

■ Drinking water

Two water samples were taken from the lake, UNEP 045, 133. The natural uranium concentration of 0.6 µg/l was very low.

■ Botanical samples

Samples of roots and grass contained uranium levels in the order of 0.5 – 1.5 mg/kg sample and there was no indication of the presence of DU.

Site-specific conclusions

■ Measurements

Penetrators, jackets and surface contamination:

According to the information given by NATO, 655 rounds were fired at the area investigated. However, only one penetrator was found, plus two jackets. On the other hand there were several clear indications of penetrator hits. The search for a possible buried penetrator was unsuccessful and illustrated the difficulties that can be encountered.

As at other sites, no widespread surface contamination by DU was detectable with either the field beta instruments or from soil sampling. This means that any surface contamination was less than 0.1 g DU/m² (1% of the Reference Case).

If all the penetrators were aerosolised on impact, about 200 kg DU would have been dispersed. The area needed to distribute 200 kg DU to a contamination level of less than 0.1 g DU/m² would be 2,000,000 m². As the size of the targeted area is of the order of

100,000 m², a much wider area, including the nearby lake, would have been contaminated. Because very limited surface contamination was found in the target area, which would have been the most heavily contaminated in the case of a ground level release on impact, the widespread contamination scenario is not very likely. Therefore, it seems probable that the majority of penetrators are hidden in the ground.

The results from two specific investigations are discussed below.

(a) Soil contamination under a penetrator

In one case, soil contamination was detected in the upper 10-20 cm beneath a penetrator. At a distance of 1.5 m away from a penetrator hole no DU could be detected. The total amount of DU under the penetrator can be estimated to be 0.1-1% of the penetrator's mass. The contamination could have occurred on impact or by chemical dissolution during the period of 1.5 years that had elapsed since the attack. Because the impact must have been quite soft – the penetrator was lying on the surface – the latter explanation would seem more probable. On the other hand, there is also some surface contamination, albeit low level, around the penetrator, which indicates air dispersal at the moment of impact.

(b) Contamination after penetrator impact on a concrete bunker wall

The special studies on the effects of a penetrator hit on the thick concrete wall of a bunker illustrate the highly complex contamination situation. Unlike in other situations, DU contamination could be identified over a relatively large area of 10 x 30 m. The explanation is the presence of hard materials such as concrete which contribute to shattering of DU on impact. There were also signs of several shots in the investigated target area. The results clearly prove the initial presence of some DU dust in the target area.

■ Botanical samples

Some measurements were also made of roots and grass but there was no indication of DU. This might mean that there was no DU available or alternatively that the uptake by roots had been very low. Both explanations are likely.

■ Residual risks

In case of the less probable scenario of dispersal over a very large area, the corresponding residual risk of DU exposure by inhaling contaminated dust or ingesting contaminated food is insignificant.

The more probable scenario that most of the penetrators are hidden in the ground means that drinking water could possibly become contaminated in the future. Radonjicko Jezero dam, which supplies drinking water for several hundred thousand people is close to the targeted area. The total water volume is approximately 4 x 10⁷ m³ (1.5 km x 5 km x 5 m). In the worst case that all 200 kg of DU had been dispersed

into the lake, the concentration would be of the same order of magnitude as the WHO provisional guideline for drinking-water quality of 0.002 mg/l and one to two orders m^3 (1.5 km x 5 km x 5 m). In the worst case that all 200 kg of DU had been dispersed into the lake, the concentration would be of the same order of magnitude as the WHO provisional guideline for drinking-water quality of 0.002 mg/l and one to two orders of magnitude lower than the drinking water standard in many countries from both toxicological and radiological points of view. Assuming that there is some water turnover during the time it takes for DU to reach the lake, if it ever happens, the concentrations will be even lower, by one to several orders of magnitude.

In conclusion, any significant future DU contamination of the drinking water reservoir can be ruled out.

There may still be some penetrators and jackets on the ground at, close to, or relatively far from the target area. If these were picked up by people, there would be a potential risk of external radiation exposure, which might be significant. There may also be some risk of contamination of hands and subsequent ingestion. Corresponding radiation exposure is insignificant but from a toxicological point of view the exposure may be significant.

Because of local contamination of the ground close to the penetrator, some risk may occur of internal contamination by ingestion of soil or contamination of hands. Were this to occur, the exposure would be insignificant in terms of radiation (<10 μ Sv) but could be significant from the toxicological point of view.

The level of U-236 concentrations is insignificant from the health point of view (UNEP 145, 176, 177, 186, 188).

■ Need for mitigation

There is no risk of high radiation doses or serious heavy metal toxicity now or in the future.

However, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators and jackets found should be dealt with by the authorities or KFOR. They should not be kept in homes or by children.

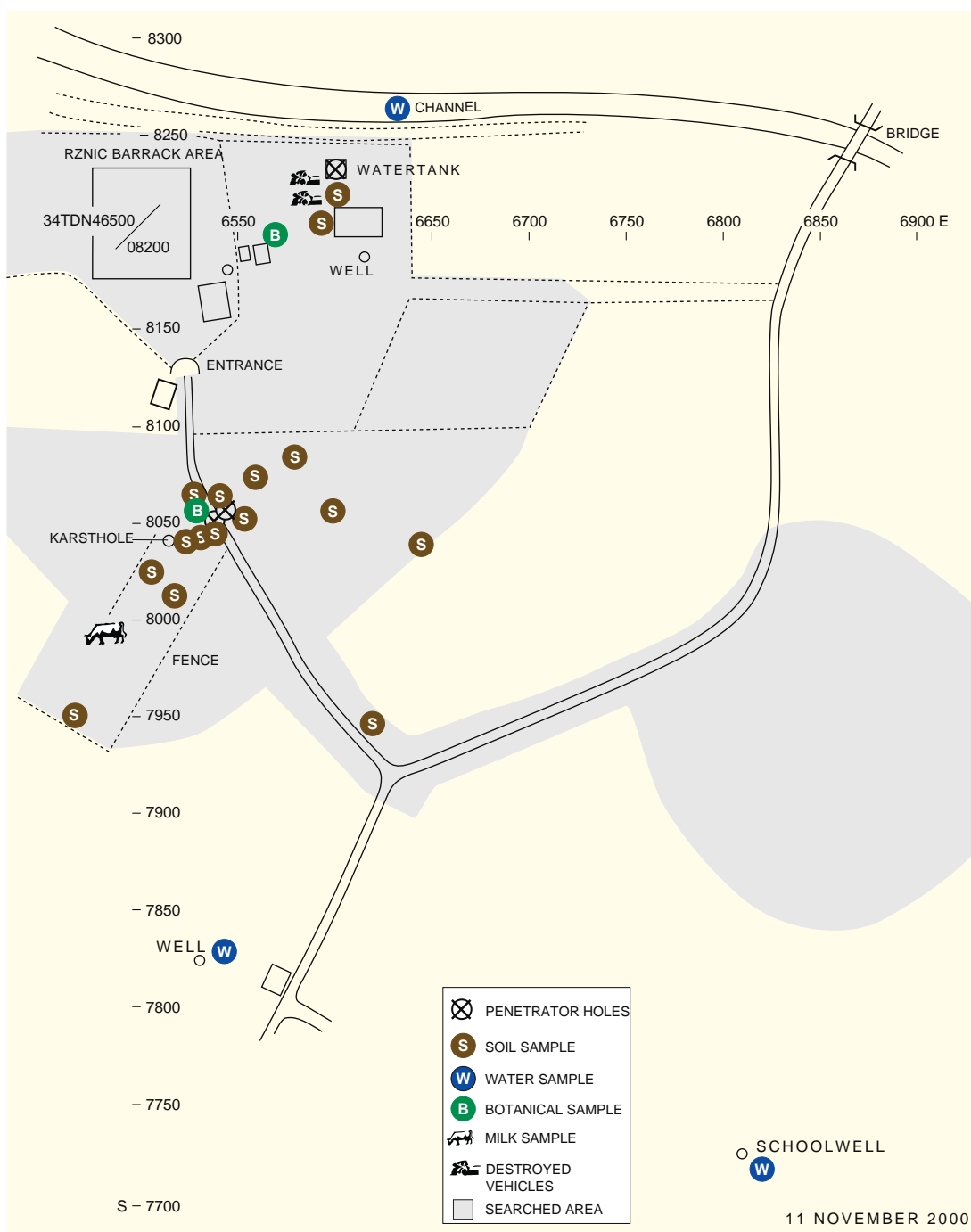
7.5 Irzniq/Rznic barracks

Site description and general information

- Irzniq/Rznic barracks (NATO reference no. 97).
- Coordinates: DN465 083
- See map and map of site.
- Investigated by the UNEP mission on 7 and 11 November 2000.

Irzniq/Rznic barracks is a former Yugoslavian army (VJ) arms depot 500 m to the north of Irzniq/Rznic village. The site contained several partly or completely destroyed buildings and military vehicles. The barracks are surrounded by fields and pasture where cows were grazing at the time of the UNEP mission. According to NATO information A-10 aircraft attacked the barracks and the adjacent areas on 7 June 1999. During the attack, 530 rounds were fired. Prior to the UNEP mission, an Italian KFOR EOD unit had found a penetrator hole in a water tank at the barracks and a penetrator lying in a field 400 m south east of the barracks. The size of the attacked area is approximately 500 x 500 m.

► Map 9: Irzniq/Rznic barracks site



The ground in the area is red-brown silty-clayey soil. There are no rock outcrops but four newly formed karst holes in the area studied indicate that the bedrock consists of limestone. The uranium concentration in the soil is low (2-3 mg/kg U). The gamma radiation is about 0.1 $\mu\text{Sv/h}$.

Summary of samples taken at Irzniq/Rznic barracks:

- 40 soil samples from a total of 21 localities
- 11 botanical samples
- 8 water samples of which 3 were taken from the canal north of the barracks, 2 from the school well and the rest from other wells in the area
- 1 milk sample

Field investigations

In the asphalt road 100 m south-east of the barracks there were clear indications of four impacts by penetrators or other ammunition. In addition to these observations there was a contamination point inside a concrete underground water tank east of the barracks. However, there was no other indication or sign of the actual penetrator.

The beta/gamma radiation survey was made on both sides of the road to a distance of 50 m from the holes in the road. A 'line-up survey' (see Appendix III) was made along lines of 30 m parallel to the road, with 2 m between each person, in fields adjacent to the road.

A 'line-up survey' was also made in the field east of the barracks running from the road up to the irrigation channel (see sketch map). The field contained destroyed vehicles, a destroyed house and a water tank. Other areas were measured at random.

A number of soil samples were taken, particularly south-east of the barracks near the holes and in the fields on both sides of the road. Water samples were taken from wells at two farms and the school. Surface water was collected from an irrigation channel situated just north of the barracks. Some biological samples were also taken.

Summary of results

■ Penetrators and jackets

No penetrators or jackets were found.

■ General contamination

Except in the penetrator holes and other slightly contaminated points, the beta and gamma surveys did not indicate any measurable contamination of the ground surface or of soil, i.e. there was no measurable widespread contamination of the area.

■ Soil samples

Close to the holes and other contamination points soil samples were taken at various depths. At one location (UNEP 281 and 282) west of the road and 2 m from a slightly contaminated hole in the road south of the barracks there was a clear indication of DU in the grass, as well as in soil 0 – 1 cm below the surface but not any deeper. The concentration of uranium was within the range of natural variation.

Another soil sample, which was taken close to contaminated points on the road is the sample numbered UNEP 197 (surface soil 0 – 5 cm). This sample was collected 2 m away from the positions where holes with increased beta- and gamma activity (penetrator shot holes) in the road were found. The DU contamination in the surface was low, at about 0.1 mg DU/kg soil.

The sample UNEP 200 (surface soil 0 – 5 cm) was taken 10 m away from the positions where penetrator impact holes with increased beta and gamma activity were found in the road, and on the opposite side of the road from sample UNEP 197. Based on observation of the impact holes, this was considered to be the direction in which the attack had occurred. The DU contamination in the surface was in the same range as for sample UNEP 197, i.e. about 0.1 mg DU/kg soil.

All other samples taken further away from the impact holes showed no measurable contamination.

These results show that contamination by DU can occur in a very limited area if penetrators hit an asphalt road. However, the DU contamination recorded in this situation was very low, at about 0.1 mg DU/kg soil. This low level of contamination might result from the fact that only a few DU penetrators hit the asphalt road surface, which, though harder than the surrounding soil, is relatively soft when compared with concrete. In any case the level of DU found is negligible in comparison with the natural uranium level at the site.

Two other soil profiles were taken in the Rznice area. The samples were collected using a stainless steel core sampler (with a 15 x 15 cm frame) down to a depth of 15 cm. Each core was subdivided into three samples each 5 cm thick. The first core (core 1) was taken from the field behind the Italian KFOR camp, close to the wrecks of bombed and burnt-out vehicles. The profile was taken 155 cm away from the underground concrete water tank where enhanced beta and gamma radiation had been measured, and in the direction in which the rounds were probably fired. The second core (core 2) was taken 50 cm from the penetrator holes on the asphalt road leading to the Italian KFOR camp. The results of uranium assay in the soil samples are presented in table 7.7.

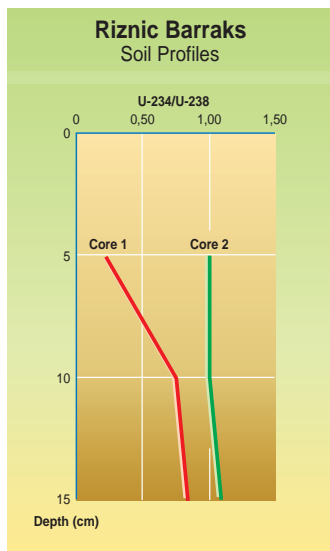
Figure 7.7 Soil Profiles (Irzniq/Rznic Barraks)

Sample number	Core number	Depth [cm]	U-238 [Bq/kg]	U-234 [Bq/kg]	Utot [mg/kg]	U-234/-238
UNEP 055	1	0 – 5	591±874	130±18	25±51	0.22
UNEP 056	1	5 – 10	82±30	62±9	4±2	0.76
UNEP 057	1	10 – 15	77±19	64±8	5±1	0.85
UNEP 051	2	0 – 5	51±11	50±4	5±1	0.99
UNEP 052	2	5 – 10	69±9	69±10	5±1	0.99

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

The distribution of U-234/U-238 activity ratios within the soil profiles is shown in Figure 7.3.

Figure 7.3 Soil Profiles (Irzniq/Rznic Barraks)



In other soil samples taken close to the underground concrete water tank (UNEP 146 – 151) there was a strong indication of DU (70-80 % DU) in the sample taken at 0 – 5 cm depth and a weak indication (15-20% DU) at 5 – 15 cm depth. The total uranium concentration in the upper 5 cm was 11 – 13 mg/kg, or about 4 times the normal natural uranium concentration.

■ **U-236**

The concentration of U-236 in soil was not measurable (i.e. less than a few ng U-236/kg sample) in the samples taken close to the road because the DU concentration was rather low. At the underground water tank the concentration

was 0.2-0.3 µg U-236/kg soil in the upper 0 – 5 cm, corresponding to 2·10⁻⁵ times the U-238 concentration. Levels of U-236 were 10 times lower at 5 – 10 cm depth.

■ **Localised points of concentrated contamination**

Measurable contamination was found by beta/gamma field measurements at the holes in the road (less than 10 cps) and at a concrete underground water tank.

■ **Drinking water**

The water samples (UNEP 048-050, 125-127, 329 and 330) were collected from three nearby wells and the irrigation channel north of the barracks. The uranium content was found to be very low, at 0.03-0.5 µg/l. With regard to possible DU contamination, the results are not conclusive.

■ **Milk sample**

The milk sample, UNEP 341, had a uranium content that was below the detection limit.

■ Botanical samples

Samples were taken from moss, fungus and lichen. Only the lichen sample (UNEP 046) provided an unambiguous measurement result, with a clear indication of the presence of DU (60-100 %).

Site-specific conclusions

■ Measurements

- Penetrators, surface and soil contamination:

According to the information provided by NATO, 530 rounds were fired against Rznic barracks in June 1999. While the UNEP team found no penetrators, an Italian EOD unit had previously found one on a nearby field. Furthermore, the UNEP mission found clear evidence of penetrator holes in the road and a number of other slightly contaminated points.

The field measurements of beta and gamma radiation did not indicate any detectable surface contamination apart from the localised points of contamination in penetrator impact marks. Soil samples taken any further than 10 m from these points did not indicate any measurable contamination. From these results it is concluded that any widespread surface contamination is less than 0.1 g DU/m² (1% of the Reference Case; a maximum of 10 cm migration depth is assumed).

530 rounds equate to approximately 160 kg DU. In the extreme case that all penetrators converted to aerosols on impact and were dispersed by strong winds over an area of at least 160,000 m² the inferred surface contamination of less than 0.1g DU/m² could theoretically be achieved. The targeted area is approximately 500 x 500 m (i.e. 250,000 m²).

Another extreme scenario is that all except a few penetrators never became aerosolised but simply buried themselves in the ground, where they remain hidden.

Some soil samples taken alongside the road close (≤ 10 m) to the penetrator holes in the road surface were contaminated by DU, indicating the shattering of one or more penetrator and subsequent dispersal into the air and fallout onto the ground. The very low contamination (about 0.1 mg DU/kg) might be due to only a few DU penetrators a surface harder than soil, i.e. the asphalt road, which itself is soft when compared with concrete.

One interesting observation is that from the same general area at approximately the same distance from contaminated penetrator holes one UNEP team member obtained a contaminated soil sample, while another did not. This indicates that surface contamination was uneven.

- **Localised points of concentrated contamination**

The amount of measurable DU at the contamination points is small, of the order of 10-100 mg DU.

- **Botanical samples**

The contamination found in the lichen sample appears to be a good indicator of earlier atmospheric DU contamination. However, further investigations are needed before any quantitative or qualitative conclusions can be drawn.

■ **Residual risks**

In the less likely scenario of DU dispersion over a very large area the corresponding residual risk of DU exposure by inhaling contaminated dust or ingesting contaminated food is insignificant with regard to both radiological and toxicological risks.

The more probable scenario is that most of the penetrators remain intact and buried in the ground. This means that there is a chance of drinking water becoming contaminated in the future.

There may still be some penetrators and jackets on the ground at, close to, or relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure through being picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure might be significant.

Because of local contamination of the ground close to the penetrator, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, however, the exposure would be insignificant with regard to radiation (<10 μ Sv) but could be significant from a toxicological viewpoint.

■ **Need for mitigation**

There is no risk of high radiation doses or serious heavy metal toxicity, either now or in the future.

Nevertheless, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators or jackets found should be dealt with by the local authorities or by KFOR. They should not be kept in homes or handled by children.

The drinking water in nearby wells should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

7.6 Bandera and Pozhare/Pozar

Site description and general information

- Bandera and Pozhare/Pozar (NATO reference no. 88).
- Coordinates: DN474 090.
- See map of general location in Kosovo and sketch map of site.
- Investigated by the UNEP mission on 12 November 2000.

The site consists of two small villages surrounded by fields and pasture. A forest and a small river lie to the south. During the Kosovo conflict the whole area was a theatre for a range of military operations involving tanks and armoured vehicles. A mortar position was located in the forest. During the UNEP mission it could be seen that the area had been attacked by cluster bombs, and that some of houses were partly destroyed. According to NATO, the site had been attacked by A-10 aircraft on two occasions on 6 June 1999. During these attacks, 945 rounds had been fired. By November 2000, the area had only been partly cleared of mines and unexploded ordnance, which hampered the investigation. The size of the attacked area was approximately 400 x 500 m.

➤ Map 10: Bandera and Pozhare/Podzhar site



The ground in the area consists of red-brown silty-clayey soil. The uranium concentration is low (the one soil sample taken in the area had a concentration of 2 mgU/kg sample). The gamma radiation was found to be about 0.08 μ Sv/h.

Summary of samples taken at Bandera – Pozhare/Pozar:

- 1 mixed soil sample
- 12 water samples (3 of river water, 3 from a well at ‘farm 1’, 3 from a well at ‘farm 2’, and 3 from a well at ‘farm 3’)
- 3 botanical samples (1 fungus, 2 bark)
- 1 milk sample

Field investigations

The area was visited because a large number of rounds had reportedly been fired during the conflict and there were possible signs on the walls of one building that it had been hit several times (though not necessarily by DU rounds). However, at the time of the UNEP mission the area had not been made safe from landmines and unexploded cluster bombs, meaning that regular ‘line-up survey’ measurements were not possible.

However, the roads near the two villages were surveyed with beta and gamma measuring equipment as were farmhouse gardens, yards and buildings. The area where the mortar station had been located was also measured. These measurements were made on an individual, random basis. For security reasons, it was not possible to take measurements from the surrounding fields.

12 water samples were taken from wells at the farms and from an adjacent river. Two bark and one mushroom samples were also taken.

Summary of results

The results can be summarised as follows.

■ Penetrators and jackets

No penetrators or jackets were found.

■ General contamination

The beta and gamma field measurements did not indicate any measurable DU contamination of the area.

■ Localised points of contamination

No areas of elevated activity were detected.

■ Soils samples

Only one soil sample (UNEP 301) was taken, namely, a near-surface (0 – 5 cm) sample from one of the farms. No evidence of DU contamination could be detected.

■ Drinking water

The drinking water samples were taken from wells at the farms, at depths of 11 m and 14 m; from a hand dug well at 4 m depth; and from a nearby river. No DU contamination could be detected.

■ Milk sample

Milk sample UNEP 342 had a low uranium concentration of 0.036 µg/l.

■ Botanical samples

Samples of bark, UNEP 058, 060 clearly indicated DU contamination, but at low levels.

Site-specific conclusions

■ Measurements

- Penetrators, jackets, surface and soil contamination:

945 rounds were reportedly fired at the area visited, but no penetrators or jackets were found. Nor were any signs of penetrator hits found (i.e. no contaminated holes or marks in the road or elsewhere). Therefore the rounds were either converted to aerosols on impact, with the DU dust dispersed over a wide area, or most of the DU penetrators are buried in the ground within an area of approximately 400 x 500 m².

The measurements from the bark samples indicated earlier atmospheric contamination by DU, probably as a result of DU dust dispersal. However, because of the security risk posed by unexploded ordnance, potentially contaminated areas could not be measured, or soil samples taken. Therefore, no clear conclusion can be drawn concerning this targeted area.

- Drinking water:

No DU contamination could be detected and the uranium concentration was within the range of natural variation.

- Botanical samples

The contaminated bark appears to be a good indicator of atmospheric contamination by DU. However, further investigations are needed before any quantitative and qualitative conclusions can be drawn.

- Residual risks

Because only very limited measurements could be made, the few results available are inconclusive for the area as a whole. However, bearing in mind the results from

the other sites visited by the UNEP mission, there are no special reasons to suspect that this particular site had been contaminated to levels that would be of any concern with regard to human health.

There may still be some penetrators and jackets on the ground at, close to and relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure through being picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure might be significant.

However, it is likely that most of the penetrators fired remain intact and buried in the ground. This means that there is a chance of drinking water becoming contaminated in the future.

Because of local contamination of the ground close to penetrators, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, the exposure would be insignificant with regard to radiation (<10 µSv) but could be significant from a toxicological viewpoint.

■ Need for mitigation

Because of the very limited area that could be investigated in detail, it is recommended that the site should be subject to further studies once the area has been cleared of land mines and unexploded cluster bombs.

It is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators or jackets found should be dealt with by the local authorities or by KFOR. They should not be kept in homes or handled by children.

The drinking water in nearby wells should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

7.7 Rikavac

Site description and general information

- Rikavac (NATO reference no. 69).
- Coordinates: DM743 720.
- See map of general location in Kosovo and sketch map of site.
- Investigated by the UNEP mission on 13 and 16 November 2000.

The investigated site lies a few kilometres south-west of Prizren. It consists of an asphalt road bordered on both sides by flat farmland containing minefields that had not yet been cleared at the time of the UNEP visit (though one field had been

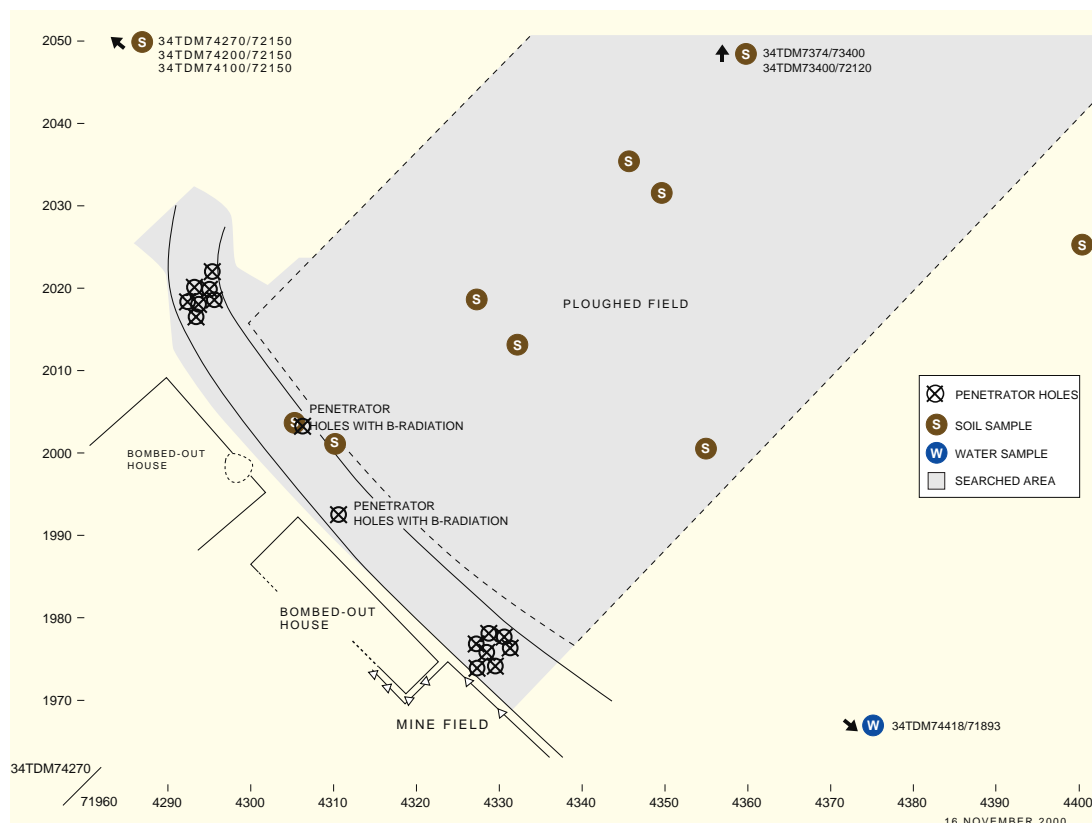
ploughed by farmers and was considered relatively safe). Destroyed farm buildings were situated close to the road but these were considered unsafe to visit. The road provides the only access to a small village located higher up in the nearby hills. It was clear that the area had been heavily bombed, with the probable targets having been a vehicle on the road and adjacent military positions. According to NATO, A-10 aircraft had attacked the site on the 2 June 1999. During the attack, 400 rounds had been fired. The size of the attacked area was approximately 200 x 300 m.

The ground consists of black soil. The natural uranium concentration is very low (0.6-1.5 mg/kg), with gamma radiation of 0.05-0.1 $\mu\text{Sv/h}$.

Summary of samples taken at Rikavac:

- 16 soil samples from 13 different places
- 3 water samples from a nearby stream

► Map 11: Rikavac site



Field measurements

Because there were still mines and cluster bombs in a large part of the area of interest, it was not possible to perform field measurements and soil sampling as planned.

A ‘line-up survey’ was carried out in a safe area at a cement factory south of the main road and on a ploughed field, while individual field measurements were made along about 200 m of the side road, starting from the main road.

There were a number of clearly identifiable ammunition holes and impact marks from DU rounds on the asphalted side road. However, only two of the approximately 15 impact marks showed any measurable DU contamination.

Soil samples were taken from the two contaminated holes, from the side of the side road close to the contaminated holes, from the ploughed field every 50 m from the side road, and from a nearby field. Along the main road in a westerly direction, three samples were taken between 5 and 15 m north of the road, with one at 30 m, one at 100 m and one at 190 m from the junction of the main road and side road. These last samples, UNEP 323 – 325, were considered as background samples taken far from the target area.

Water samples were taken from a nearby stream.

Summary of results

■ Penetrators and jackets

No penetrators or jackets were found.

■ General contamination

With the beta/gamma instruments used, there was no detectable DU contamination either on the road (except in two impact holes, see below), beside the road, in the cement factory, or in the fields.

■ Soil samples

Soil samples were taken at various depths in one of the contaminated holes in the road. The results are summarised in table 7.8.

Table 7.8 Isotopic compositions of soil samples taken from contaminated hole in road surface

Sample number	Sample type and depth	U-238 [mg/kg]	U-235 [µg/kg]	U-236 [µg/kg]	U-235/U-238	% DU of total U
UNEP 228	Hole 0 – 5cm	529	1070	12.6	0.002025	99.6
UNEP 229	5 – 10 cm	2753	5557	71.0	0.002019	99.7
UNEP 230	10 – 15 cm	6615	13317	165	0.002013	99.8
UNEP 231	15 – 20 cm	6608	13319	167	0.002016	99.8
UNEP 232	Soil 0 – 5 cm	1.33	8.40	ND*	0.006342	17.1
UNEP 233	0 – 5 cm	1.47	10.57	ND*	0.007190	1.0
UNEP 234	0 – 5 cm	1.61	10.70	ND*	0.007277	<1

*ND = below the detection limit

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

The samples UNEP 228 – 231 were taken from an impact hole in the asphalt road where field measurements had showed higher gamma- and beta activity at the surface immediately above the hole. The samples were taken out of the hole using a stick sampler that fitted directly into the hole. The samples showed contamination by DU in the layer 0 – 5 cm depth of 527 mg DU/kg, followed by 2,745 mg DU/kg in the 5 – 10 cm layer, 6,602 mg DU/kg in the 10 – 15 cm layer, and 6,595 mg DU/kg in the 15 – 20 cm layer. The total weight of these samples was about 10 g. The analysis results show that the contamination within the hole consisted of some 100 mg of DU.

Two metres away from the hole discussed above, and directly beside the road, a surface (0 – 5 cm) soil sample, UNEP 232, was taken. It showed low-level DU contamination of 0.23 mg DU/kg. Sample UNEP 233 was taken from the ploughed field, 20 m away from the impact hole, and showed 0.015 mg DU/kg, a very low level of contamination.

The sample UNEP 234 was taken in the direction in which the A-10 attack could have taken place, 100 m from the impact hole referred to above, and at the edge of a mine field where the soil had not been disturbed. No DU contamination was found.

The results confirm the observations for other sites visited by UNEP, namely that low level DU contamination of soil may occur within a few metres of the point of impact of a DU penetrator.

With regard to the other soil samples taken (0 – 1 cm in the ploughed field at 1.5 m, 50 m, 100 m and 140 m from the road), there was no indication of DU and the uranium concentration did not differ significantly from those of the samples taken further along the main road some distance away from the targeted area.

■ Localised points of concentrated contamination

Two contaminated penetrator impact holes were found. Field measurements showed 16 cps and 22 cps respectively. The second hole was the one from which the soil samples discussed above were taken. Assuming 0.03 cps per Bq, with at least 90% absorption, which is not unreasonable in the given situation, the reading of 22 cps would correspond to at least 60 mg of DU. This compares with the figure of 100 mg estimated above.

■ U-236

U-236 was measurable in the soil samples taken from one of the contaminated holes in the road, with the activity concentration varying from $2.4 - 2.6 \cdot 10^{-5}$ times the U-238 concentration in the case of pure DU. This value is in good agreement with the values obtained from other sites (e.g. Radoniq/Radonjick lake).

■ Water samples

There was no indication of DU contamination in the stream water, where uranium concentrations were found to be within the range of natural values, at about 0.4 µg/l.

Site-specific conclusions

■ Measurements

- Penetrators, surface and soil contamination:

400 rounds had reportedly been fired against the area visited, but none was visible on the surface or elsewhere. However, several signs of penetrator hits were found, two of them still showing DU contamination. There was a clear evidence of DU dust dispersal and contamination of the ground from within the nearest few metres from the contaminated points of impact on the road.

As at other sites the question remains of what happened to all the other penetrators. The measurements at this site did not give any new information that could help to provide an answer. One possibility is that the majority of penetrators hit soft surfaces and remain buried in the ground.

There was no detectable DU concentration in the soil a few metres away from the road. The field measurements along both sides of the road did not indicate any surface contamination other than the two contaminated penetrator holes themselves. Even though the field measurements and the number of soil samples were limited by safety considerations to the area close to the road and on the nearby ploughed field, it would be reasonable to conclude that there was no detectable DU contamination of the area as a whole.

■ Residual risks

The only DU contamination was that found in two of the impact holes in the road. The remaining activity is rather tightly bound to soil and asphalt material in the hole, but it is always possible that people could be contaminated as a result of intentional or unintentional contact with this material. However, the corresponding risks of exposure to DU by inhalation or ingestion are insignificant from both chemical and radiological viewpoints.

The only possible way of being significantly exposed would be through direct ingestion of contaminated soil and asphalt. This would result in very low radiation doses ($< 10 \mu\text{Sv}$) but could be significant with regard to the toxicological consequences.

Because there was no detectable contamination of the ground other than close to the contaminated penetrator holes, any widespread surface contamination must be less than $0.1\text{-}1\text{g DU/m}^2$. The residual risk of DU exposure through inhalation of contaminated dust or ingestion of contaminated food is insignificant.

There may still be some penetrators and jackets on the ground within, close to, or relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure if picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure

is insignificant but from a toxicological point of view the exposure might be significant.

Because of local contamination of the ground close to penetrators, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, the exposure would be insignificant with regard to radiation ($<10 \mu\text{Sv}$) but could be significant from a toxicological viewpoint.

It is possible that many penetrators remain intact and buried in the ground. This means that there is a chance of drinking water becoming contaminated in the future through dissolution and percolation into wells and streams.

■ Need for mitigation

There is no risk of high radiation doses or serious heavy metal toxicity, either now or in the future.

Nevertheless, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators and jackets should be dealt with by the local authorities or by KFOR. Penetrators and jackets (including fragments), should not be kept in homes, and children should be warned not to touch them.

The drinking water in adjacent wells should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

The contaminated penetrator holes could easily be isolated by repairing the road.

Only few measurements were possible because of safety concerns. It would therefore be prudent to carry out further investigations, once the area has been made safe, to confirm the preliminary conclusion that there is no widespread surface contamination in the area as a whole.

7.8 Ceja mountain

Site description and general information

- Ceja Mountain (NATO reference no. 83).
- Coordinates: DM6725 6935.
- See map of general location in Kosovo and sketch map of site.
- Investigated by the UNEP mission on 14 November 2000.

This mountaintop site, which lies close to the Albanian border, was a former Serbian army and anti-aircraft position. According to information provided by NATO, A-10 aircraft attacked the site on 5 June 1999, firing 290 rounds. At the time of the UNEP mission, the site had not been cleared of mines and unexploded ordnance. Consequently, investigations

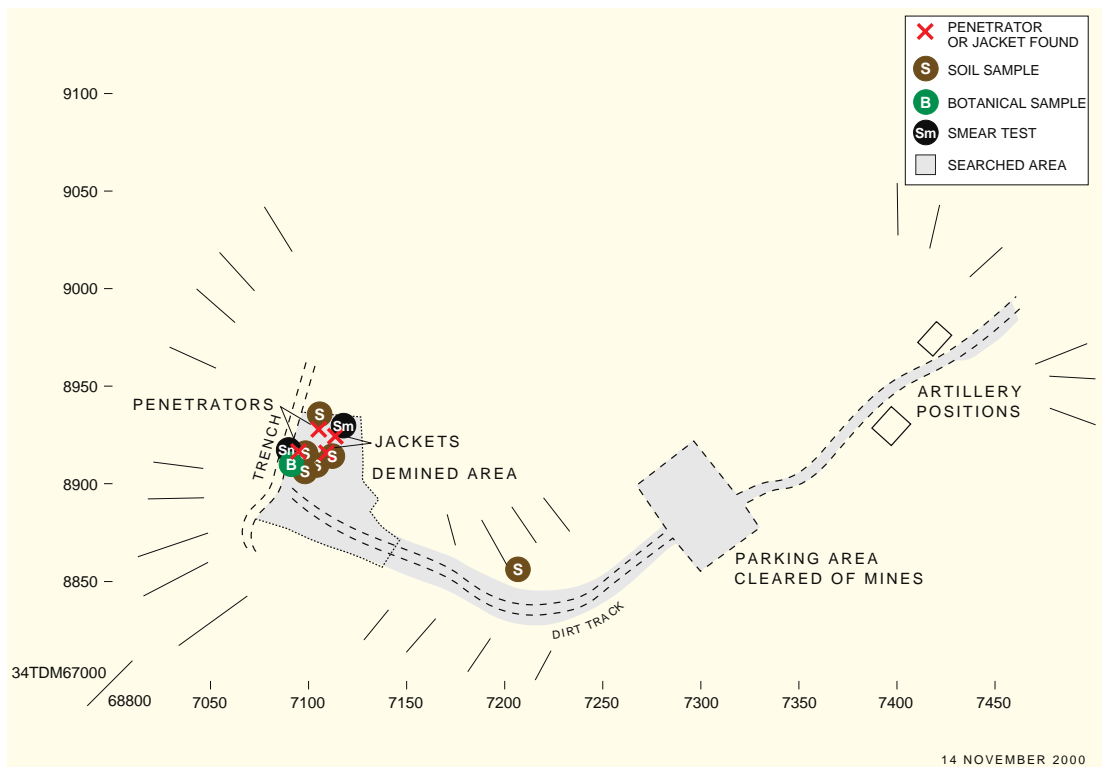
had to be concentrated in an area of 35 x 70 m. A German EOD unit had previously found two jackets in this area.

The ground consists mainly of limestone outcrops with a thin layer of stony sandy-silty soil. Woody shrubs (e.g. rosemary, thyme, heather) form the main components of the vegetation. The uranium concentration in the soil is low, at 0.8-2 mg/kg, with gamma radiation being about 0.05 µSv/h.

Summary of samples taken at Ceja Mountain:

- 24 soil samples from 21 different places
- 14 botanical samples, mainly plants and roots
- 4 smear tests on the penetrators and jackets found at the site
- 2 jackets

► Map 12 : Ceja Mountain site



Field investigations

Because of the very strict safety restrictions in this area, it was not possible to make any regular 'line-up survey'. Instead, individual surveys and measurements were carried out at random. These successfully located two DU penetrators, four jackets and three contaminated holes.

A number of soil samples were taken from beneath and at varying distances around the penetrators and jackets. Samples were also taken from within and around the contaminated impact holes. Some of the samples contained plant matter.

A number of smear tests were carried out on the two penetrators and four jackets located in the area.

Finally, a number of experimental measurements were taken.

Summary of results

■ Penetrators and jackets

Two penetrators and four jackets were found in a relatively small area of 35 x 70 m. This represents the highest density of found penetrators and jackets at any site investigated by the UNEP mission. The surfaces of the penetrators and jackets were smear tested for loose contamination, and the ground surface and soil around them were sampled for contamination (see below). All the penetrators and jackets were removed from the site.

■ General contamination

The searched area was too small to draw any conclusions with regard to any general surface contamination of the site as a whole.

■ Soil samples

Most soil sampling was carried out as part of the studies of contamination below and around penetrators and jackets. Only a few samples were taken to measure possible contamination further away from these specific areas. Some results are shown in table 7.9.

Table 7.9 Soil samples from contamination points at Ceja mountain

Sample number	Sample depth	U-238 [mg/kg]	U-235 [µg/kg]	U-236 [µg/kg]	U-235/U-238	% DU of total U
UNEP 206	5 – 15 cm	7591	15297	233	0.002015	99.8
UNEP 207	15 – 20 cm	2774	5585	85.6	0.002014	99.8
UNEP 208	0 – 20 cm	2076	4192	61.3	0.002019	99.7
UNEP 209	0 – 5 cm	2.01	13.22	-	0.006594	12.3
UNEP 210	0 – 5 cm	1.84	12.15	-	0.007217	<1
UNEP 211	0 – 5 cm	1.59	11.49	-	0.007228	<1

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

Samples UNEP 206 and 208 were taken from a penetrator hole which showed elevated gamma- and beta activity during field measurements of the ground surface. A penetrator jacket was found at this point. The corresponding DU contamination from this impact lies in the range of 2,100 mg DU/kg to 7,600 mg DU/kg. The area from which contaminated material was extracted measured 10 x 10 cm to a depth of 20 centimetres, though large stones could not be removed. About 2 kg of soil and stony

material was removed in total and measurements showed that the penetrator had lost a few grams of DU (1 – 10% of the weight of a penetrator) in this material. No penetrator fragments could be found in the hole. There is no clear explanation of why the beta field measurements reached natural background levels once more beyond a depth of 20 cm. It might be that this penetrator continued as a ricochet.

Sample UNEP 209 was taken 5 metres away from the impact site discussed above. It showed DU contamination of the surface soil of 12.3% or 0.25 mg DU/kg. Samples UNEP 210, taken 20 m further away, and sample UNEP 211, from 100 metres away, did not show any DU contamination of top soil.

This overall picture is consistent with the surface contamination observations made elsewhere during the mission. It also shows that localised points of contamination can be heavily contaminated and that the level of contamination can vary greatly. For example, at another contaminated penetrator impact hole, the soil contamination varied from about 100 to 700 mg DU /kg soil.

Additional measurements beneath a jacket also showed high concentrations of DU (85-90% DU) or 4 g DU/kg soil at 0 – 5 cm depth and 1 g DU/kg at 5 – 10 cm depth. The DU contamination is evident within the upper 20 cm in all these measurements.

In another study, the ground contamination at various depths between two penetrators was measured. The total distance was 18 m and the results are presented below in table 7.10.

Table 7.10 The relative concentration of DU in samples taken in the upper part of the ground between two penetrators found at Ceja mountain

Sample number penetrator 1	Distance from	Sample type and depth	U-238 [mg/kg]	U-235 [µg/kg]	U-235/U-238	DU % of total uranium
UNEP 302	0.3 m	grass, roots, soil	7.03	18.5	0.00263	88
UNEP 303a	0.3 m	roots 0 – 1 cm	5.84	15.9	0.00272	86
UNEP 303b	0.3 m	grass, roots, soil 0 – 1 cm	1.70	7.00	0.00411	59
UNEP 304	0.3 m	soil 1 – 5 cm	1.28	6.60	0.00516	39
UNEP 305	0.3 m	soil 5 – 10 cm	0.914	5.80	0.00634	16
UNEP 306	6 m	grass, roots	1.31	6.6	0.00504	41
UNEP 307	6 m	roots, soil 0 – 1 cm	1.28	8.1	0.00634	16
UNEP 308	6 m	roots, soil 1 – 5 cm	0.793	5.6	0.00706	3
UNEP 309	6 m	roots, soil 5 – 10 cm	1.03	7.3	0.00709	2
UNEP 310	12 m	grass, roots, soil	2.77	10.7	0.00386	64
UNEP 311	12 m	roots, soil 0 – 1 cm	1.45	8.40	0.00581	27
UNEP 312	12 m	roots, soil 1 – 5 cm	1.14	7.60	0.00665	11
UNEP 313	12 m	roots, soil 5 – 10 cm	0.862	6.10	0.00708	2
UNEP 314	17.7 m	grass, roots, soil	19.5	44.7	0.00229	94
UNEP 315	17.7 m	grass, roots, soil 0 – 1 cm	24.2	55.3	0.00228	95
UNEP 316	17.7 m	soil 1 – 10 cm	7.84	22.1	0.00282	84

Notes: the concentration values are related to the leachable part of the uranium, which might mean an underestimate of natural uranium and an overestimate of the DU percentage.

Information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise, and, if so, whether it passed, is contained in Appendices III and X.

From the results shown in Table 7.10, it can be concluded that there is clear DU contamination in all the samples, that the DU fraction is highest close to the penetrators, and that the contamination goes deeper into the ground (0 – 10 cm) immediately below the penetrators. Half way between the penetrators the contamination is superficial. These results show once again that the surface contamination caused by a penetrator impact on the ground (though bearing in mind the soft substrate in this case) is significant only close to the point of impact.

The apparent DU contamination of biological material is controversial because uptake by roots is believed to be small. This phenomenon should be examined in more detail in order for firm conclusions to be drawn.

■ U-236

The concentration of U-236 was measurable in some of the samples and found to be 0.003% of the total uranium concentration.

■ Botanical samples

The botanical samples were those described above. The measurement results were not conclusive.

■ Smear tests

Smear tests were carried out on two penetrators. One showed 52 Bq U-238 and 0.8 Bq U-235 or 4 mg U-tot. The other gave 88 Bq U-238 and 1.27 Bq U-235 or 7 mg U-tot. Both samples indicated DU (0.2% abundance of U-235).

Site-specific conclusions

■ Measurements

- Penetrators and jackets:

According to information provided by NATO, 290 rounds were fired at this area. Two penetrators and four jackets were found by the UNEP team in a relatively small area. The overall target area was presumably much larger than the investigated area and it is most probable that there are still many penetrators and jackets lying on the surface elsewhere at the site. Another reason for this assumption is the fact that the ground was quite rocky, which may have resulted in many ricochets. All penetrators and jackets found were taken away from the site.

- Soil

Soil was only found to be contaminated either close to or beneath the penetrators and jackets lying on the ground, with contamination extending only a few metres away. Soil contamination appeared to be mainly in the upper 10 – 20 cm, similar to the findings from other sites visited by UNEP. The amount of DU contamination is a few grams, i.e. a few per cent of the activity of a penetrator.

Because of the very limited area investigated there are no conclusions regarding contamination of the targeted area as a whole.

■ Residual risks

Because of safety restrictions the investigated area was very small when compared with the total potentially affected area. However, in the area actually studied, there is no risk of high radiation doses or serious heavy metal toxicity, either now or in the future.

There may still be some penetrators and jackets on the ground within, close to, or relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure if picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure might be significant.

Because of local contamination of the ground close to penetrators, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, the exposure would be insignificant with regard to radiation ($<10 \mu\text{Sv}$) but could be significant from a toxicological viewpoint.

Because the large distance to populated areas there is no risk of drinking water becoming contaminated from DU that may remain in the environment. For the same reason, the other possible risks associated with remaining penetrators, jackets and contamination points are much smaller than for sites close to populated areas. Nevertheless, it is unsatisfactory that the risk cannot be assessed quantitatively because the targeted area could not be investigated in its entirety.

The findings support the conclusion that the pattern of DU contamination in rocky areas might be significantly different from that in soil-covered areas. The risks of DU ground surface contamination may be much higher than in areas with a thick soil layer. This possibility should be considered when planning and carrying out any future decontamination work.

■ Need for mitigation

There is no risk of high radiation doses or serious heavy metal toxicity either now or in the future.

Nevertheless, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators and jackets should be dealt with by the local authorities or by KFOR. Penetrators and jackets (including fragments), should not be kept in homes, and children should be warned not to touch them.

As few measurements were possible because of the risk to personal security, it would be prudent to complete the investigation after the area has been made safe. This would permit the drawing of conclusions for the site as a whole.

7.9 Planeje/Planeja village

Site description and general information

- Planeje/Planeja village (NATO reference no. 60).
- Coordinates: DM65 73.
- See map of general location in Kosovo and sketch map of site.
- Investigated by the UNEP mission on 14 November 2000.

The study area is close to the small village of Planeje/Planeja on the slopes of the Pastric mountain which marks the border between Albania and Kosovo. The site itself is at a road junction close to a cemetery. During the conflict, the Serbs held positions in and around the village. In November 2000, the whole area showed signs of heavy fighting and the village was mostly in ruins. According to NATO it had been attacked on 31 May 1999 by A-10 aircraft which fired 970 rounds. The size of the targeted area is not known.

➤ Map 13: Planeje/Planeja site



The terrain is very solid and rocky. The uranium concentration in the soil was found to be low (1-2.5 mg/kg), with gamma radiation of 0.05-0.1 $\mu\text{Sv/h}$.

Summary of samples taken at Planeje/Planeja village:

- 9 soil samples
- 3 water samples, all from the same well
- 1 milk sample
- 2 botanical samples
- 2 penetrators
- 1 jacket

Field investigations

Beta/gamma radiation survey measurements were made by 'line-up survey' in an area 150 x 200 m in a field close to the cemetery. Individual survey measurements were made at random along the road in the village and at a largely destroyed house (the first house on the right-hand side of the road).

Soil samples were taken from the field close to and at varying distances from both a penetrator and a contaminated impact site.

Drinking water samples were taken from a nearby well. One milk sample, UNEP 343, was collected from a farm in the village.

Summary of results

■ Penetrators and jackets

Two penetrators and one jacket were found on the surface.

■ General contamination

Except at localised places such as contaminated impact points or close to penetrators and jackets, the beta/gamma surveys did not indicate any measurable widespread contamination of the area.

■ Soil samples

Samples were taken from beneath and at various distances from a penetrator. The results are summarised in table 7.11.

Table 7.11 The ground contamination below a penetrator and at varying distances from the penetrator, Planeje/Planeja village

Sample number	Sample type and depth	U-238 [mg/kg]	U-235 [µg/kg]	U-236 [µg/kg]	U-235/U-238	DU % of total uranium
UNEP 216	Soil 0 – 10 cm, beneath penetrator	177	360	5.086	0.002035	99.4
UNEP 217	Soil 0 – 5 cm, 1 m from penetrator	2.20	11.41	0.0257	0.005198	38.9
UNEP 218	Soil 0 – 5 cm, 10 m from penetrator	1.43	9.69	-	0.006801	8.4
UNEP 219	Soil 0 – 5 cm, 20 m from penetrator	1.32	9.38	-	0.007130	2.1

Note: information on which laboratory provided a particular result, whether that laboratory participated in the quality control exercise and, if so, whether it passed, is contained in Appendices III and X.

As can be seen from table 7.11, the concentration of DU decreases drastically beyond 1 m from the penetrator. At 10 – 20 m from the penetrator DU accounts for only a few percent of the total uranium concentration.

A sample taken at a contaminated impact point contained about 790 mg uranium/kg soil, more than 90% of which was DU.

■ U-236

U-236 was measurable in soil close to the penetrator. The maximum concentration was 2.9 10⁻⁵ times the U-238 concentration.

■ Drinking water

No measurable DU concentration was found in drinking water (UNEP 077, 123, 338).

■ Milk sample

The milk sample had a total uranium concentration of 0.77 µg/l (UNEP 343).

Site-specific conclusions

■ Measurements

- Penetrators and jackets:

As indicated above, some 970 rounds were reportedly fired at the target area, probably only a small part of which was investigated (i.e. an area of 150 x 200 m at the cemetery, together with a few measurements in the village). Nevertheless, two penetrators and one jacket were found.

The field measurements and soil sample analyses showed no detectable contamination except within a few metres of penetrators or penetrator impact sites. This means that any widespread contamination was less than 1 g DU/m² (10% of the Reference Case). If all 970 penetrators had aerosolised on impact, the approximately 300 kg of DU released into the environment would have to have been dis-

persed over an area of at least 300,000 m² in order to be not measurable. This is entirely plausible if the whole area of the village is taken into account. However, the conversion of all penetrators to aerosols is, in itself, not very probable.

According to the conclusions from other sites, the majority of the penetrators are probably buried in the ground after having missed the target or after hitting relatively soft targets. It is not known if there are any further penetrators on the surface of the ground inside the village.

■ Soil samples

The results from soil sampling confirmed the conclusions from other sites that measurable ground contamination is limited to the immediate vicinity of penetrators lying on the surface. The very few soil samples taken at greater distances from the penetrators did not indicate any DU contamination of the soil.

■ Residual risks

Because of safety restrictions, the investigated area was small when compared with the total area potentially affected area during the military attack. However, within the investigated area, there is no risk of high radiation doses or serious heavy metal toxicity either now or in the future.

There may still be some penetrators and jackets on the ground within, close to, or relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure if picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure might be significant.

Because of local contamination of the ground close to penetrators, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, the exposure would be insignificant with regard to radiation (<10 µSv) but could be significant from a toxicological viewpoint.

Many penetrators may remain hidden in the ground. Eventually these could dissolve, with the DU entering the ground water. There is consequently a possibility that the drinking water in some nearby wells could become contaminated.

Because the village is very close to, or possibly part of, the area targeted by DU ammunition, many penetrators could be buried in the ground in the village. In the near future, during restoration of the village, some penetrators may therefore be brought up to the surface again. Should this happen, people will need to know what to do.

■ Need for mitigation

It is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators and jackets should be dealt with by the local authorities or by KFOR. Penetrators and jackets (including fragments), should not be kept in homes, and children should be warned not to touch them.

The drinking water in nearby wells should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

Few measurements were possible owing to security concerns. Therefore it is recommended that investigations be completed once the area has been made safe, in order to confirm the preliminary conclusion that there is no widespread ground surface contamination of the area as a whole. This additional survey work should also include a search for any penetrators remaining on the surface, particularly within the village area.

7.10 Bellobrade/Belobrod

Site description and general information

- Bellobrade/Belobrod (NATO reference nos. 30 and 35).
- Coordinates: DM74 62
- See map of general location in Kosovo and sketch map of site.
- Investigated by the UNEP mission on 15 November 2000.

The investigated site lies at approximately 1,000 m altitude and consists of a flat, grassy field on soft soil. A road runs through the field and there is a village (Bellobrade/Belebrod) nearby. During the Kosovo conflict, the site had been used by Serbian heavy artillery, signs of which were still visible. There were probably also armoured vehicles in the vicinity. According to NATO the site was attacked twice on 15 May 1999, with more than 1,000 rounds fired. The size of the targeted area is not known. At the time of the UNEP mission, sheep were grazing on adjacent fields. The soil in the area was found to consist of silt and fine sand. The natural uranium concentration was low (3 – 4 mg/kg), with gamma radiation readings of 0.06 – 0.1 $\mu\text{Sv/h}$.

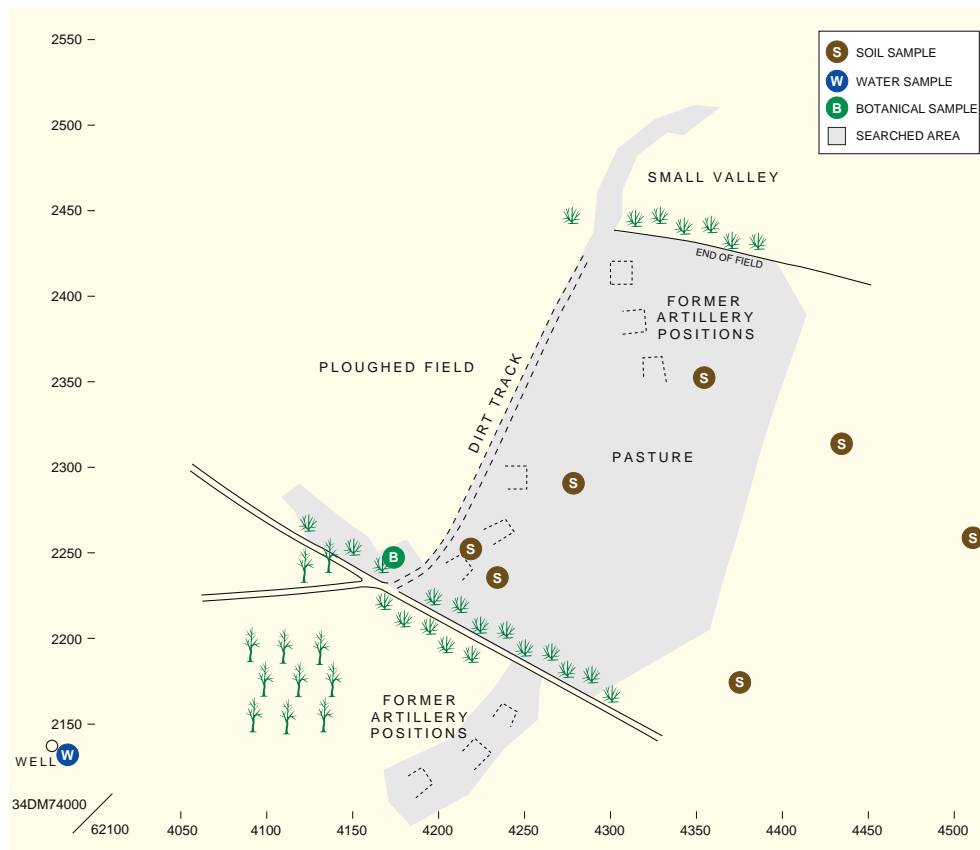
Summary of samples taken at Bellobrade/Belebrod:

- 7 soil samples
- 1 lichen and moss sample
- 3 water samples collected from the same well

Field investigations

Beta/gamma radiation survey measurements were made by using the 'line-up survey' technique in an area of 250 x 100 m in a field north of the road to the village.

► Map 14: Bellobrade/Belobrod site



Individual survey measurements were made at random, particularly at places where there were signs in the ground of artillery and tanks, as well as along the road. The whole area surveyed was about 200 x 300 m.

Soil samples were taken from 0 – 5 cm depth at various points in the area.

Summary of results

■ Penetrators and jackets

No penetrators or jackets were found.

■ General contamination

Neither the beta/gamma field measurements, nor the soil sample measurements indicated any measurable widespread contamination of the area (see below for more details).

■ Soil samples

None of the soil samples showed any indication of DU contamination.

■ Botanical samples

A sample of lichen and moss (UNEP 078) taken from a tree in the area contained clear indications of the presence of DU. The U-238 concentration was 3.6 mg/kg sample, while the U-235 concentration of 0.0103 mg/kg indicated more than 80 % of DU in the sample.

Site-specific conclusions

■ Measurements

- Penetrators, jackets and surface contamination:

More than 1,000 rounds were reportedly fired at the area but no penetrators or jackets were found and there were no signs of any impact points or residues of penetrators or jackets. There was also no indication of any contamination of the ground.

However, the measurements from the lichen and moss sample indicate earlier airborne DU contamination which must have come from DU rounds that aerosolised on impact during the military attack in 1999. The measurements and sampling from the ground do not answer the question of how much DU became airborne. Possible contamination of the ground was not measurable either with field beta/gamma equipment or with soil sampling. This means that any ground contamination was less than 0.1 g DU/ m² (<1% of the Reference Case), at least in the investigated area which covered some 25,000 m². 1,000 penetrators would contain about 300 kg DU. From these figures, it can be concluded that 2.5 kg of DU could be contained within the investigated area, though so thinly scattered that it was below detection limits. In any case, 2.5 kg would account for approximately 1% of the total DU fired.

Therefore, either more than 1% of the penetrators were aerosolised and dispersed over a much larger area, or 99% of the penetrators remain intact and buried in the ground.

■ Residual risks

There may still be some penetrators and jackets on the ground within, close to, or relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure if picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure might be significant.

Because of local contamination of the ground close to penetrators, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, the exposure would be insignificant with regard to radiation (<10 µSv) but could be significant from a toxicological viewpoint.

Many penetrators may remain hidden in the ground. Eventually these could dissolve, with the DU entering the ground water. There is consequently a possibility that the drinking water in some nearby wells could become contaminated.

■ Need for mitigation

In the area investigated, there is no risk of high radiation doses or serious heavy metal toxicity, either now or in the future.

Nevertheless, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators and jackets should be dealt with by the local authorities or by KFOR. Penetrators and jackets (including fragments), should not be kept in homes, and children should be warned not to touch them.

The drinking water in nearby wells should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

Because of safety considerations, only a limited part of the potentially contaminated area could be investigated. Consequently, some further work, particularly a search for any remaining penetrators on the ground surface, should be carried out.

7.11 Kuke/Kokovce

Site description and general information

- Kuke/Kokovce (NATO reference no. 64).
- Coordinates: DM77900 60250.
- See map of general location in Kosovo (no sketch map of site was made).
- Investigated by the UNEP mission on 15 November.

This site is situated on the slopes of Maja mountain, above the village of Kuke/Kokovce. It consists of pasture land, at 1,550 m altitude. During the Kosovo conflict the area was probably used as an artillery position. It had been heavily attacked by cluster bombs and was defended by mines. According to NATO, A-10 aircraft attacked the area on 1 June 1999, firing 500 rounds. Prior to the UNEP mission, a Turkish EOD team had found a jacket in the area. Although partial mine clearance had been carried out, the continuing presence of mines somewhat limited the team's investigations. The size of the targeted area is not known.

The site was steep in various places and rocky. The bedrock consisted largely of gneiss with quartz dykes. The soil cover was rather thick. The soil was red-brown, stony and silty. The uranium concentration in the soil was low (1-2 mg/kg), while gamma radiation readings were around 0.1 µSv/h.

Summary of samples taken at Kuke/Kokouce:

- 2 mixed samples taken at the same location, UNEP 317a (grass and roots)

- 317b (soil) and 318 (soil)
- 1 botanical sample

Field investigations

Because the area was considered to be very unsafe (owing to only partial clearance of mines) the measurements and sampling were very limited. Some individual random measurements were made within an area of approximately 200 x 400 m. One penetrator was found and two soil samples were taken.

Summary of results

■ Penetrators, jackets and general contamination

The one penetrator found on the ground surface proved that DU ammunition had been fired at this site. The very limited beta/gamma field survey did not give any indication of DU contamination of the ground. However, the soil samples gave positive confirmation of DU contamination, albeit very weak.

Site specific conclusions

■ Measurements

- Penetrators, jackets and general contamination:

500 rounds were reportedly fired at the area. The few measurements made did not provide an unambiguous answer to the question whether there had been a substantial shattering of penetrators outside the area searched. 500 rounds are equivalent to about 150 kg DU. If all the penetrators had become aerosolised and the contamination was distributed over 80,000 m² and at 10 cm depth, the beta/gamma field measurements would not be capable of detecting such low level contamination.

However, from experience at other sites, the most probable scenario is that most of the penetrators are buried in the ground.

■ Residual risks

Because of safety considerations, a limited area was searched. However, there are no indications that many penetrators remain on the surface at this site, and the field measurements made do not indicate any ground surface contamination that could pose a significant risk. The site is relatively far from populated areas, though people graze animals in the region, and there are no wells or water reservoirs nearby.

The overall conclusion is that the area visited does not imply any significant risk.

■ Need for mitigation

In the area investigated, there is no risk of high radiation doses or serious heavy metal toxicity, either now or in the future.

For safety reasons, only a limited part of the potentially contaminated area could be investigated. Consequently, some further work, particularly a search for penetrators on the ground surface would be appropriate.

7.12 Buzesh/Buzec

Site description and general information

- Buzesh/Buzec (NATO reference no. 37).
- Coordinates: DM 755 619.
- See map of general location in Kosovo (no sketch map of site was made).
- Visited by the UNEP mission on 15 November 2000.

This site is located along a road going towards the village Buzesh/Buzec. There are fields on both sides. According to information provided by NATO, the site was attacked on 17 May 1999 with the use of 170 rounds. The targets were most probably army vehicles on the road or close to a nearby building, which had been severely damaged. The building was under reconstruction in November 2000. Three rows of bullet holes were found in the asphalt road surface. However, beta and gamma measurements around the holes gave no indication of DU contamination.

The fields on both sides of the road had not been made fully safe from mines and any unexploded ordnance. This prevented a fuller investigation of the site, even though cows were seen grazing in the area.

Summary of samples taken at Buzesh/Buzec: One tap water sample was taken (UNEP 141).

Field investigations

Because the area was unsafe, measurement and sampling work was very limited. Some beta/gamma field measurements were made along the road with a few readings taken from adjoining fields.

Summary of results

■ Penetrators, jackets and general contamination

No penetrators and no jackets were found and no ground contamination could be detected.

Site-specific conclusions

■ Measurements

- Penetrators, jackets and general contamination:

According to information received and visual observation of the holes in the road, there had been military activity in the area, with NATO stating that 170 rounds were fired against targets located there. However, there was no evidence from the measurements taken of any DU in the area, meaning that any remaining contamination was below the detection limit of 1g DU/m² (10% of Reference Case).

■ Residual risks

There may still be some penetrators and jackets on the ground within, close to, or relatively far from the targeted area. These pose a potential risk of causing a significant external radiation exposure if picked up. There may also be some risk of contamination of hands and subsequent ingestion. The corresponding radiation exposure is insignificant but from a toxicological point of view the exposure might be significant.

Because of local contamination of the ground close to penetrators, there may be some risk of internal contamination through ingestion of soil or contamination of hands. In such cases, the exposure would be insignificant with regard to radiation (<10 µSv) but could be significant from a toxicological viewpoint.

Many penetrators may remain hidden in the ground. Eventually these could dissolve, with the DU entering the ground water. There is consequently a possibility that the drinking water in some nearby wells could become contaminated.

■ Need for mitigation

In the area investigated, there is no risk of high radiation doses or serious heavy metal toxicity, either now or in the future.

Nevertheless, it is advisable to inform people about the possible presence of penetrators and jackets in the environment and that any penetrators and jackets should be dealt with by the local authorities or by KFOR. Penetrators and jackets (including fragments), should not be kept in homes, and children should be warned not to touch them.

The drinking water in nearby wells within the target area should be kept under surveillance by taking samples at appropriate intervals for uranium testing.

Because of safety considerations, only a limited part of the potentially contaminated area could be investigated. Consequently, some further work, particularly a search for any remaining penetrators on the surface should be carried out.

APPENDIX I

RISK ASSESSMENT

I.1 The concept of 'risk'

The word 'risk' is used frequently, but with a variety of different meanings. It might be the probability of occurrence of an event that is understood to be unpleasant or deleterious, for instance the risk of getting the flu. Everyone knows what flu implies and is only concerned with the 'risk' (i.e. the probability) that he or she will get it.

Another meaning is more related to the consequence of an event or situation. For example, in response to the question 'what are the risks of radiation?', a typical answer from a member of the public might be 'getting cancer'. Alternatively, saying that the radiological/radiation risk of a given situation is small, it is usually meant that the radiation dose, and therefore the health consequences, are likely to be small.

A third meaning is a combination assessment of probability and consequence used to guide selection of an appropriate response to a given situation. For instance, in a case where one is judging whether a report on an approaching flu epidemic should change travel plans, both the probability of catching flu, and the likely consequences of doing so, are taken into account in the decision-making process.

In this report, the second meaning of risk is the dominant one when used in connection with a given event, situation or scenario. If probability is also included in the judgement, then the third meaning is used.

An additional complicating factor is the difference between actual risk and the concept of risk. This is a highly complex issue that will not be developed in detail here. However, it is clear that scientific quantification of a given risk has to be expressed comprehensibly, so that the risk can be conceived in a way that favours appropriate judgements and responses. In a report such as this, it is important that the quantification of a given risk is as objective as possible. One possible way of judging the consequences of levels of radioactivity is to compare findings and measurements with natural levels, given limits and standards, and with so-called 'action levels' (levels at which action is deemed necessary).

Through such comparisons, it should be possible to express the risk as small, significant or large, having in mind the basis for comparisons. However, technical comparisons alone are not enough to justify decisions and responses. Relevant economic and social factors must also be dealt with, as well as the probability of occurrence.

In this report, the possible consequences of events in a given scenario are dealt with in terms of possible intake of DU by ingestion and inhalation, and of possible external exposure to radiation from DU.

In the case of radiation risks the consequences can also be expressed as radiation doses, quantified as ‘effective committed dose’ or ‘annual effective dose’. The name of the unit is sievert (Sv), usually expressed as ‘millisieverts’ (mSv or 10^{-3} sievert) or ‘microsieverts’ (μ Sv or 10^{-6} sievert). The comparisons are made with natural levels of radiation and intakes of uranium, with limits of radiation doses to the public, with so-called action levels for an existing contamination or radiation situation, with doses, that are considered to be trivial and with doses that are expected to give deterministic effects. These values are given in Appendix IX.

In the case of chemical risks, the consequences are expressed as resulting concentrations of uranium in air, water and food and as intake by inhalation and by ingestion. The comparisons are made with natural concentrations and intakes, with limits and hygiene standards for water, air and food and with concentrations that are expected to give acute biochemical effects in humans. These values are given in Appendix IX.

I.2 Methods of risk assessment

The method of risk assessment used and the precision of the assessment should be adjusted to the objective of the assessment. If the objective is to estimate the consequences of an event as close to the real conditions as possible, it is necessary to use realistic models, parameters and input data. This means special requirements on accuracy and quality of measurements and assessments.

If on the other hand, the objective is to verify the existence of a consequence only, and the consequence is far below any level of concern, more approximate models may be applicable as long as the assessments are based on conservative assumptions and the models do not underestimate the consequences. If by any chance the result of that assessment leads to a result that is ambiguous or close to the level that would trigger concern a more precise assessment is advisable.

Any assessment will be in some way defective and this is particularly so for those based only on models. It is therefore always necessary to supplement the theoretical assessments with practical measurements if a high degree of accuracy is needed.

I.3 The application of the risk assessment methods to Kosovo

The objectives of the mission to Kosovo are defined in Chapter 1. Measurements in Kosovo were judged necessary in order to verify the theoretical

results given in the UNEP/UNCHS Balkans Task Force (BTF) Report October 1999 'A preliminary assessment'. The assessments were based on conservative assumptions from a safety point of view, with regard to the conditions of exposure to DU but with realistic assumptions with regard to resulting doses and chemical effects. Some of the theoretical results were ambiguous and the resulting consequences in some parts of the assumed scenario were close to levels of interest from the health point of view. More sophisticated models did not help in this case because of poor input data.

In this report the scenario described in the theoretical 1999 assessment is used as the *Reference Case*. The assumed activity levels are translated to corresponding measurement results by calibration and used as input data in the comparison with the measured ground contamination. The method is described below.

It was concluded that the measurement values corresponding to the *Reference Case*, were well above the level detectable with the field instruments chosen. Thus zero results implied a sufficient margin of safety before thresholds of possible concern from a health viewpoint were reached.

Therefore the method of assessment is applied to the use of the *Reference Case*, in the actual situation about 1.5 years after the event causing environmental contamination, i.e. the military conflict in 1999. Because DU is the same as natural uranium in many aspects and all results up to now indicate very low concentrations of DU in the ground, it appears appropriate to make comparisons with natural uranium in the assessments of radiological and chemical consequences. The use of theoretical environmental dispersion models are used only exceptionally because of insufficient measurement data and knowledge of the local geochemical and geohydrological properties.

1.4 The application of the *Reference Case* in the risk assessments

The *Reference Case* from the UNEP DU Desk Assessment Report (October 1999) is originally defined as follows:

"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 1,000 m². 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, in addition to 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 1,000 m². It is assumed that someone very close to the target at the time of attack, would instantaneously be exposed for a short time to the DU dust cloud, which probably has a very high DU concentration. 100 mg DU/m³ air is assumed.

After some time people may enter the area which will then be cultivated. By entering the area people cause re-suspension of DU dust in the air, breathe contaminated air, are contaminated by touching objects in the area, and 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 the ground and contaminate the groundwater which serves a well nearby.

Some animals 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-term perspective be spread over larger areas”.

From these conditions, possible exposures were estimated. These referred to the situation that might have occurred during the time shortly after the attack. The conclusions in that respect are still valid.

At the time of the November 2000 mission, 1.5 years after the military conflict in Kosovo, the conditions have changed. Rain and snow have partly cleaned the superficial ground contamination, there might have been some migration into the ground, people have in different ways disturbed the environmental conditions by moving contaminated objects etc.

The purpose of the UNEP mission was mainly to assess the situation in both short-and long-term perspectives. Therefore many of the possible exposures in 1999 are irrelevant. Table I.1 below summarises the changes of issues of interest.

Table I.1 Possible exposures in 1999 after the attack and in late 2000 onwards

Means of exposure in 1999	Means of exposure in 2000 and forwards
(a) Solid pieces of DU picked up	(a) Same
(b) Rounds that passed or missed the target and can contaminate the ground water	(b) Same. The risks refer to (a) or (i)
(c) Instantaneous inhalation of DU dust after an attack	(c) Not applicable
(d) Inhalation of re-suspended DU(e)	(d) Same
(e) Soil in mouth	(e) Same
(f) Surface-contaminated vegetables	(f) Not applicable
(g) Contaminated hands	(g) Same
(h) Open wounds	(h) Not applicable
(i) Contaminated water	(i) Same
(j) Contaminated food	(j) Same
(k) External radiation	(k) Same
(l) Activity spread over large areas	(l) Same

‘Same’ in the Table does not mean that the risks are the same quantitatively, but of the same kind and have to be considered in the risk analyses. The eight means of exposure to date and the consequences are described below. If the consequences in the *Reference Case* are ambiguous or close to limits, standards, or any other value of relevance, the actual values today must be at least a factor ten below the values in the *Reference Case* to be safe.

1.5 The risks in the *Reference Case*

The means of exposure refer to table I.1 above. The comparisons to natural levels, limits etc. refer to Appendix IX. All radiation doses refer to youths (7-12 years) which means that the doses to children less than 1 year old may be up to 5 times higher per unit of intake. In practice, the dose to very young children is less than that because of lower intake. The dose to adults is 2 times lower than that of youths per unit of intake.

(a) Picked up solid pieces of DU

The only significant exposure may be by external beta (β) radiation. The gamma (γ) radiation is very weak and the alpha (α) radiation cannot 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 beta radiation is somewhat reduced, 50% is assumed. The exposed skin area will be quite small each time and from day to day it may shift a little making the skin dose smaller.

By keeping the piece of DU in the pocket for several weeks it might be possible that the skin dose will exceed values corresponding to the limit for the public (50 mSv/year) and workers (500 mSv/year). It is out of the question that there will be any deterministic effects (skin burns) even though the skin dose might be high.

The gamma radiation may give a radiation dose to tissues close to a piece of DU in the pocket. The gamma dose rate at different distances from a penetrator, about 300 g DU, has been measured and the approximate dose rates are as shown in table I.2.

Table I.2 External gamma dose rate from a penetrator

External dose rate [μ Sv/h]	Distance from the penetrator [m]
2.7	0.05
0.85	0.1
0.25	0.2

Considering 0.1 m being the closest distance of significance it would need more than 1,000 hours of continuous exposure until the organ dose approaches the natural annual gamma radiation dose to that organ.

Another way of exposure in picking up a piece of DU, for instance a penetrator, is contamination of hands from loose activity on the surface of the penetrator. Smear tests have shown that less than 10 mg of DU is lost in a test which might be a good

indicator of possible hand contamination from touching a penetrator. The subsequent possible intake into the mouth would be more depending on bad hygiene than intentional ingestion. Therefore the probable intake would be 10 to 100 times less than 10 mg, i.e. 0.1 – 1 mg of DU.

An intake of 10 mg would lead to about 7 μ Sv, which is an insignificant dose. Probable doses are 10 to 100 times less. An intake of 10 mg DU is much above generic standards (WHO, 1998) for daily intake but less than corresponding annual intake. If the intake is 100 times less it approaches the WHO limit. Acute heavy metal toxic effects from uranium might occur if the amount of intake is 10 times or more higher than 10 mg, see the UNEP DU Desk Assessment Report of October 1999.

The conservatism lies in the assumption of an intake of 10 mg DU.



Italian EOD taking samples at Djakovica.

(b) Inhalation of re-suspended DU

In the *Reference Case* it is assumed that 10 kg DU is spread over 1,000 m² i.e. 10 g/m². By wind, walking in the area, digging etc. dust from ground may become airborne and be inhaled. All DU is assumed to be present in the form of small particles (<10 μ m) 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 the DU contamination, and all will become airborne dust. With the assumption of 10 kg DU spread over 1,000 m², the top 1 mm of soil in this area contains 1 m³ of soil, weighing 1,500 kg. The DU concentration in the dust will therefore be 6 μ g DU per 1 mg dust.

Normal dust concentration is $50 \mu\text{g m}^{-3}$ in the air outdoors and under very dusty conditions 5 mg m^{-3} , which leads to $0.3 \mu\text{g m}^{-3}$ of DU, and 30 mg m^{-3} of DU, in the air respectively. From a toxicological point of view these levels are lower or within the range of given hygiene standards for chronic exposure.

A two-hour stay in a dusty area like a field being ploughed, with a breathing rate of 1 m^3 per hour, would lead to an intake of $60 \mu\text{g}$ of DU corresponding to an effective dose of $7 \mu\text{Sv}$.

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 i.e. of the order of 0.1 mSv per year. The heavy metal risks are in all cases insignificant.

The conservatism in the assumptions is that all DU is respirable and of S-type and that all DU is distributed in the first upper 1 mm of soil. If for instance the measurements should indicate that the DU, if any, is distributed in a 10 cm depth instead of 1 mm the consequences (radiation doses) would be 100 times less with the same area deposition (10 kg over $1,000 \text{ m}^2$) i.e. a few μSv per year and insignificant.

(c) Soil in mouth

The concentration of DU in soil is assumed to be 6 mg DU/g soil, see above. 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 $4 \mu\text{Sv}$. Acute heavy metal toxic effects from uranium may occur if the amounts are about 10 times higher.

The same conclusions can be drawn in the case of a contaminated spot containing DU contaminated soil or sand.

The conservatism is founded on two assumptions:

1. In the general case DU is assumed to be distributed in a 1 mm thin layer of soil. If it is found to be thicker the corresponding doses are proportionally smaller.
2. In the case of a contaminated spot the conservatism is in the assumption that some one (a child) is digging soil from that hole and eats it (a low probability).

(d) Contaminated hands

Hands can be contaminated by touching contaminated objects, clothes etc, and then the contamination can be ingested during meals etc. However, as in the case of contamination from a penetrator, see no.1 above, the intake is more depending on bad hygiene than intentional ingestion, which more or less was the case in e. (table I.1) above. Therefore, the amount is assumed to be 10–100 times less than in e. (table I.1) and correspondingly the doses 10–100 times less i.e. less than $1 \mu\text{Sv}$ and no risk of any acute heavy metal toxic effect but it may be close to the Tolerable Daily Intake (TDI)(WHO, 1998). With the corrected assumptions as described above there is no special conservatism.

(e) Contaminated water

Contamination of drinking water may result from migration of soluble uranium to the ground water that serves a well nearby, or a larger drinking water reservoir. An esti-

mation of the level of DU contamination of water in the short-and long-term perspective, caused by an initial ground surface DU contamination and by a number of penetrators in the ground needs more data concerning the specific situation in Kosovo than is at present available. Information needed concerns the geochemical and geohydrological properties of the ground that are relevant in estimating the rate of oxidation, the solubility and the transport to the ground water and drinking water, of uranium. Some data and discussion of uranium behaviour in natural environments is given in Appendix IV.

Therefore, it is necessary to make more robust calculations that should be conservative by nature, in order to minimize the possibility of making underestimations of possible problems from a health point of view in the short and long term perspectives. At the same time the calculations should not be unrealistic in order to avoid unjustified mitigation measures.

As regards the short and long term perspectives, there are different conditions of the radioactivity of DU. At present there is only one radionuclide of any significance from the radiation dose point of view and that is U-238. In a long term perspective (assumed to be 1,000 years) there might be other radionuclides added because of the build up of activity. The other radionuclides may also have higher radiotoxicity i.e. a higher dose per unit of intake (Sv/Bq). Table I.3 shows in column 1 the radionuclide (only alpha radiation emitters are considered), in column 2 the activity (Bq/mg uranium) in relation to U-238 (the activity of which is 12.4 Bq/mg uranium) and in column 3 the dose factor (Sv/Bq) in relation to U-238 (the dose factor of which is $4.5 \cdot 10^{-5}$ Sv/Bq ingested, for adults).

Table I.3 The relative activity and dose factor for alpha radiation emitting uranium daughter products to day and after 1000 years

Column 1 Nuclide	Column 2 Relative activity to U-238, Bq/mg U after 1,000 years	Column 3 Dose factor relative to U-238	Column 4 Weighted factor relative to U-238 (Column 2 x Column 3) %
U-238	1	1	100
U-234	0.2	1	20
Th-230	0.0016	4.4	0.7
Ra-226	0.00032	6.2	0.2
Po-218*	0.00032	27	0.9
Po-214*	0.00032	27	0.9
Po-210	0.00032	27	0.9

*Assumed values

As can be seen from table I.3 column 4, even after 1,000 years the relative contribution of radionuclides other than uranium isotopes is negligible.

One method of getting a measure of possible levels of contamination of drinking water is a comparison with natural levels of uranium in water and in the soil/rock from which the water is coming. A number of measurements on uranium in drinking water and in soil, were made in Kosovo. By taking all values except two extreme values from Vranovac hill, the arithmetic and geometric means are $8 \cdot 10^{-5}$ and $6 \cdot 10^{-5}$ mg U-238/l water. The concentration of U-238 in soil in Kosovo is in the range of 0.3-3

mg/kg soil. If 1 mg/kg is chosen, a relation between concentration of uranium in water and soil is about 10^{-4} by weight. In Vranovac hill the relation is $2 \cdot 10^{-3}$.

In the *Reference Case* it is assumed that 10 kg of DU is spread over 1,000 m². Assuming 3 m depth to the water table the total volume of soil that might be contaminated by dissolved DU will be 3,000 m³ which is about 5,000 tonnes. In this amount of soil the natural uranium content is 5 kg, this would correspond to the measured water uranium concentration of $7 \cdot 10^{-5}$ mg/l water. 10 kg DU over this area would mean an increase by a factor of 2 and a corresponding increase in drinking water.

An uncertainty here, is the solubility of DU as compared to natural uranium. If it is more soluble the uranium concentration in water would increase by more than a factor of two.

The number of penetrators shot at an area was about 2,500 at the most. If all penetrators are hidden in the ground under 1,000 m² the increase of uranium will be 750 kg. That would mean a substantial increase of the uranium concentration in ground, a factor of 150. A much higher solubility of DU than natural uranium would make the DU concentration in drinking water even higher than 150 and clearly exceed the WHO guidelines for uranium in water (0.002 mg/l) by more than a factor 10. The resulting radiation dose will still be insignificant.

The conservatism in the assumptions is the size of the area of 1,000 m² in the case of 2,500 penetrators fire against the area. It is not unreasonable to assume that in such exceptional circumstances the target area is at least 10 times larger, which makes all values 10 times less. Another conservatism in the assumptions is the size of the uptake area for the water to be only the soil volume below the 1,000 m² surface. It is probably much larger which will make concentration smaller using the analogue assessment method.

A second method would be to make an estimation of possible leakage from a contaminated area to an adjacent well.

By rain, DU deposited on the ground may be transferred downwards eventually to the groundwater that serves a well nearby. The soil depth between the ground water table and the surface of the bedrock is assumed to be 3 m, the contaminated area 1,000 m², 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 m³ per year.

The available water volume for dilution of the leakage of DU is accordingly 900 m³ and the concentration will be 1 g DU per m³. During a year the rainfall is approximately 0.5 m leading to a total of 500 m³ 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 1g DU per m³ water (1 mg per l water) is much above health 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. If the amount of DU over the same area is higher the consequences, whatever they are, are proportionally greater.

The conservatism is probably the leakage rate, 10% per year, and the water dilution. Other calculation might give 10 times less DU concentration in water. But even so the resulting concentration in water may be higher than the WHO guideline for drinking water.

An alternative means of assessment is given in Appendix V.

A third method, at least in judging a result, is comparison with natural uranium levels in drinking water. Values vary for ground water from 0.0001 to 0.014 mg/l (UNSCEAR 1993) with exceptionally high values (e.g. in Finland) of up to 10 mg/kg in some drinking water. In comparisons to these the normal values of uranium in drinking water in Kosovo are low (at the places visited).

► **Conclusion:** if the amount of DU dispersed over an area of approximately 1,000 m² is much less than 10 kg (the Reference Case) and the number of penetrators buried in the ground is less than 30 there will never be a problem with DU contamination of drinking water.

If on the other hand, in the area, contamination is much higher than the *Reference Case* or the number of penetrators is much higher than 30 (more than 100) over 1,000 m², there should be special consideration of possible future DU contamination of drinking water in adjacent wells.

(f) Contaminated food

More than one year after ground contamination by DU, there may be an intake of DU by ingestion of contaminated food. This may be vegetables, fruits etc. which are contaminated indirectly by root uptake of DU, and milk, meat and pork from animals eating contaminated plants and soil. These long term consequences can be assessed by comparison with natural levels of U-238.

As regards the contamination of plants and meat, caused by root uptake the following relationship can be used (UNSCEAR 2000):

35 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 35 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 1,000 m² and distributed in a 10 cm deep layer (which seems to be a reasonable assumption from the measurements in Kosovo) is assumed to be available for the roots. That corresponds to a concentration of 70 mg DU / kg soil (870 Bq/kg) if the density of soil is 1,500 kg / m³. That will result in an effective dose by ingestion, of 7 mSv per year. The corresponding toxicological risks are insignificant.

An uncertainty is the uptake factor for DU. Natural uranium has a plant:soil concentration ratio of $10^{-4} - 10^{-3}$. The low resulting dose caused by ingestion ($7 \mu\text{Sv}/\text{year}$) will allow more than 100 times more effective root uptake for DU than natural uranium before the doses begin to be significant.

If somewhere in Kosovo the DU ground contamination is as in the *Reference Case* ($10 \text{ kg DU}/1,000 \text{ m}^2$) and still very close to the surface, the uptake by animals may be substantial, mainly by 'consumption' of soil. A large animal may consume up to 0.5 kg of soil every day. If the DU contamination in this case is distributed in only 0.5 cm deep soil layer the worst case is the consumption of 0.5 kg of this 0.5 cm layer corresponding to about 0.1 m^2 contaminated ground. This means a daily consumption of 1 g of DU by the animal, which is probably unhealthy for the animal. People eating the meat (and drinking the milk from cows) will probably be exposed to a higher intake than the 'Tolerable Daily Intake' (TDI). The radiation doses will be less than $1 \mu\text{Sv}$ per day consumption of that meat or milk.

The underlying assumptions are very conservative for this particular case. However, it can be concluded that grazing animals should be kept away from (potentially) contaminated areas (at a level corresponding to the *Reference Case*) where the contamination is still close to the surface.

Conclusion: if the ground contamination is at the level of the *Reference Case* and distributed to at least 10 cm deep there is no problem from either a chemical or radiological point of view. In the case of a still close to the surface contamination, of the same order of magnitude, some mitigation measures could be discussed. If the contamination level is less than $1/10$ of the *Reference Case* there is no problem whatsoever.

(g) External radiation

The same deposition is assumed, i.e. $70 \text{ mg DU} / \text{kg soil}$ over $1,000 \text{ m}^2$. Natural uranium ($3 \text{ mg}/\text{kg soil}$) in the level of equilibrium that 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 g-radiation from DU is only 0.8% of that of natural uranium. Therefore the resulting dose from 10 kg DU on $1,000 \text{ m}^2$ would be $0.02/3 \times 70 \times 0.008 \text{ mSv per year} = 4 \mu\text{Sv per year}$.

► **Conclusion:** if the DU contamination of ground is as in the *Reference Case* or even 10 to 100 times more, external radiation will not be a problem.

(h) Activity spread over large areas

A wider dispersion than assumed in the *Reference Case* means a larger area than assumed, and all possible consequences will decrease proportionally.

I.6 The Reference Case and corresponding measurement values

I.6.1 Field beta measurement

The assessments are made assuming the *Reference Case* as defined in the UNEP DU Desk Assessment report of October 1999 (UNEP/UNCHS, 1999). That means 10 kg DU over 1,000 m². By calibration the following relations apply (Inspector model instrument, see Appendix III).

(a) Sensitivity of detection

No absorption

10 kg DU/1,000 m² = 10 g/m² = 100 mg/dm² gives 120 cps

Absorption

With DU covered by dust, grass etc there is only slight absorption. By assuming 90% absorption the readings will consequently be reduced by a factor of 10 and will probably not underestimate the surface contamination. That means that in the Reference Case 10 kg/1,000 m² gives 12 cps.

(b) Detection limit

■ **Surface contamination**

The detection limit is dependent on the sensitivity and the background of the instrument. With the instrument used the background with normal natural background radiation is 0.1-1 cps using the count rate meter. The limit of detection is defined as double background i.e. 1cps.

Assuming no absorption (which might be true for a short time after the contamination) the limit of detection would be:

1% of the *Reference Case* or 100 mg DU/m² = 1,240 Bq/m² corresponding to 1 cps (nett)

Assuming some absorption (< 90%) the limit of detection would be:

10% of the *Reference Case* or 1,000 mg DU/m² = 12.4 kBq/m² corresponding to 1 cps (nett)

■ **The activity distributed in a 10 cm deep soil layer.**

The *Reference Case* means a surface contamination of 10 kg DU/1,000 m² or 100 mg DU/dm². If the activity is evenly distributed in a 10 cm depth only the activity in the upper layer will be detected with any efficiency in a field beta measurement. 1 mm efficient depth is used in the assessment (1 mm correspond to about 150 mg/cm² leading to about 60% absorption of the beta radiation).

In the 1 mm layer there is 1/100 of the total activity i.e. 1 mg/dm² = 12.4 Bq/dm² = 1240 Bq/m² corresponding to 0.5 cps with 60% absorption which is just below the limit of detection with field beta measurement.

► **Conclusion:** If the activity is evenly distributed in a 10 cm deep soil layer, not less than a factor 2 to 5 times the activity of the *Reference Case* can be detected i.e. not less than 20 – 50 kg DU/1,000 m² or 20 – 50 g DU/m² or 200 – 500 mg DU/dm² can be detected.

The contribution of the gamma radiation from DU is still minor, about 1% of the natural background.

1.6.2 Soil samples measurement sensitivities

The overall sensitivity for detection of DU in a soil sample is dependent on the uncertainties of the laboratory analysis and measurements, and on the uncertainties of the background natural content of uranium in the sample. Background measurements show that the overall uncertainty (variation) for each individual team member and site is around 10% (1 σ).

Using the ratio $R = U-235/U-238$ by weight as an indicator of DU (see Appendix IX) the samples containing DU can be identified. If the limit of discernability of DU in a sample is defined as 20% above the average background value and the background is measured to be 20 Bq U-238/kg soil the limit of detection would be 4 Bq DU/kg soil. By 20% the R value is clearly DU indicative.

The *Reference Case* means 10 kg DU/1,000 m². Assuming the activity is distributed in 10 cm depth means 70 mg DU/kg soil or 830 Bq U-238/kg soil. 4 Bq DU/kg soil means 0.005 or approximately 1% of the Reference Case, which means 0.1 g DU/m².

► **Conclusion:** In laboratory measurements the limit of detection is 0.01 of the *Reference Case* or 0.1 g DU/m².

I.7 Summary

The results of the risk assessments are summarised in table 2.4.

Table I.4 The risks of different sources of exposure in various ways of exposure

Source of exposure	Means of exposure											
	Inhalation		Soil in mouth		Contaminated hands		Contaminated water		Contaminated food		External radiation	
	Rad	Chem	Rad	Chem	Rad	Chem	Rad	Chem	Rad	Chem	Rad	Chem
Penetrators etc. (>30)	Na	Na	Na	Na	Ins	S	Ins	→S	Na	Na	S (b)	Na Ins(γ) Na
Contamin.spots <10g U/kg soil	Na	Na	Ins	S	Ins	S	Na	Na	Na	Na	Ins	Na
Ground/surface contamin.≥ RC On surface In 10cm layer	Ins Ins	Ins Ins	Ins Ins	S Ins	Ins Ins	S Ind	Ins/S Ins/S	S S	Na Ins	Na Ins	Ins Ins	Na Na
Ground surface cont.= 0.1 RC On surface In 10 cm layer	Ins Ins	Ins Ins	Ins Ins	S Ins	Ins Ins	Ins Ins	Ins Ins	S S	Na Ins	Na Ins	Ins Ins	Na Na
Ground surface cont.=0.01 RC On surface In 10 cm layer	Ins Ins	Ins Ins	Ins Ins	Ins Ins	Ins Ins	Ins Ins	Ins Ins	Ins Ins	Na Ins	Na Ins	Ins Ins	Na Na

Explanations:

Rad = radiological aspects
 Chem = chemical toxicity aspects
 >30 = > 30 penetrators
 →S = may approach a significant level of exposure when number of penetrators increases
 Na = not applicable
 Ins = insignificant levels of exposure/risk (< 1 mSv, < WHO standards/guidelines)
 S = significant levels of exposure/risk (> 1mSv, > WHO standards and close to acute risks)
 RC = Reference Case = 10 kg DU/1000 m² = 10 g DU/m²
 On surface = the contamination is superficial in the upper mm of ground
 In 10 cm layer = the contamination is distributed in the upper 10 cm deep soil layer

Comments:

A ‘significant’ (S) level of exposure or risk does not mean that at that level there are major adverse consequences such as serious illness. On the contrary, at the levels given above there would still be large margins before an unconditionally unacceptable situation was reached. However, by surpassing these levels there should be a degree of concern, since it might be justified and necessary to do something about the situation, at least in the long run.

In case of ‘insignificant’ (Ins) levels there is no reason whatsoever to be concerned.

APPENDIX II

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PREREQUISITES AND LIMITATIONS

II.1 The objectives

The objectives of the mission (see p.14) defined the minimum requirements of the work to be done by the mission. Some of the corresponding tasks were performed during the visit to Kosovo, some were completed in laboratories after the mission, and some by the publication of this report. In short the objectives of the mission have been met.

By setting these objectives a number of tasks were automatically excluded. The consequences of this can be summarised as follows:

The limited number of places visited

Approximately 12% of the sites where DU had been used were visited by the mission. This could be said to be too few to give a representative picture of the overall situation in Kosovo. If the results of the mission based on this 12% of sites had fluctuated significantly, despite the same external conditions, it would have been very difficult to make any truly representative conclusions. On the other hand if the results were about the same, and particularly those that are related to the question of possible environmental contamination, it would be easier to make some more general conclusions. Another important question was how to select sites. A fuller discussion of the criteria used is contained in Appendix III.

No activity measurements of food (other than a few milk samples)

The only reliable and scientifically correct way to make general conclusions on this would be to collect and measure representative “food baskets” from markets. However, from earlier assessments it was concluded that it is very unlikely that contamination of food would be a problem or concern. It would be easy, however, to do such collection and measurement in the future in order to confirm this.

No measurements of people and no health examination

Until an extensive and credible health examination programme is implemented, it is probable that rumours and suspicions of the health implication of DU exposure will persist, irrespective of statements to the contrary. However, this was not within the framework of the mission and the team did not include any medical experts. Furthermore, it was not considered possible and meaningful to do any health studies on the basis of the limited knowledge of the extent of exposure, and locations of individuals exposed during the military conflict. The question of health studies might be taken up by the WHO at a later date.

II.2 Possible consequences of a one-year delay

Because of lack of information for almost a year on if, and where, DU has been used in Kosovo, the mission could not be organised until November 2000. This delay has influenced both the potential exposure of people to DU and the conditions of the mission.

Potential exposure

In the UNEP/UNCHS report of October 1999 “The potential effects on human health and the environment arising from possible use of depleted uranium during the 1999 Kosovo conflict. A preliminary assessment”, it was recommended that further measurements should be organised, with highest priority given to finding pieces of depleted uranium, heavily contaminated surfaces and other “hot spots”. Pieces of DU, heavily contaminated objects and loose contamination should be collected and removed. This work should be done under controlled conditions with proper protection for people the involved. The collected DU should be stored in safe conditions under the responsibility of a designated authority. At contaminated places signs should be posted to forbid public access. Also the access of grazing animals should be curtailed by fences or similar provision. Local authorities and people concerned should be informed about the results. A programme of measurements, countermeasures and waste disposal should be developed.

None of these activities has taken place in the way as prescribed. Military personnel have made measurements and some DU rounds have been taken away. However, the extent, accuracy and strategy of these measurements are not known. Military personnel of different countries also have given differing priority to the DU problem.

In conclusion, if there has been any risk of significant exposure to DU in the one year between its use and the mission (such as picking up penetrators, internal contamination via ingestion of loose DU or DU dust and via contaminated animals), then that potential risk remained unchanged at the time of the mission. The possible (and probable) health consequence of this potential exposure are those described in the UNEP/UNCHS report of October 1999.

The consequence of changed conditions for the mission

During one year the conditions for finding DU have changed in a not easily predictable way. A possible scenario and its consequences are described below.

Penetrators and other solid pieces of DU on the ground surface are covered by soil/ grass/dust. The consequence is that if covered by several cm (> 10 cm) of soil they cannot be detected by measurement of gamma and beta radiation.

Penetrators and other solid pieces of DU on the ground surface have been taken away by members of the local population, possibly by children, or by military personnel. The consequence is that the mission will not find these subjects.

Ground surface contaminated by DU dust is covered by soil/grass/dust. The consequence is that contaminated ground surface covered by some mm of soil will not be detectable (by beta radiation).

DU dust originally dispersed over an area has been moved by wind, rain and melting snow. The consequence is that if the dust has been moved by wind it has simultaneously been dispersed over large areas and diluted, and the mission has no chance to detect it. If it has been moved by rain or melting snow, it will have been dispersed into the ground and from experience it is expected that one year after the depositing of the DU, that it will be in the upper 5-10 cm of the soil. If so it will be found in the soil samples.

If on the other hand there has been a flood caused by heavy rain or intensive snow melt, the DU dust may have been swept away into a ditch, stream or river and the mission will not find it. If the ground surface is made of concrete or asphalt the same thing might happen with normal rain and snow melt, even though it is possible and probable that the DU dust will have been absorbed in adjacent soil. In that case the mission should find it.

Contaminated vehicles have been taken away. The consequence is that the mission will not find them.

II.3 Sources of information

Information was needed for all the various phases of the mission. The choice of site to be investigated was based on information from KFOR military personnel whose advice was based on their own observations and measurements. The exact positions of the attacks where DU ammunition had been used were found via the coordinates provided by NATO (see Appendix VIII for the table of grid coordinates provided by NATO).

At the sites the team used visual indicators as the primary evidence of potential DU contamination. A military experience of a member of the team was useful in

distinguishing impact holes caused by DU rounds and those caused by cluster bombs. He gave advice on the direction to search for penetrators, using the alignment of the impact holes as a guide. At possibly contaminated areas, soil and water samples were chosen by using experience of the team itself. Information was also provided by the local population, which assisted in filling in gaps.

II.4 Safety limitations and their consequences

In ensuring the safety of the team, the main concern was the risk of mines and unexploded cluster bombs. Mine clearance specialists always accompanied the team. The military of different countries had different approaches to the risk of mines. Some relied on measurements with a mine detector, which reacted on metal. This method means a week is necessary to search an area of 1,000-40,000 m². Some relied more on their own experience and made surveys by visual observation that were much faster. This was the particular method used to check if there were any new mines laid since the previous survey.

Sometimes the field in question had been ploughed by the farmer, and the experts took this as a guarantee of safety. In general the farmers and their children moved around apparently quite unconcerned, possibly because they knew where the risks of mines occurred, sometimes based on tragic experience.

The risk of mines limited the time available for practical work and the areas that could be investigated, sometimes quite significantly. Sometimes it also limited the depth down to which soil samples could be taken, because the risk of buried cluster bombs also sometimes limited the depth from which the soil could be sampled. These obstacles were accepted because the safety of the team had been given the highest priority.

APPENDIX III

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METHODOLOGY AND QUALITY CONTROL

III.1 Strategies

Both during the planning stage of the UNEP mission and once the team was in the field in Kosovo, decisions had to be made on which sites to visit, which areas of those sites to study, and what were the central matters of interest for the mission. Decisions were also made on how to organise the work for optimal results.

The strategy for **site selection** was that the choice should be based on:

- (a) Availability of information from NATO that provided coordinates of attacks using DU munitions, and from KFOR that gave locations on maps.
- (b) Other information on locations where DU had been used and DU penetrators or/and jackets had been found.
- (c) Local information or rumours on DU or contamination.

The strategy for the **choice of areas** to be investigated once at the above sites was based on:

- (a) Instructions by KFOR EOD (Explosive Ordnance Destruction) teams as to which areas were safe.
- (b) Marks on the ground made by penetrators and/or clusterbombs particularly on roads (asphalt) and other hard surfaces.
- (c) Probable direction of the air-attack. This was concluded from the impact holes left by the DU rounds. This gave a line along which (and to 10-20 cm each side) contamination could be expected.
- (d) Locations of destroyed vehicles and gun emplacements.
- (e) Destroyed buildings that had probably been used for hiding tanks or other military equipment.
- (f) Where jackets and penetrators have been found earlier by military personnel.
- (g) Drinking water sources and other nearby surface waters.
- (h) Adjacent population and buildings.
- (i) Information from the population on areas of probable interest (based on their own observations during the military activities).
- (j) Other particular points of interest from scientific point of view.

The **central matters of interest** were chosen following the criteria that the mission would concentrate on matters where it was realistic to expect that evidence would be available, or that the investigation would be within the realms of what was possi-

ble for the mission. Therefore certain matters of interest had to be excluded, for example deeply buried penetrators could not be investigated due to the impossibility of major excavations. The issues of interest were:

- (a) Widespread contamination
- (b) Penetrators below grass or a thin layer of soil/sand/mud
- (c) Penetrators deeper in the ground
- (d) Jackets
- (e) Contamination spots (contaminated holes, dents, small areas etc.)
- (f) Penetrators on surface
- (g) Dispersion in ground
- (h) Contamination of water
- (i) Contamination of milk
- (j) Contamination of houses, vehicles etc.

The **organisation of work** was dependent on the task, available resources and time. The strategy was to be as flexible as needed, in order to maximise the results of the mission as a whole. For that purpose there were short position reports made in the middle of each visit to a site, after which the organisation of the work could be changed if needed. Factors to be considered in the organisation of the work for a specific task were:

- (a) Competence needed
- (b) Number of persons or groups needed
- (c) Time needed against time available (because of transports, weather, meals, darkness etc)
- (d) Choice of methods and techniques

III.2 Methods and techniques

III.2.1 General overview

In choice of methods and techniques a major requirement is that they are suited to meeting the objectives and strategies decided upon. They have also to match the prerequisites and limitations of the mission. Furthermore, instruments give the framework of possible techniques. It is not possible to do more than the capacity (quantitatively and qualitatively) of the instruments allow.

Methods and techniques must also be adaptable to the specific characteristics of a given area such as:

- (a) *topography* – it is not possible to survey a broken ground in the same way as a flat field, or a village, a garden etc. Different techniques have to be applied.
- (b) *surface conditions* – in a soft ground the uranium dust may have dispersed into the ground, a penetrator that has missed the target could easily penetrate deep into the

ground, there may be grass and other vegetation shielding the radiation etc., but soil sampling is possible and useful. With a hard surface like rock or concrete, there are quite different conditions and possibilities, thus the methods and techniques have to be adjusted to them.

(c) *probability of finding DU at a place and the area of distribution* – if it is known with relative certainty that DU has been used in an area, then field survey is done more carefully and systematically. In other cases the measurements are made more at random and only in more interesting or ‘suspicious’ places.

(d) *presence of mines and other explosives* – the only areas that were examined, were those that were declared as safe which meant that the area had been searched for mines and there was only a low probability of remaining mines. If the feeling of uncertainty was too strong the number of measurement points and the extent of sampling were, consciously or unconsciously, reduced. Sometimes there was the possibility of hidden cluster bombs in the ground and this excluded deep digging for soil samples.

III.2.2 Measurements in the field

■ Methods

a) *Gamma radiation.* For a gamma survey with the purpose of identifying radiation slightly higher than the background, the requirement is that the instrument is sensitive enough to measure the gamma background (NaI crystal detector with channel integrated total counts); is relatively insensitive to varying gamma energies; gives a quick response (a short time constant) to gamma radiation; gives a sound-signal with an intensity increasing with the radiation intensity; is insensitive to the direction of radiation, is insensitive to rain, humidity and temperature (down to -20° Celsius); and is robust but light.

Gamma spectrometric differential measurement are more sensitive but much more expensive, difficult and laborious, particularly if the instruments need cooling with liquid nitrogen. In field measurements they can only be considered complementary equipment for special measurements.

The unit of measurement is not critical but units of cps and μSv (or μGy) per hour would be preferable. The instrument should meet the ordinary ISO standards, being well calibrated, and its ‘normal’ background should be known.

The gamma instrument is used to identify penetrators, other solid pieces of DU and highly contaminated surfaces i.e. hot spots. It is normally not sensitive enough to detect slightly contaminated areas ($< 10 \text{ Bq cm}^{-2}$).

b) *Beta radiation.* The instruments for field measurements on beta radiation are normally of GM type or proportional chamber type with thin windows to permit beta radiation to enter the sensitive detection chamber. The efficiency is high for beta radiation energies above 0.5 Mev, about 30% up to 2 cm above a small source (\leq the window of the beta instrument).

The purpose of using a beta instrument is to discover surface contamination, hot spots and penetrators all covered with less than a thin layer of grass, leaves or dust. Otherwise the beta radiation will be absorbed and not detected by the instrument. The window for detection should not be too small, a diameter of at least 5 cm is recommended.

It must be possible to easily shield the window to measure gamma radiation only if necessary, for instance, to conclude if the measured activity is superficial or at some depth. It must be realized that without a shield the instrument measures both beta and gamma radiation.

It should be light but robust, give a quick response to beta radiation, give a sound-signal with an intensity increasing with the radiation intensity and be insensitive to rain, humidity and temperature.



Measurement of beta radiation with the Inspector instrument wrapped in a plastic bag and held close to the ground. Ceja mountain.

The unit of measurement should be cps ($\mu\text{Sv/hr}$ can be used in case of gamma measurements). The instrument should meet the ordinary ISO standards and be well calibrated (cps per Bq cm^{-2} for surface contamination or cps per Bq for contamination spots, point source).

In practical field measurements the instrument, and particularly the thin window foil has to be protected against dirt and contamination. This can easily be done by covering the instrument with a thin plastic bag. This will not reduce the beta response more than about 10%.

c) *Alpha radiation.* Even though DU emits alpha radiation it is not practical to measure this radiation in field measurements. The reason is that the alpha radiation is very easily stopped by a thin layer of dust, grass or similar coating and the range in air is only a few cm. The result of the measurement will therefore be very uncertain and cannot be used. Therefore alpha measurements were not done.

■ Techniques



"Line-up survey" surveying at Bellobrade/Belobrod.

The objective of the field measurements were to identify penetrators, jackets and surface contamination. For that purpose the measurements were more quantitative than qualitative and an exact calibration might not be necessary. Another objective was to compare the measurement result with the result of the sampling. This was particularly the case when the sample was composed of a superficial soil contamination. In this case the measurement is more qualitative.

Two different techniques of field surveying were used, that can be called a systematic 'grid survey' and an informal 'random survey'. When performing a grid survey, the area to be examined is divided into a grid marked using x and y axes, so that exact positions can be given coordinates. The distance between the lines of the grid was 5 metres. The team members were then lined up along the x or y line and walked along the respective line with the same speed continuously measuring by placing the instrument close to the ground, and sweeping it from side to side. The technique was precise but time consuming. It is recommended when many penetrators, jackets or areas of contamination (spread or contamination spots) are expected. The technique was used at Gjakove/Djakovica and Vranoc/Vranovac hill.

A variant of the 'grid survey' technique, the 'line-up survey', is used when there is either, an expectation of finding many penetrators, or nothing at all, and the purpose of the survey is to confirm existence or non-existence of activity at the place of interest. On these occasions the team members are also lined up with a given lateral distance of 2 or more metres depending on the expectancy of finding something. The larger the distance the closer this is to the 'random survey' technique.

The ‘random survey’ technique means that the team members are left to search on their own, either guided by own experience and visible signs of attacks, and/or after being given instructions. In all cases they had to follow safety instructions. This technique can be used with a well coordinated and experienced team and might be very effective because only the most interesting and probable places are measured. Every place where activity is found is given an exact position coordinate. Use of the word ‘random’ is therefore misleading, but when carried out it gives the impression of being random.

Depending on the results of a first preliminary survey using one technique, the technique might be changed to another one. This happened often during the mission.

During the survey the instruments were held as close to the ground as practically possible in order to maximize the sensitivity. The speed at which the instruments could be moved along the surface without losing a hot spot or similar was measured at < 1 m/s.

III.2.3 Sampling in the field

■ Methods

The equipment for sampling was simple and conventional. Soil samples were taken with a shovel or a hollow iron instrument and collected in plastic bags, marked with the coordinates of the place where the respective sample was taken and stored until departure back to the laboratory at the end of the mission. Other solid samples like lichen, leaves, grass etc were taken using conventional instruments (knife, scissors etc.), marked and collected in plastic bags.



The Bristol University group prepares water samples in their field laboratory.

In impact holes and immediately below penetrators, soil samples were taken with a small shovel or the hollow iron instruments. The surface dimension and depth of the samples were adapted to the individual situation, and the samples were not pooled. Strongly inhomogeneous deposition of DU, which could be found close to hit objects or shot holes in the ground, could be a critical factor to give reliable results for DU ground deposition. Taking not too small cores and pooling of the cores over the sampling field of 25 square metres to some extent will smooth out extreme local variations in DU content.

Liquid samples like drinking water, water from ditches, rivers, lakes etc and milk were collected in bottles, treated chemically to avoid adsorption on the walls of the bottle, marked and stored for laboratory analyses.

The requirements for good sampling are the following:

- Use proven and standardised sampling procedures.
- Be aware of possibly very inhomogeneous deposition of DU on soil surface. Do not take a too small mass of sample, and from not a too small ground surface. Alternatively it is possible to pool a number of smaller samples.
- Avoid cross contamination of samples.

III.2.4 Instruments and Equipment Used

■ Measurements of radiation in the search for DU penetrators and DU contamination

Depleted uranium is a radioactive material. The radiation can be used to detect DU penetrators, pieces of penetrators and contamination by DU dust on the ground. Uranium decays by emission of alpha, beta and gamma radiation. The main part of the alpha radiation is emitted at the decay of uranium-238, the beta radiation at the decay of protactinium-234m and the gamma radiation at the decay of protactinium-234m and thorium-234 (Appendix IX, Table IX.8).

The emitted *gamma radiation* is rather weak, thus a significant increase above the natural background gamma radiation only occurs at intact penetrators or pieces of DU, and where the ground surface has been heavily contaminated with DU dust. Even with a sensitive scintillometer gamma meter it is not possible to measure a significant increase in gamma radiation further away than about 50 – 100 cm from a penetrator lying on the ground (depending on the type of instrument used).

The *beta radiation* from DU is rather strong (about 50% of the beta radiation emitted in the whole of the uranium-238 series emanates from protactinium-234m). However, as the beta radiation is absorbed by air the radiation from a penetrator or contamination on the ground decreases fast by distance. Thus to be able to measure the emitted beta radiation the detector must be close to the object that emits the beta radiation.

The range of *alpha radiation* in air is only some few cm. Thus the detector must be held very close to the object, and in the field it is not practical to search for DU by alpha radiation measurements.



The Turkish EOD test their mine detector for its ability to find a DU penetrator.

■ Use of mine detectors

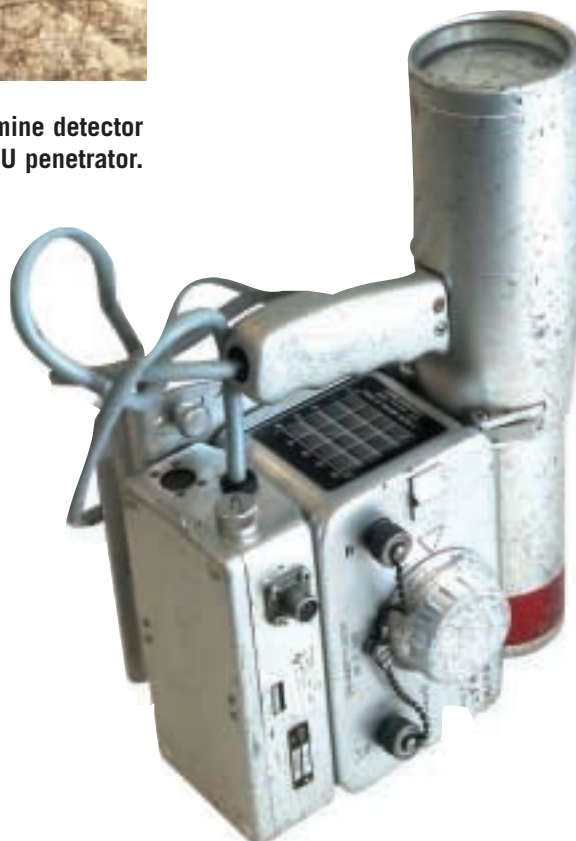
Together with the Turkish KFOR EOD team, a test was made on using a Hytech type mine detector in the search for penetrators and jackets. The test showed that a penetrator gives a signal down to about 20 cm depth. To detect penetrators at depths of more than 10 cm the mine detector has to be very slowly moved over the soil. However, in areas with metal scrap there will be many “false” signals.

■ Instruments

During the mission in Kosovo several different instruments were used and tested in order to get information on their suitability for use in future investigations of DU contaminated areas.

The mission was supplied with gamma meters and beta counters brought from Sweden. The team members from Switzerland, Italy and IAEA also brought instruments to Kosovo. A description of the instruments used follows.

From Sweden, for the measurements of gamma radiation, 15 scintillometers of type *Saphymo-SRAT S.P.P.2 NF*, were brought. For beta measurements 10 Geiger-Müller Inspector instruments provided by Radiation Alert, were used. Each team member was equipped with a *SRAT* and each group of two members used one or two *Inspectors*.



The Saphymo-SRAT S.P.P.2 NF scintillometer used at the gamma measurements.

The *Saphymo-SRAT S.P.P.2 NF* scintillometer is manufactured by Saphymo-PHY, Massy, France (Saphymo-SRAT 1969). It is designed to be used for uranium exploration in rugged conditions. The detector is a 1x1.5 inch (15.2 cm³) NaI (TL) (sodium iodine activated with thallium) scintillation crystal. The operation range for gamma radiation is 0.02 to 30 mikrosievert per hour ($\mu\text{Sv/h}$). The instrument has a built in audible alarm that gives a high signal. The threshold and the frequency of the sound alarm can be varied according to the strength of the radiation. The time constant for the sound alarm is 0.25 second. The unit of measurements used by the *SRAT* is cps (counts per second). The size of the instrument is 32x13x12 cm and the weight, 3.6 kg.

The *SRATs* used on the field mission were originally used in Swedish uranium exploration work and are now stored in preparedness for a nuclear accident. They were chosen to be used on the field mission because of their high sensitivity, the good alarm and durability.

The *Inspector* instrument is manufactured by S.E. International, Inc. Summertime, TN 38483, U.S.A. (S.E. International Inc. 1999). The detector is a halogen-quenched Geiger-Müller tube of the pancake type that has an effective diameter of 45 mm. The detector is covered by a mica foil, which is protected against damage by a metal net.



The Inspector instrument used for beta measurements, size 15x80x30 mm.

The window has a diameter of 50 mm. It can be covered by a metal lid, that when used, only allows gamma radiation to reach the detector, as the beta and alpha rays cannot penetrate the metal lid. With a removed lid the Inspector measures gamma, beta and alpha radiation. Units of measurements are cpm, cps, mR/h or $\mu\text{Sv/h}$. The instrument can be used in a direct reading mode or as a counter. The counting time can be set in the range 1 minute to 24 hours. A timer can be set at the desired counting time. The instrument is equipped with a sound alarm, which clicks for each radiation event detected. The Inspector size is 15x80x30 mm and weighs 272 g.

The *Inspector* instrument was chosen for the field mission because of its high sensitivity to beta radiation, which is due to the pancake GM-tube and the rather large window. To detect beta radiation from DU on the ground or in the upper few millimetres of the soil it is necessary to measure very close to the ground, thus for holding the Inspector instrument long handled grippers designed for picking up litter were used. Scan-Motor AS, Denmark, manufactures the grippers. As the Inspector instrument is not water resistant it had to be placed in a plastic freezer bag to protect it from moisture. The bag also prevented the mica foil from being punctured by grass and twigs and stopped the alpha rays.

The Swiss team from AC-Laboratorium Spiez, brought one *Automess AD 6* instrument with a *6150 ADB* detector used for gamma measurements, and one *Nuclear Enterprise Portable contamination Monitor PCM5/1* with a *Dual Probe DP2R*, used for the measurement of beta radiation.

The *Automess AD 6 with detector 6150 ADB* is manufactured by Automess Automation and Messtechnik GmbH in Germany (Automation und Messtechnik 1995). The Automess is specially designed to measure gamma radiation around and even below normal background levels. It is equipped with an organic scintillation ZnS-coated detector (3 inch thick and 3 inch in diameter). The organic scintillation detector has a flat energy response for gamma radiation between 30 keV and 7 MeV. The range of measurements is 0.01 to 100 $\mu\text{Sv/h}$. The instrument can be used in a direct reading mode or as a counter. The counting time can be set in the range of 1 minute to 24 hours. When working with detector 6150 ADB the audio indication is not usable. The instrument's size is 353x195x96 mm and the weight 2.5 kg. It is water-resistant.

The rate meter *Nuclear Enterprise PCM 5/1* is designed to be used with different types of scintillation and GM probes for monitoring all types of radiation (Nuclear Enterprises Limited. 1980 a). The rate meter brought to Kosovo was equipped with the Nuclear Enterprise Dual Phosphor Probe DP2R (Nuclear Enterprises Limited 1980 b). The detector in the probe consists of a plastic phosphor scintillation plate coated on one face with zinc sulphide. A thin layer of aluminised polycarbonate covers the detector. The window area is 49 cm². The instrument can be used in a direct reading mode or as a counter. The rate meter has a sound alarm. It is not water resistant. The size of the rate meter is 240x120x100 mm and the weight 1.8 kg + the weight of the probe 0.45 kg. To prevent the layer of polycarbonate from being damaged it is protected by a metal grill.

The ANPA team member used a *Berthold Contamination Monitor LB122* equipped with a Xenon counter tube (proportional counting tube). The tube has a window of 5 mg cm⁻² and an effective area of 160 cm². The operation of this counter tube is based on the principle of charge multiplication in the immediate vicinity of a thin counting wire which is applied to a positive high voltage and is surrounded by a special counting gas. The beta particles or the secondary electrons of the gamma rays entering the counter tube ionise the atoms of the counting gas along their trajectory, thus creating ions and electrons. The electrons move with growing energy toward the anode wire until new ion pairs are created and the number of these ion pairs rises in a snowball-like fashion in the proximity of these counting wires. The charge created is proportional to the primary ionisation. The *Berthold Contamination Monitor LB122* beta-gamma detector cannot distinguish between these types of radiation. The counter tube counts the sum of the beta and gamma pulses per second. With a background count rate the statistical uncertainty (2 sigma) will be 4%, with a measuring time of 200 s. The instrument is not waterproof.

■ Calibration

Before the instruments were transported to Kosovo they were calibrated or at least tested for their response against sources with known activities of radioactive elements.

The Saphymo *SRAT*'s were calibrated against sources of radium-226. 1 cps corresponds to a gamma exposure rate of 0.002 µSv/h.

The *Inspector* instruments were calibrated for the beta response against a (⁹⁰Sr+⁹⁰Y) source with the source strength of 432.6 Bq. The response to DU at an area with a contamination of 1 mg DU per cm² is approximately 120 cps ± 24 cps, when measured 1 cm above the surface. Thus 1 cps roughly corresponds to a contamination of 0.01 mg DU per cm² or 0.1 g per m² deposited on the ground surface. This is the approximate lower detection limit for the *Inspector*. The beta radiation measured at 10 cm above evenly contaminated ground is 40% of that measured at one cm above the surface. For beta radiation the shielding effect of a plastic freezer bag around the *Inspector* instrument means a reduction of 5%.

Calibration of ANPA's *Berthold Contamination Monitor LB122*) was performed by the Italian Institute of Ionising Radiation Metrology. The Xenon counter tube was calibrated against ⁹⁰Sr+⁹⁰Y and ¹⁴C sources with an active surface of 150 cm². At these maximum beta energies, the efficiency of the probe is 48% and 9% respectively. The overall efficiency uncertainty is 5%.

Before use, the performance check for the probe requires a check in a stable and reproducible geometry (plate with the test source directly below the detector) with a ⁹⁰Sr source or a background measurement.

■ Views on the instruments and the techniques used in the search for DU

The field mission team found *SRAT* and *Inspector* instruments well fitted for the work. The robust construction of the instruments made them easy to handle in the field without

any special precautions. Not a single instrument failed during the mission.

The *SRAT*'s very low time constant and the loud audible signal made it possible to walk quite quickly over the areas and still have good control over the slightest changes in radioactivity. In the search for radioactive objects high sensitivity is preferred above accuracy in measurement. One disadvantage of the instrument is that it is rather heavy.

The *Inspector* instrument proved to be quite good. It is light, has a fairly good alarm signal and it is easy to handle, even for an inexperienced user. The plastic freezer bag protected the window-foil very well. Not a single GM-detector was punctured. We had no days of rain during the mission. Therefore we do not have any experience on how reliable the *Inspector* is in wet conditions.

The *Automess AD 6 with detector 6150 ADB* for gamma measurements is fairly rugged and is well suited for the type of mission. The high sensitivity makes it specially suited to measurements of near background levels. The instrument gives precise and fast readings of local dose rates. A disadvantage is that the audio indication, when working with detector 6150 ADB, is not usable.

With the *Automess* it is possible to measure the gamma radiation from DU rounds (PGU 14/B API) or larger pieces of DU lying on the surface or at some distance (maximum about 10-20 cm) below from a distance of maximum 1 meter, with a measuring time of about 10 seconds. From a position of about 0.5 metre above ground level, only rather high contamination of the ground surface with more than about 10 gram DU-aerosol per square metre can be detected.

The *Nuclear Enterprise PCM 5/1* rate meter equipped with the *Nuclear Enterprise Dual Phosphor Probe DP2R*, can also be used for the measurement of gamma and alpha radiation. At a distance of 1 cm above surface contamination consisting of 1 gram DU per square metre, the instrument will indicate about 10 counts per second, that is about 5 times the background count rate. This calibration factor is not very precise (estimated error of about a factor of 2) and not certified. This instrument gives a fast indication of even very low surface contamination of the ground and other objects, by radioactive substances. As a disadvantage, it is not very rugged and has to be handled with care in the field. It is not water-resistant and pointed objects easily puncture the Mylar entrance foil.

With this instrument one is able to detect DU rounds (PGU 14/B API) or larger pieces of DU in the field lying on the ground from a distance of a maximum 1 metre with a measuring time of about 10 seconds. Contamination of the ground surface from about 0.1 gram DU aerosol per square metre can also be detected from a distance of a few centimetres above ground level.

The *Berthold Contamination Monitor LB122* equipped with a Xenon counter tube, gives a fast indication of beta-gamma contamination on the ground. As a disadvantage, the instrument is not very rugged and due to its weight it is not easy to manage in the field. In addition the beta-gamma detector is not water resistant and pointed objects can damage its tin foil window.

■ Concluding remarks on Instruments

The opinion of the team members is that in a search for DU penetrators and DU-dust contamination one needs gamma instruments that are sensitive, have a short time constant and such a strong alarm signal that it can be heard above traffic noise and the wind. To be used in the field under harsh conditions it must be waterproof and shock resistant. To be sensitive enough it has to have a rather large scintillation detector either organic or of NaI(Tl) type. A very large detector, for example a NaI(Tl) detector of the size 3x3 inch does not make the instrument more sensitive as the larger crystal volume also registers more of the background gamma radiation from the soil and rocks.

The gamma radiation measured directly on a penetrator lying on the ground is 5 $\mu\text{Sv/h}$, at 10 cm distance from the penetrator 0.8 $\mu\text{Sv/h}$, at 20 cm 0.3 $\mu\text{Sv/h}$ and at 30 cm 0.15 $\mu\text{Sv/h}$. When searching for contamination, it is thus very important that the instruments are held close to the ground. As the detection distance in the horizontal plane is rather limited, in the search for DU penetrators and fragments it is necessary to perform the measurements in a very detailed manner not to miss any DU objects. Penetrators and pieces of DU that are covered by more than 10 cm of soil or water are almost impossible to detect by their gamma radiation. If covered by more than 20 cm of soil they are impossible to detect.

The background gamma and beta radiation in the investigated areas was very low, which is due to the bedrock consisting of limestone and dolomite rock or as at the site Radonjick Lake, of basaltic lava, all rock types with low or very low concentrations of uranium, thorium and potassium. The gamma radiation in these areas is 0.04–0.10 $\mu\text{Sv/h}$, which includes the contribution from cosmic radiation. The only area visited with higher gamma radiation was the Kokouce mountain area in South West Kosovo. There the bedrock consists of acid gneiss, and the gamma radiation is 0.10 - 0.15 $\mu\text{Sv/h}$. The low natural radioactivity increased the possibilities of detecting and finding penetrators and contamination by DU. However, in other areas in Kosovo where the bedrock consists of acid rocks with higher levels of uranium, thorium and potassium the possibility of finding penetrators or contamination by measurements might be less, due to the higher background radiation.

A portable gamma ray spectrometer would have been useful in Kosovo. With the spectrometer it would have been possible to do *in-situ* determinations of the concentrations of uranium, thorium and potassium in the soils and rock. By comparing uranium concentrations in adjacent areas to those of the investigated sites it would have been possible to judge if the radiation measured at the site was normal for the rocks and soil in the area or increased due to DU contamination.

When planning the Kosovo DU mission the use of a solid-state detector for *in-situ* gamma ray spectrometer isotopic determination of concentrations of uranium-238 and -235, was discussed. It was decided not to bring one, the main reason being that it was not possible to transport the liquid nitrogen that is needed to cool the GeLi detector, to Kosovo.

The team members' opinion is that the use of a solid-state instrument would have been limited. With the very low background radiation in the parts of Kosovo which we visited there was no need of an instrument that could distinguish between enhanced natural radiation and an increased radiation due to contamination with DU. To use the solid-state instrument for *in-situ* determinations of the concentrations of U-238 and U-235 to investigate if there existed a deficiency of U-235, would have needed long measurement times, and because of the limited DU contamination of the areas, it was felt that it was better to take soil samples.

■ Other Equipment

When planning the Kosovo mission there was little knowledge on the situation at the target areas that the team was to visit, or on what the likely weather conditions would be. Was there any risk of heavy contamination with DU dust, burnt out vehicles full of DU dust or windblown DU dust in the air? What kind of equipment would be available in Kosovo? The mission had to be prepared for the worst situation. Thus the UNEP team brought to Kosovo protective equipment, tools for sampling, plastic freezer bags and bottles for samples, and for mapping of the sites, graph paper pads and 50 m measuring-tapes. The team also brought rolls of red plastic tape to be used to mark contaminated areas.

For the personal use of each team member, UNEP supplied two blue overalls meant to protect personal clothing. In case one set of overalls was contaminated with DU, it would be possible to burn that set.

Each team member was also provided with a pair of disposable white whole body covering non-woven overalls and with rubber gloves, and from UNEP with a warm UN Jacket.

In case the team had to investigate a vehicle that had been hit by DU rounds one set of a whole body covering rubber overalls was included in the equipment brought to Kosovo.

The equipment also included half masks with special filters suited to prevent inhalation of DU dust and more simple dust respirator masks. Disposable Latex examination gloves were also part of the outfit.

The team members were asked to use their own rubber boots in Kosovo. The use of rubber boots would make it possible to decontaminate the boots in case of contamination by DU-dust.

The team's use of the same type of overalls and United Nations jackets proved to be of value as it was easy to distinguish the team members among any onlookers. This also made the job easier for the soldiers guarding the team.

Straight away at the first visited site, the Djakovica Garrison, the measurements of gamma and beta radiation showed that there were no measurable DU contamination on the ground, except at contaminated points. This was also confirmed at the other sites. Therefore there was no reason to suspect any significant airborne DU contamination and thus it was not necessary to use any respiration protection. Nor was there

any requirement for the use of the special protection overalls brought to Kosovo. The situation was found to be the same at the other sites visited.

As there were no armoured vehicles that had been hit by DU rounds at the sites visited, the team never had to use the half mask and the rubber overalls brought to Kosovo.

Several of the team members also brought GPS navigators, which were used for mapping the site areas and for determining the positions of the collected samples.

III.3 Individual Laboratories' Field and Laboratory methods

III.3.1 Samples and Analyses: an Introduction



Preparing the soil samples.

During the Kosovo mission the team members visited 11 different sites and collected altogether 355 samples. Of these, 249 were soil and concrete samples, 46 water samples, 37 botanical samples (grass, roots, lichen, moss and mushrooms), 3 milk samples, 13 smear test samples, 3 penetrators and 4 jackets. All samples have been given a UNEP code number.

Many of the samples were duplicate samples taken by different team members, of the same soil (e.g. below a penetrator) or water from the same well. Some of these samples have not been analysed, mainly because they were duplicate samples,

others has been divided into sub-samples. Altogether, including the sub-samples, 327 samples have been analysed. A complete list of the samples including type of sample, location and the results of the analysis is given in Appendix X. 7 penetrators, and 1 half penetrator, that were collected during the mission have also been analysed for their content of plutonium, and some other radioactive elements.

Samples collected by respective team members were taken back to their home countries and analysed at laboratories there. The following laboratories have been engaged in the analytical work: The AC-Laboratorium Spiez, Switzerland, the Italian National Environmental Protection Agency (ANPA), Rome, Italy, the International Atomic Energy Agency (IAEA) Siebersdorf Laboratory, Austria, the SGAB Analytica Laboratory, Luleå and Swedish Radiation Protection Institute (SSI) laboratory, Sweden, the Finnish Radiation and Nuclear Safety Authority (STUK), and the Bristol University Department of Earth Sciences Laboratory, United Kingdom. Each of the laboratories has respectively, given a report on sample preparation and the analytical methods they used (ANPA 2001, Burger and Schmid 2001). A synthesis of the reports is given in the sections below.

The analyses include the determination of concentrations by weight and activity of the U_{tot} , ^{234}U , ^{235}U and ^{238}U . In some cases the concentration of ^{236}U was also determined.

The analysis performed by the Bristol University on water samples also included analysis of Th, P, S, Si, Al, Fe, Mn, Mg, Ca Na, K pH, Eh, HCO_3^- , total CO_2 , free CO_2^- and CO_3^- . The concentration in the soil samples was analysed by Bristol (see below). Analyses performed on the penetrators and jackets included the activity concentration of the uranium isotopes, plutonium and other fission products, and on the surface of the four penetrators the transformation phases have also been studied (Appendix VII).

The main objectives of the sampling performed in the field were:

- to determine the possibility of widespread ground contamination around or within the areas visited by the mission;
- to determine whether highly contaminated localised areas or “contamination points” are present and the level of depleted uranium activity concentrations;
- to assess the maximum depth along the soil profile reached by the depleted uranium contamination in “contamination points”;
- to determine the uranium isotopes activity concentrations in the underground aquifer;
- to identify whether bioindicators (lichens, mosses, etc.) are capable of revealing amounts of DU;
- to assess the amount of uranium isotope activity that can easily be removed from DU penetrator;
- to assess the possible presence of DU contamination on the wrecks of targeted vehicles.

III.3.2 Sampling in the field

■ AC-Laboratorium Spiez sampling procedures

The Swiss team members from AC-Laboratorium Spiez used the following sampling procedures (Burger and Schmid 2001). If possible, the location of the centre and dimensions of the attacked target site were defined first by field measurements. Soil samples were normally taken when an indication of the use of DU ammunition at the site visited was visible. The team proceeded as follows:



Sticker used for taking cores of soil.

10 to 20 sampling areas of 5x5 m (25 square metres) were defined. Some of them within the attacked target site and most symmetrically around the target site up to some hundred metres away to make sure that it would be possible to define the spread of contamination by DU

Within the sampling areas of 5x5 m a total number of 10 cores primary of top soil (layer 0–5 cm) were randomly taken and, at one site, the below surface soil (5–15 cm layer) was also taken.

Topsoil sampling was performed using a bulb sticker. The 10 cores taken were pooled in a double plastic bag with the correct numbering on it according to the laboratory's procedures based on ISO/IEC 17025. In addition a sample form (NATO AEP 49 Volume 2, Environmental Sample) for each sample was written up during the sampling. The typical weight of such soil samples taken was about 2 kilograms.

Below surface sampling was performed using soil sampling stickers (diameter of the core 25 mm) commonly used for such a purpose. Here the cores were separated and the top layer collected separately from the below surface layer. Samples were handled further as described above. The typical weight of the top surface samples was about 0.5 kg and of the below surface samples, about 1 kg.

Samples of special interest were, for example, impact holes, meaning holes where clearly a DU penetrator had hit the surface. Soil or concrete samples were taken directly from the hole by using the instrument described above or a trowel. The surface dimension and the depth of sampling were adapted to the differing situations. Samples were not pooled and were described in detail. Procedures were as described above.

Penetrators and jackets were collected properly and at least double bagged to make sure that contamination by any other sample could be excluded. All relevant information was written down in detail. Procedures were as described above.

Pictures were taken of all sites sampled.



Sampling of a penetrator impact at Djakovica/Djakovica garrison.

■ ANPA sampling procedures

The Italian team member from ANPA used the following sampling procedures (ANPA 2001). Soil samples were collected using a stainless steel coring sampler with a tube of 10 cm diameter and 20 cm length or a stainless steel frame 15x15x5 cm. The soil cores were cut into slices 2-5 cm thick and then preserved in plastic bags. Generally the soil samples were collected vertically along the soil profile, in the place where penetrators, fragments of penetrators, “hot spots” or jackets were found on the soil surface. In some locations, soil samples were also collected in areas close to the “target”, in the direction in which the DU rounds had been fired.

Potable water samples were collected from private wells, stream channels and reservoirs. The samples were collected by means of polyethylene bottle and preserved in polyethylene containers by adjusting their pH to <2 at time of collection.

Vegetation samples were generally collected close to the areas where penetrators, fragments of penetrators, “hot” spot or jackets were found.

Smear tests were taken around the holes produced by the impact of ammunition on destroyed cars. Smear tests were also taken directly on the penetrators found on the soil surface.

■ International Atomic Energy Agency (IAEA) sampling procedures

The IAEA members of the team collected in total 16 samples. The samples were taken in the vicinity of penetrator impact holes on paved areas and underneath penetrators and jackets found on the ground surface. The IAEA experts collected 4 core and 5 surface samples. Most of the samples were shared with team members from ANPA and Bristol University, and IAEA sampling equipment was used by the other members of the team.

■ Swedish Radiation Protection Institute (SSI) sampling procedures

The Swedish team members from the Swedish Radiation Protection Institute (SSI) used the following sampling technique. Soil and botanical samples were taken with trowels. The samples in most cases were spot samples, normally a topsoil sample, 0-2 cm, was taken and often also a sample from 2-5 cm depth, in some cases deeper down to 40 cm. Mixed soil samples were also taken when convenient. In these cases samples normally were taken from three to five 15x15 cm large squares within an area of approximately 16 m². The samples were collected in plastic freezer bags.

Water samples were collected in polyethylene bottles that had been cleaned with acid. The samples were not filtered. Some of the water samples were acidified in the field. Others acidified by addition of nitric acid (at 1%) when they arrived at the laboratory.

■ Bristol University sampling procedures

For sampling the members of the team from Bristol University used the same procedures as the ANPA members.

Potable water samples were collected from private wells, stream channels and reservoirs. The samples were collected by means of polyethylene bottles and filtered through 0.2 m cellulose filters. Samples were stored in 125 ml polyethylene bottles. One bottle was acidified for uranium and thorium analysis. The samples were acidified with nitric acid in order to prevent uranium and thorium precipitation or sorption to the surface of the bottle. One bottle was not acidified for major element analysis. The pH and Eh were analysed immediately in the field. Also, the water samples were titrated in the field with HCl to determine the alkalinity of the water.

Penetrators were collected where possible. Smear tests were also taken directly from penetrators found on the soil surface.

III.3.3 Preparation of samples and analysis

The team members and the laboratories that have been engaged in the project gave the following information on the methods used for sample preparation and analysis.

The samples collected by team members from the AC-Laboratorium Spiez, IAEA, SSI and Bristol University were analysed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Some of IAEA's samples were also analysed by gamma spectrometric measurements. The samples collected by the team member from the ANPA were analysed by measurements of the gross beta activity and for determination of alpha-particle-emitting isotopes of uranium, the alpha pulse-height measuring technique was used. Determinations of uranium isotopes were also made by gamma spectrometry. The isotopic composition was carried out on a Finnigan Thermal Ionisation Mass Spectrometer (TIMS). The major elements in the water were analysed on an ICP-AES and the anions on an ion chromatograph. The penetrator surfaces were analysed with micro Raman spectroscopy and X-ray Photoelectron Spectroscopy.

■ AC-Laboratorium Spiez samples (Burger and Schmid 2001)

Chemical and isotopic analysis was performed implementing ASTM Designation C 1345-96, Standard Test Method for Analysis of Total and Isotopic Uranium and Total Thorium in Soils by inductively Coupled Plasma-Mass Spectrometry of the American Society for Testing Materials.

Sample preparation

- Soil samples

The samples were dried at 40°C in air recirculating drying ovens until weight constancy was achieved. The dried samples were then sieved (2 mm/mesh 10). The sieved materials were mixed in soil sample bottles in a mixer for 10 minutes.

50g of the dried and mixed soil fractions were milled in a 250ml zirconium oxide ball-mill with zirconium oxide balls (6 balls, diameter 20 mm) for 10 minutes at 400 rpm. 50 g of the dried mixed and milled soil samples were then ashed in quartz crucibles at 650°C in high temperature furnaces for 12 hours (weight constancy). Digestion in HNO₃/HF, followed by rapid fuming with H₂O₂ with ²⁰⁹Bi as internal standard.

The procedure for Reference samples was started directly with the ashing step. The moisture of the samples was determined separately.

- Penetrators

In the laboratories penetrators were handled properly to avoid any contamination under the aspect of lowest level analytic. The penetrators were weighed directly after unpacking.

The penetrators were washed in distilled water for some minutes using an ultrasonic bath.

Surface corrosion (yellow/white) was washed off with diluted HNO₃ followed by washing with water and drying in an oven at 105°C for 30 minutes. After weighting, the top part of the penetrators (2-3cm) was held for 1 hour in 50 ml of 2M HCl for partial remove/digestion of the penetrator. These solutions were put on a hotplate until the samples reached a near dryness state. Several times concentrated HNO₃ was added and all of the samples were brought near to dryness. The residues were then redissolved in 50 ml 6M HNO₃, filtered and brought to 100 ml with water in a 100-ml PMP flask.

Chemical and isotopic analysis

Chemical- and isotopic analyses were performed implementing ASTM Designation C 1345-96, Standard Test Method for Analysis of Total and isotopic Uranium and Total Thorium in Soils by inductively Coupled Plasma-Mass Spectrometry of the American Society for Testing Materials.

The analysis was performed according to ASTM Designation C 1345-96, Standard Test Method for Analysis of Total and isotopic Uranium and Total Thorium in Soils by Inductively Coupled Plasma-Mass Spectrometry of the American Society for Testing Materials. Divergent from this standard test method, just 5 grams of each soil sample were digested with the half the normal quantity of acids and internal standard. This decision was based on the fact, that the homogeneity of the samples was given and the fact that the ICP-Mass Spectrometer FINNIGAN ELEMENT 2 is (compared to the quadrupole technology in C 1345-96 used) more than 1000 times more sensitive. The Thorium procedure was not carried out.

Column extraction on TRU® resin was carried out, but due to the high performance of the ICP-Mass Spectrometer FINNIGAN ELEMENT 2 these solutions have not been measured. Statistics are involved in the specific testing reports on which this report is based on. All calculations are in accordance with SN EN 45001, respectively ISO/IEC 17025.

Detection limits for the procedure followed is given in the formulations below:

^{234}U	^{235}U	^{236}U	^{238}U	isotopic ratios
1 ng/kg	1 ng/kg	1 ng/kg	200 ng/kg	1 / 100,000

■ ANPA samples (ANPA 2001)

The samples collected by the ANPA team member were analysed at the ANPA Laboratory, Rome.

Sample preparation

- **Soil samples**

The soil samples were dried at 105 °C and then sieved to remove material >2 mm. The samples were then split into sub-samples of 20 g each, using a stainless steel sample splitter.

- **Water samples**

Water samples were directly treated for chemical separations and alpha pulse-height analysis.

- **Botanical samples**

Vegetation samples were dried at 105 °C, and then split into sub-samples of 20g each, using a stainless steel sample splitter.

Determination of gross beta activity

- **Soil samples**

Gross beta activity of the soil samples was measured in the 3 sub-samples (those with the highest, the lowest and the medium gross beta activity), they were separately powdered in a ceramic miller, homogenised and the uranium isotopes were determined by alpha spectrometry in an aliquot of 0.5 g of each sub-sample.

The gross beta activity was measured using a low-level planchet counter with proportional gas flow counter tubes, allowing the simultaneous measurement of 10 sample planchets. The planchets are arranged in a matrix consisting of 5 drawers made of copper with 2 samples each. The ultra-flat flow proportional counter tubes with thin aluminised plastic windows are located directly above the planchets. The 10 measuring counters are covered at the top by a large area flow counter tube acting as common guard counter. Slider and counter tubes are surrounded by a 10 cm thick shielding made of machined lead bricks. The 11-fold beta discriminator unit (preamplifier) is located outside the lead shielding. This unit includes in a common housing the pulse preamplifier discriminators with integral discriminators for direct connection of measuring counter tubes and a discriminator with integral threshold and pulse shaper module for the connection of the guard counter tube. It supplies standard pulses to the interface unit.

- **Water samples**

The water samples were analysed by alpha pulse-height analysis.

- **Botanical samples**

Gross beta activity was measured in all the sub-samples. When available, 3 sub-samples (with the highest, the lowest and the medium gross beta activity) were separately powdered in a ceramic miller and homogenised. The uranium isotopes were determined by alpha spectrometry in an aliquot of 1–2 g of each sub-sample.

Determination of alpha-particle-emitting isotopes of uranium

The method used for the determination of alpha-particle-emitting isotopes of uranium was by means of chemical separations and alpha pulse-height analysis.

- **Soil samples**

In the analytical method used for the Kosovo soil samples 0.5 g of soil is melted with Na_2CO_3 , Na_2O_2 at 600 °C and leached out with HCl, HNO_3 + HF and HNO_3 by heating. After melting, to quantify the chemical recovery ^{232}U is added to the samples. The mineralised or leaching solution in 2 M HNO_3 is passed through a Microthene-TOPO (tri-octyl-phosphine oxide) column; after washing, uranium is directly eluted into a cell with ammonium oxalate solution, electrodeposited on a stainless steel disc and measured by alpha spectrometry.

- **Water samples**

The method used for the Kosovo water samples covers the determination of alpha-particle-emitting isotopes of uranium by means of chemical separations and alpha pulse-height analysis. Uranium is pre-concentrated from water samples by co-precipitation with iron (III) hydroxide at pH 9-10 using ammonia solution and the precipitate is dissolved with HNO_3 and mineralised with H_2O_2 and HF. To quantify the chemical recovery ^{232}U was added to the samples. The mineralised solution in 2 M HNO_3 is passed through a Microthene-TOPO (tri-octyl-phosphine oxide) column; after washing, uranium is directly eluted into a cell with ammonium oxalate solution, electrodeposited on a stainless steel disc and measured by alpha spectrometry.

- **Botanical samples**

1-2g of vegetation samples were leached out using HCl, HNO_3 + HF and HClO_4 by heating, ^{232}U tracer is added before leaching. After this step the procedure follows that described for soil samples.

Determination of isotopes of uranium by gamma spectrometry measurements

- **Soil samples and smear tests**

The uranium isotopes on smear tests and soil samples with high levels of gross beta activity were measured by gamma spectrometry using p-type extended range HPGe detectors. The detectors were calibrated using a multi-peaks source prepared by the Italian Institute of Ionising Radiation Metrology. The samples were counted for 80,000 s. The activity concentration of ^{238}U were assessed using the mean activity

concentrations of the peaks at 63 and 93 keV of ^{234}Th ; ^{234}U was assessed by the 120.9 keV peak and ^{235}U from the 186 keV peak corrected for the interference of ^{236}Ra .

Accuracy and calibration

The lower limits of detection, assessed using Currie's method (1968), are 0.20 mBq for one litre of water and 2 Bq kg for 0.5 g of soil using 80,000 s as counting time. Average uranium recovery for water and soil samples are $82 \pm 6\%$ and $80 \pm 9\%$ respectively. The lower limit of detection, assessed using Currie's method (1968) is 2 Bq kg⁻¹ for 0.5 g of soil using 80,000 s as counting time. Average uranium recovery is $80 \pm 9\%$. The accuracy was evaluated by analyses of soil reference material prepared by the IAEA (IAEA 2001). Accuracy for natural uranium in the IAEA soil samples was $85 \pm 7\%$ for ^{234}U and $89 \pm 1\%$ for ^{238}U , whereas ^{235}U was near to the detection limits. The accuracy of the method has been assessed only for natural uranium due to the lack of reference materials containing depleted uranium. Most probably an increase of the accuracy of the method for depleted uranium is expected, because DU is not as strongly bound to soil particles as natural uranium.

Participating in inter-laboratory exercises regularly tests the accuracy of the gamma spectrometry measurements.

■ IAEA samples

All samples collected by the team members from the IAEA were analysed at the IAEA Seibersdorf Laboratory, Austria.

Sample preparation and gamma spectrometric measurements

Before preparation the samples that were exhibiting measurable radioactivity were screened by gamma spectrometry (HPGe, p-type, 26% relative efficiency). This was in order to decide the order for processing and analysing the samples. The activity of the two uranium isotopes of interest, ^{235}U and ^{234}U was calculated as a weighted average of the following gamma lines: 84 keV, 109 keV, 144 keV, 163 keV, 183 keV, 202 keV, 205 keV for ^{235}U , and 63 keV, 113 keV, 766 keV, 1001 keV for ^{238}U .

All samples were visibly heterogeneous, containing stones, large agglomerates of soil and pieces of vegetation. After drying, each sample was separated by sieving into two fractions, i.e. a coarse fraction (>3 mm). Individual subfractions of the fine fraction were prepared for the ICP-MS measurements (after milling), for XRF measurements (without milling, for particle size analysis (to be carried out at a later stage by SEM-EDXRF) and for storage (archiving).

Analytical methods

The samples utilized for determination of the isotopes by ICP-MS were dissolved using standard laboratory procedure. Suitable aliquots were utilized for the analyses. For quality assurance purposes, appropriate reference materials and isotopic compo-

sition standards of known uranium concentration were always analysed together with each batch of samples.

■ SSI samples

All soil, botanical and water samples collected by the team members from the Swedish Radiation Protection Institute were analysed at SGAB Analytica laboratory in Luleå. Swedish normal methods for environmental samples were used at sample preparation and analysis.

The penetrator that the SSI team members collected was analysed at the SSI laboratory in Stockholm.

SGAB Analytica is accredited by SWEDAC (reg. nos. 1087, 1007) for a number of analytical methods, including determination of total uranium in natural waters. Consequently, SGAB Analytica in its accredited activities also fulfils relevant ISO 9002 requirements.

Sample preparation

- Soil

The Kosovo soil samples were dried at 105 °C till weight constancy was achieved. The dried samples without significant amount of vegetation fragments were then sieved (1mm), mixed and digested in MW oven with nitric acid. For samples with significant amount of vegetation fragments, an additional ashing step at 550 °C overnight was included. For selected samples with high uranium content (information supplied by SSI) additional grinding of the whole sample amount was included. Prior to ICP-SFMS analysis, digestion solutions were diluted with DDIW resulting in a dilution factor of 2,000.

- Water

The water samples were acidified by addition of nitric acid (at 1%) to the original sample bottles and were left to stand for 72 h. Then 2 ml of nitric acid was added to 20 ml aliquot of the samples followed by MW digestion for 1hour. Prior to ICP-SFMS analysis, digestion solutions were diluted 10-fold with DDIW.

Analytical methods

Uranium concentrations were determined by ICP-SFMS using internal standard correction and external calibration in accordance with modified Method 200.8 Determination of trace elements in waters and wastes by ICP-MS of the United States Environmental Protection Agency. Uranium concentration is reported as the mean value of three consecutive determinations (50 scans each) with corresponding instrumental spread. Isotope ratio measurements were performed in accordance with the procedure reported in detail in Rodushkin et al., *Nuclear Instrument & Methods in Physics Research*, Section A (1999), 423, 472-479. Mass bias corrected uranium isotope ratios are reported as the mean value from two consecutive determination (2,000 scans each) with corresponding instrumental spread.

Instrumentation

The analyses were performed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The ICP-SFMS instrument used was an ELEMENT (Finnigan MAT, Bremen, Germany) equipped with an ASX 500 sample changer (CETAC Technologies Inc., Omaha, USA). The device was operated in low-resolution mode (LRM, $m/\Delta m$ about 400). A microwave oven (MDS-2000, CEM Corporation, Matthews, USA), equipped with 12 perfluoroalcoxy (PFA) lined vessels (ACV 50) was used for sample digestion.

Reagents and control samples

Distilled de-ionized water (DDIW) was used for digestion blanks and for dilution of samples, blanks and standards. It was prepared from de-ionised Milli-Q water (Millipore Milli-Q, Bedford, USA) by sub-boiling distillation in a Teflon still (Savillex Corp., Minnetonka, Minnesota, USA). Analytical grade nitric acid (Merck, Darmstadt, Germany) was used after additional purification by sub-boiling distillation in a quartz still.

Detection limits

Detection limits determined as 3 times the standard deviation of uranium concentrations in preparation blanks are:

for water samples	^{238}U 0.5 ng/l,	^{234}U and ^{235}U 0.005 ng/l
for soil samples	^{238}U 1 ng/g	^{234}U and ^{235}U 0.01 ng/g

Accuracy and calibration

Accuracy and precision of the method was evaluated using results from control materials. For determination of uranium concentration in natural waters the method results in an accuracy of better than 5% RSD. Accuracy for determination of uranium concentrations in urine and soil samples cannot be evaluated due to absence of control materials with certified total uranium concentration (urine) or acid leacheable uranium fraction (soil). SGAB Analytica regularly perform external accuracy assessments by participation in a specific ICP-MS Interlaboratory Comparison Program for trace metals in biological materials (Le Centre de Toxicologie du Quebec, Canada), which include the determination of uranium in urine, blood, serum and hair matrices. Between batches, precision is better than 10% RSD in all matrices.

For uranium isotope ratio measurements, both accuracy and precision are commonly better than 1% RSD and 10% RSD for $^{235}\text{U}/^{238}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ respectively.

Penetrator analysis

From the penetrator that SSI brought back from Ceja Mountain in Kosovo, a sample was taken by drilling a hole in the back of the penetrator. Of the chips, 0.8 g were used for chemical and alpha spectrometric analysis. These analyses followed the method

described in the SSI-report 93-15, "Method for determination of plutonium isotopes in food and environmental samples"(Soumela 1993). The chips were dissolved in HNO_3 and a ^{242}Pu tracer was added. The sample was diluted with nitric acid and a mixture of nitric and hydrochloric acid. The plutonium is oxidized to the tetravalent state and separated by anion exchange technique. The isolated plutonium was electroplated on a stainless steel planschett and analysed by alpha spectrometry for 149 hours.

■ Bristol University samples

All analytical studies performed at the Department of Earth Science, University of Bristol, were carried out according to standard procedures for good laboratory practice. All water used in the field and in the laboratory was deionised 18 M Milli-Q. All lab-ware was soaked over night in 10% v/v HNO_3 , rinsed in deionised water and dried in an oven. All reagents were of analytical grade or higher and were supplied by Fisher Scientific UK. Acids were ARISTAR grade (99.999% purity).

Sample preparation

- Water samples

Water samples were filtered in the field in Kosovo through 0.2 m cellular filters. Two samples were taken. One was acidified in the field with concentrated HNO_3 for uranium and thorium analysis by ICP-MS and TIMS. The other sample was not acidified and used for major, and other trace element analysis by ICP-AES and ICP-MS. The pH and Eh of the waters were measured in the field and the waters were also titrated for alkalinity in the field. The samples were analysed for total uranium and thorium by mixing the water with equal volume of a 1% v/v HNO_3 solution containing 20 ppb Bi. The internal standard was thus 10 ppb.

- Soil Samples

All results of soil analysis are for dry mass. The soil samples were dried at 40 °C in drying ovens. The dried samples were then sieved (2 mm; mesh 10) and the less than 2 mm fraction was homogenised by shaking the soil in plastic bags. 200 mg of each sample were weighed out into 50 ml Teflon beakers. The samples were digested in concentrated HNO_3 and 10 ml of 40% v/v HF according to a standard geochemist's procedure for total dissolution of solid samples and analysis of trace metals in rocks and soils (see, for example, Bailey et al. 1993). The overall dilution of the sample was 1,000 and the internal standard is 100 ppb or 10 ppb in the analysing solution. For soils that contained high concentrations of uranium, the solutions were diluted 10 to 500 times prior to ICP-MS analysis for uranium. For isotope analysis using TIMS, the soil samples that were dissolved for ICP-MS analysis were used. Waters used for analysis by TIMS were the ones that were acidified in the field. For uranium separation from other elements a sample aliquot was poured through anionic columns (AG1x8). Major elements were eluted with 7N HNO_3 , trace elements were eluted with 6N HCl and finally uranium was eluted with H_2O . The sample containing uranium was loaded in $\text{HNO}_3\text{-H}_3\text{PO}_4$ on double Re filament assemblage and

dried. The filament was then loaded into the TIMS and the analysis was run at about 1800 °C. The standards used for uranium isotopes were NBS reference material U500, 112a, U0002 as enriched, natural and depleted $^{235}\text{U}/^{238}\text{U}$ ratios standards, respectively.

- Milk samples

The milk samples were collected into 125 ml polyethylene bottles and acidified in the field. This made the solution 'lumpy'. In the laboratory the samples were homogenised in an ultrasonic bath. After that 10 ml of the solution was pipetted into a Teflon beaker and mixed with 10 ml of concentrated HNO_3 . The solution was heated at 100 °C on a hot plate for several hours and then dried at 230 °C. The sample was then re-dissolved in 20 ml of 1% v/v HNO_3 and to oxidize the organics and fat visible in the solution, 2 ml of 70% v/v HClO_4 and 20 ml of H_2O_2 were added. The sample was then dried and re-dissolved in 20 ml of 1% v/v HNO_3 . When the sample was fully dissolved it was transferred to a 100 ml volumetric flask and made to volume with 1% v/v HNO_3 .

- Penetrators

The surface of the penetrators was investigated under the microscope. The surface had many visible cracks and had two new visible phases, a yellow phase and a black phase. The penetrators were studied without any preparation by micro Raman Spectroscopy. The penetrators and fragments thereof were attached to a glass slide by 'blue tack' and put under the microscope of the micro Raman instrument. For XPS analysis a fragment of a penetrator was dried prior to analysis. The sample was introduced into the instrument on a copper stud. The samples were also analysed by SEM/EDS. Chemical analysis of the penetrators was undertaken on dissolved samples of a penetrator fragment and 'swipes' of penetrators taken in the field. The swiping removed a large proportion of the black and yellow alteration phases from the surface of the penetrators. A fragment of one penetrator was dissolved in a Teflon beaker with concentrated HNO_3 , evaporated to dryness at 230°C and re-dissolved in 1% v/v HNO_3 . Swipes of three penetrators were leached in a Teflon beaker with 20 ml of 1% v/v HNO_3 and shaken in an ultrasonic bath for 30 minutes. 1 ml of concentrated HNO_3 was added and the solution was heated to 100°C for one hour. After that the swipe cloth was removed, the solution was heated at 230°C to dryness and then re-dissolved in 1% v/v HNO_3 .

Chemical and isotopic analysis

The analyses of total uranium and thorium were carried out by ICP-MS mass spectrometer as described by Bailey et al. (1993).

The following Quality control standards were used: International rock standards: G-2, RGM-1, MAN-N, AC-E, SCO-1, JR-1, JA-2 and JR-2.

Thermal Ionisation Mass Spectrometry

Thermal Ionisation Mass Spectrometry analysis for uranium isotopes at Bristol University was undertaken using a Finnigan MAT Triton thermal ionisation, sector multi-collector mass-spectrometer.

Measurement uncertainties for ICP-MS analysis at Bristol

The uranium and thorium measurements are presented giving the standard deviation for each analysis.

Detection limits (ng/kg) for the Bristol University ICP-MS are given in the information below.

²³² U	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U
2	10	2	1	13
³⁹⁹ Tc	²³⁰ Th	²³² Th	²³⁷ Np	²³⁹ Pu
2	1	365	2	2
²⁴⁰ Pu	²⁴¹ Pu	²⁴² Pu	²⁴³ Pu	²⁴⁴ Cm
2	2	1	2	2

III.4 Quality control exercise (NAT-9)

During the mission in Kosovo the team members decided that it was necessary to organize a quality control exercise for the laboratories that participated in the analysis of the samples. As most samples consist of soil, it was agreed to use two soil materials for this exercise. The study (NAT-9) was organized by the Section of Nutritional and Health Related Environmental Studies (NAHRES) of IAEA. The result of this exercise is reported in: Report on the NAT-9 quality control exercise on uranium isotopes in two soil samples. (NAHRES-60, 2001).

Due to the shortage of time no quality control exercise was organised for water and biological samples.

The laboratories were not instructed to use any specific leaching or digesting method; on the contrary they were encouraged to use their established analytical method. The NAT-9 quality control exercise comprises two soil materials; Soil-1 was a podsollic soil with a uranium-238 concentration of 2.7 mg/kg and Soil-2 a marine sediment with a uranium-238 concentration of 1.4 mg/kg. The concentrations are well within the contents of the soils that the mission sampled in Kosovo.

Four of the five laboratories analysing the samples from the mission participated in the exercise, which included determination of U-238, U-235 and U-234. The results of the Quality control exercise are shown in tables III.1 and III.2. Three of the laboratories passed the quality control criteria. The quality control showed that all four laboratories are capable to distinguish the different uranium isotopes. However, for the sample Soil-1 with a complicated matrix most results were lower than the target value. The applied digestion methods were not sufficient to dissolve all uranium. This shows that the problem is not the analytical method but the dissolution of the uranium bounded in the matrix of the samples. The three laboratories that passed the quality control used acid leaching with HNO₃ / + H₂O₂-leaching + HNO₃/HF-leaching and acid digestion. The fourth laboratory used leaching with HNO₃ / + H₂O₂ but no HF, which is a procedure according to the U.S. Environmental Protection Agency (EPA) method 3050B. This EPA method is not a total digestion technique for most samples and dissolves only the environmental available elements. When deter-

mining the total uranium content in soils it is necessary to use the EPA method 3052, or other total digestion procedure.

The best results for U-238 and U-234 were achieved by a laboratory that prepared the samples by melting with $\text{Na}_2\text{CO}_3 + \text{Na}_2\text{O}_2$ before leaching. This laboratory analysed the samples by alpha spectrometry. However, the U-235 concentrations of the soils were too low to be determined by the used equipment.

In the final Table of Results (Appendix X) soil samples from the laboratories that did not pass or participated in the quality exercise are marked with an “+” behind the UNEP code. UNEP codes for water and biological samples are marked with “*” as no quality control exercise was made for the analytical methods used for these samples.

Table III.1 NAT-9 Quality control exercise. Results of analyses of uranium in Soil-1, a podsolc soil

²³⁴ U							
Target Value			NAT-9				
Lab. ID	Value	Unc.	Value	Uncertainty		Deviation	Lab /TargetValue
	[ng/g]		[ng/g]		%	%	
1	0.141	0.025	0.1007	0.00816	8.10	-28.6	0.71
2	0.141	0.025	0.0536	0.0089	16.60	-62.0	0.38
3	0.141	0.025	0.14	--	--	-0.71	0.99
4	0.141	0.025	0.138	0.0138	10.00	-2.13	0.98

²³⁴ U							
Target Value			NAT-9				
Lab. ID	Value	Unc.	Value	Uncertainty		Deviation	Lab /TargetValue
	[ng/g]		[ng/g]		%	%	
1	17.87	4.10	10.79	0.245	2.27	-39.6	0.60
2	17.87	4.10	5.75	0.062	1.08	-67.8	0.32
3	17.87	4.10	15.71	--	--	-12.1	0.88
4	17.87	4.10	Not reported				

²³⁴ U							
Target Value			NAT-9				
Lab. ID	Value	Unc.	Value	Uncertainty		Deviation	Lab /TargetValue
	[ng/g]		[ng/g]		%	%	
1	2733.9	484.0	1490	31	2.08	-45.5	0.55
2	2733.9	484.0	785	8	1.02	-71.3	0.29
3	2733.9	484.0	2190	--	--	-19.9	0.80
4	2733.9	484.0	2620	217	8.28	-4.17	0.96

Table III.2 NAT-9 Quality control exercise. Results of analyses of uranium in Soil-2, a marine sediment.

²³⁴ U							
Target Value			NAT-9				
Lab. ID	Value	Unc.	Value	Uncertainty		Deviation	Lab /TargetValue
	[ng/g]		[ng/g]		%	%	
1	0.0770	0.0080	0.079	0.00648	8.20	2.6	1.03
2	0.0770	0.0080	0.0439	0.0008	1.87	-43.0	0.57
3	0.0770	0.0080	0.09	--	--	16.9	1.17
4	0.0770	0.0080	0.0857	0.0069	8.0	11.3	1.11

²³⁴ U							
Target Value			NAT-9				
Lab. ID	Value	Unc.	Value	Uncertainty		Deviation	Lab /TargetValue
	[ng/g]		[ng/g]		%	%	
1	10.50	6.00	8.81	0.71	8.06	-16.1	0.84
2	10.50	6.00	4.55	0.039	0.86	-56.7	0.43
3	10.50	6.00	9.3	--	--	-11.4	0.89
4	10.50	6.00	Not reported				

²³⁴ U							
Target Value			NAT-9				
Lab. ID	Value	Unc.	Value	Uncertainty		Deviation	Lab /TargetValue
	[ng/g]		[ng/g]		%	%	
1	1419.3	282.2	1220	15.2	1.25	-14.0	0.86
2	1419.3	282.2	629	5.3	0.84	-55.7	0.44
3	1419.3	282.2	1300	0	0.00	-8.4	0.92
4	1419.3	282.2	1600	128	8.00	12.7	1.13

APPENDIX IV

MILITARY USE OF DU

IV.1 Types of military use

Depleted uranium has multiple uses by military forces. As in the civilian sector it can serve as counter-ballast, in both aircraft and missiles. It is important to note that not all counter-ballasts are made of depleted uranium. Because of its density (19.0 g/cm³) and resistance to penetration by anti-armour munitions, depleted uranium can be used in the armour of tanks. It is also important to note that not all tanks have depleted uranium armour. Depleted uranium has special properties that make it ideal as anti-armour ammunition; when depleted uranium rounds hits armour plating, the rods begin to self-sharpen, thereby enhancing their ability to pierce the armour. During this self-sharpening, the depleted uranium forms an aerosol, creating fine DU particles that may be inhaled. The amount of depleted uranium that forms as an aerosol will depend upon the ammunition, the nature of the impact and the type of target, whether it is an armoured vehicle or not. Both tanks and aircraft can fire depleted uranium munitions, with tanks firing larger calibre rounds (100 and 120 mm) and the aircraft firing smaller calibre rounds (25 and 30 mm).

Many of the world's armies possess or are thought to possess DU weapons (Rand, 1999). Depleted uranium weapons are regarded as conventional weapons and have been used in warfare. This type of ammunition is readily available on the open market. Ammunition containing DU is known to have been used in Iraq during the Gulf War in 1991, in Bosnia-Herzegovina in 1995, and in Kosovo in 1999. In addition, sites in southern Serbia and Montenegro were also hit by ammunition containing depleted uranium during the Kosovo conflict. During the Kosovo conflict, NATO aircraft used DU weapons. NATO confirmed that over 30,000 rounds of DU had been used in Kosovo (UNEP, 2000).

The effectiveness of DU in kinetic energy penetrators (the rods of solid metal) has been demonstrated at various test ranges and in actual military conflicts. Kinetic energy penetrators do not explode but if they hit a hard target they may form an aerosol of fine particles. Since uranium metal is pyrophoric, the DU particles ignite and burn, forming particles of uranium oxides due to the extreme temperatures generated on impact. Most of the contamination remains inside a vehicle that has been struck and penetrated. However, some of the dust will be dispersed out into the environment and contaminate the air and the ground.

Most of the penetrators that hit non-armoured targets will pass right through the target and, in most cases, remain intact. A penetrator that hits the ground will continue intact down into the soil. The depth depends on the angle of the round, the speed of the tank or plane, and the type of soil. In clay, penetrators used by the A-10 attack aircraft are reported to reach more than two metres depth. Penetrators hitting hard

objects, e.g. stones, may ricochet and may be found lying on the ground metres from the attacked target.

The DU dust formed during the penetration of armoured vehicles can be dispersed out into the environment and contaminate the air and the ground. It is important to note that hits by depleted uranium on “soft” targets, e.g., non-armoured vehicles, do not generate significant contamination of dust. Most contamination from depleted uranium hits on armoured vehicles should be limited to within about 100 metres of the target (CHPPM, 2000). Because 1.5 years have elapsed since the Kosovo conflict, the major interest of the UNEP mission was to examine the possible risks of remaining contamination of ground, water and biota near the impact site.

The type of DU ammunition that the A-10 Warthog aircrafts uses has a conical DU penetrator. Its length is 95 mm and the diameter at the base 16 mm. The weight of the penetrators is approximately 300 grammes. The penetrator is fixed in a “jacket” (also called “casing”). The aluminium casing has a diameter of 30 mm and a length of 60 mm. The jacket fits the size of the barrel of the A-10’s gattling gun and assists the round in flying straight. When the penetrator hits a hard object, e.g. the side of a vehicle, the penetrator continues through the metal sheet, but the jacket usually does not penetrate.

The A-10 aircraft is equipped with one gattling gun. This gun can fire 3,900 rounds per minute. A typical burst of fire occurs for 2 to 3 seconds and involves 120 to 195 rounds. The shots will hit the ground in a straight line and depending on the angle of the approach, the shots will hit the ground 1-3 m apart and occupy an area of about 500 m². The number of penetrators hitting a target depends upon the type of target. Normally, not more than 10% of the penetrators hit the target (CHPPM, 2000).

There are two sources of information on how many of the rounds fired in Kosovo by the A-10 were depleted uranium. According to the NATO information given to the United Nations in a letter dated 20 July 2000, the mix of 30 mm rounds was approximately 5 DU rounds for every 1 ATI (tracer ammunition) round. According to NATO/KFOR information provided to UNMIK the mix was 5 DU rounds per 8 fired (KFOR, 2000). The numbers of DU rounds used in one target area range from 30 to 2320.

UNEP has no information that depleted uranium was used in the cruise missiles fired by NATO forces, or that depleted uranium tank ammunition was ever fired. Nor is there any indication that depleted uranium was used by Serbian forces.

IV.2 Potential health and environmental impacts

Normally 10-35% (and a maximum of 70%) of the bullet becomes an aerosol on impact, or when the DU dust catches fire (Rand, 1999). Most of the dust particles are smaller than 5µm 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).

After an attack where DU ammunition has been used, DU will be deposited on the ground and other surfaces as DU metal in pieces, fine fragments and dust, and if the DU has caught fire, as dust of uranium oxides. 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 have been deposited within a distance of 100 m of the target (NELLIS, 1997).

Most of the penetrators that impact on soft ground (e.g. sand or clay) will probably penetrate intact more than 50 cm into the ground and remain there for a long time. Penetrators that hit armoured vehicles form an aerosol upon impact or ricochet. 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 may also redistribute the fine DU dust. A part of the fine dust particles will adsorb onto 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 groundwater. If the impact is in residual soils, penetrators and DU dust will weather more or less easily, depending on the type of bedrock. If the soil consists of weathered granite or acid volcanic rock, the environment will be acidic and the weathering may be fast. Acid rain will speed up the weathering.

Penetrators and 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. This weathering process of DU is principally by corrosion into hydrated uranium oxide (U(VI)) that is very soluble in water. Other possible uranium compounds may be more or less soluble in water. However, various adsorption effects in soil may slow the migration of uranium through soil in any case by several orders of magnitude, so it becomes essentially immobile. Consequently, it will take many years, maybe several hundred years, before DU contamination migrates from the site (see also Appendix V).

APPENDIX V

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POSSIBLE EFFECTS
OF DU ON GROUNDWATER**V.1 Possible effects**

Uranium is ubiquitous in all rocks, soils, rivers and groundwaters on the Earth's surface. Average values for uranium in rocks are about 2-3 mg/kg (20-40 Bq/kg). However, it is not unusual that uranium concentrations are much higher, e.g. in uranium-rich granites the uranium concentration is 10-30 mg/kg. Some black shales that constitute large bedrock areas, such as the Chattanooga shale, have uranium concentrations of 10-80 mg/kg and the Swedish alum shale has uranium concentrations of 50-300 mg/kg.

A rock that contains 3 mg/kg uranium contains 8.1 g of U per cubic metre of rock (1 m³). If one penetrator is added into this 1 m³ of rock the concentration of uranium increases to 308 g or 115 mg/kg of uranium. This value is thus several times higher than the average concentration in soils and rocks, but still not higher than the uranium levels of soil and bedrock in areas where many people live. The uranium concentration in natural waters is much lower than in natural soils and rocks. In natural waters, typically the concentrations vary from less than 1 µg/l (12.4 mBq/l) to 100 µg/l (124 mBq/l) or more. In many countries groundwater in uranium rich areas have concentrations of up to 1,000 µg/l, and, in areas with uranium mineralization, of up to more than 1 mg/l (UNSCEAR, 2000).

The results of the UNEP mission's field study in Kosovo suggests that the majority of the 10 tons of depleted uranium penetrators introduced into the Kosovo environment are probably buried deep in the soil, although the presence of DU in lichen in many of the locations indicates that some dust has also spread over the environment at the time of the attack.

One possible effect that the depleted uranium could have on the local population is exposure to enhanced levels of uranium in water due to the dissolution of the penetrators by water in the soil, and transport of the dissolved uranium down through the profile to the groundwater table. This uranium could thus enter drinking water wells.

During one interdiction (a steep diving attack) against a target by a single A-10 aircraft, 100-150 DU rounds are likely to be fired. Observations by the UNEP mission showed that the penetrators hit the ground in long lines at an interval of 1-3 m. Test range data from the United States indicate that in soft soil the penetrators can go as deep as 6-7 m and that they will sometimes shatter. Therefore, as available data is reviewed it is assumed that each penetrator contaminates a minimum of 1 m³ of soil. The depth to the groundwater table will then be taken into account.

The UNEP mission observed that the shallowest groundwater wells had depths to the groundwater table of 2 m. The deepest one was 35 m. If we imagine a column that goes down to the groundwater table that is 1m² in area, each penetrator has the capacity to contaminate 2 m³ to 35 m³ of soil before the groundwater is affected. Under this assumption, the average concentration of uranium in 1 m³ of soil (the natural uranium in the soil plus 1 penetrator of 300 g uranium) is 115 mg/kg, in 2 m³ of soil it is 57 mg/kg, and in 35 m³ of soil 3.3 mg/kg (1% of uranium in a rock containing U-average crustal abundance). Below, the available scientific data for the behaviour of uranium in the natural environment is summarised in order to explore whether the drinking water is likely to become contaminated by DU in future years.

Uranium metal is unstable when in contact with oxygen and water, and therefore uranium oxides form on the surface of the penetrators or fragments. In the presence of water these oxides are hydrated (i.e. they contain water). The maximum solubility of oxidised uranium phases (surface layers on penetrators - e.g. schoepite, UO₃.nH₂O at near-neutral pH (as found in the water in Kosovo) is about 10 mg/l (ppm). However, there are many processes in nature that can retard the transport of uranium (sorption to minerals and organics in the soil; co-precipitation with calcite) and reduce (if the soil contains iron-II-bearing minerals, bacteria, or organic matter) the uranium from its hexavalent soluble form to its tetravalent insoluble form (UO₂ - solubility at neutral pH 0.1 µg/l).

Before one evaluates the dissolution and transport of penetrators it is important to consider the composition of soils and rocks in Kosovo. The rocks that comprise the areas that the UNEP mission visited were largely limestone. The UNEP mission also visited Kuke/Kukovce area that was largely comprised of metamorphic rocks. Altered basalts form the bedrock at the dam at Radoniq/Radonjic Lake. At the sites, the depth of soil cover varied, from 4 m in some areas, to only a few cm at Ceja Mountain and Planeje/Planeja village.

As stated above, the depth to the groundwater table was measured to be 2 m to 35 m in areas where water was collected from private wells. Of note is that most of the wells are less than 10 m in depth and can thus be considered to be in unconfined (or surface) aquifers. The only deeper wells were on hills that rose above the flat valleys. Therefore there exists no confining layer that could protect the aquifers from depleted uranium. The climate in Kosovo can be considered humid-continental with precipitation close to 75 cm/yr. This precipitation value represents the infiltration rate into the surface aquifers.

The penetrators that were retrieved in Kosovo showed clear signs of two alteration phases, one black and the other yellow. Analysis of the penetrators at Bristol University using spectroscopy (Raman spectroscopy and X-ray Photoelectron spectroscopy) and scanning electron microscopy with an energy dispersive spectrometer (SEM/EDS), indicate that the alteration phases only contain uranium and oxygen, in addition to low levels of other metals (iron, titanium, chromium, silicon and aluminium) that are known to be present in DU ammunition. XPS analysis of a penetrator fragment shows that the uranium in these oxides is both in the form of U(6+) and U(4+) as determined from reference spectra by Allen et al. (1982; 1984). These yellow and black alteration phases are thus uranium oxides.

A French study of depleted uranium metal found on a test site in Southern France (Crançon, 2001) used X-ray diffraction studies of the alteration phases they observed (also black and yellow) to show that these two phases are $\text{UO}_2(\text{OH})_2(\text{s})$ and $\text{UO}_3 \cdot 2\text{H}_2\text{O}$ (schoepite). The former is likely to be the black alteration phase and the latter the yellow alteration phase (Allen, personal communication). Since the yellow phase is more abundant on the surface, we conclude that the black phase (U^{4+}) is an intermediary step in the alteration from uranium metal (U^0) to the fully oxidised yellow phase (U^{6+}).

At Gjakove/Djakovica garrison a penetrator was found under 5 cm of soil. From studies of the uranium concentrations in soils sampled below this penetrator and the amount of uranium that could be easily smeared off the penetrator in the field, it can be concluded that the penetrator had lost 2-8% (5-20g) of the original weight (about 295g) by the effects of being fired and hitting the ground and then by subsequent oxidation and weathering over the 18 months since it had been fired. About two-thirds of this uranium was found in the soil profile, to the depth of 12.5 cm below the penetrator. This indicates that in soil solutions the rate of schoepite dissolution is about the same as the rate of oxidation of the penetrators. This can be concluded from comparison with laboratory dissolution studies of schoepite in the presence of CO_2 from the atmosphere (Duro, 1996), which is 32 g/300 g of schoepite. This assumes that the surface area of the penetrator is 27 cm^2 . If the penetrator forms an aerosol on impact, its surface area is increased and the dissolution rate increases accordingly. Possibly all of the penetrator will dissolve in 15 to 30 years. Instead of the solid uranium metal penetrators, the soils and rocks will initially contain elevated concentrations of schoepite.

With time the schoepite will dissolve and uranium will move downward through the soil. The distance that the uranium will be transported, however, is limited if the penetrator is embedded in organic-rich soil. Once the uranium comes into contact with either organic matter or minerals (<100 μm) further down the soil profile, the uranium will initially be sorbed into these minerals (Waite et al., 1994) and organic matter (Nash et al., 1981). Due to the presence of divalent iron in the soil minerals (Liger et al., 1999) and bacteria (e.g. Loveley et al., 1991), uranium will be reduced to its insoluble tetravalent form (see for example Ragnarsdottir and Charlet, 2000, for a summary of uranium behaviour in the natural environment). In the presence of oxygen the surfaces of UO_2 will oxidise to UO_{2+x} and this effect is enhanced by the radiolysis of water. However, soil water normally contains very low levels of oxygen (0.6 mmol O_2 per litre), and therefore uranium remains reduced, unless oxygen rich waters are introduced or a high volume of water flows through the rocks.

This conclusion is supported by the above quoted French study of a depleted uranium test site in Southern France. There it was found that uranium had only been transported 30 cm down the soil profile (in approximately 30 years) and was entirely held within the A1 profile of the soil (Crançon, 2001). The complementary experimental studies show that the distribution coefficient (K_d =concentration of U in solid divided by the concentration of U in water) is 2000 in the presence of humic colloids, or that uranium moves 3000 times slower (retardation factor, $R_f=3000$) than the water

that percolates through the soil. Crançon does conclude, however, that about 10% of the uranium is able to move further down the profile and reach the underlying groundwater by the formation of uranium-humic colloids which aid in the transport of uranium. This is the cause of the somewhat elevated uranium levels in the groundwater and canal waters of the test site that reach 25 µg/l (ppb) during extreme droughts. Usually the maximum concentration does not exceed 8 µg/l (ppb). The groundwater uranium values in the Southern French site are likely to be higher than in some areas of Kosovo due to the different type of rocks in that area. In France, the soil pH is somewhere between 3.5 and 4.5 for the A1 profile, whereas the soil pore water pH for most of the sites in Kosovo is likely to be higher due to the presence of carbonate minerals from the limestone, which increases the pH. In future years, in areas in Kosovo where the penetrators are embedded in thick soil, the maximum concentration of uranium in groundwater is therefore likely to be below 25 µg/l.

When the uranium values found at the French DU test site are compared with acceptable drinking water values, it emerges that the latter vary according to regulating agencies around the world. The drinking water standards for public waters set by WHO is 2 µg/l, whereas the US Environmental Protection Agency has a standard of 20 µg/l, Canadian Health has a value of 10 µg/l and SSK in Germany 300 µg/l (but in Hessen it is 2 µg/l). WHO is currently revising its value of 2 µg/l because it is thought to be unreasonably low. EU has an indicative dose limit for radioactivity of public water of 0.10 mSv/year, which roughly corresponds to a concentration of U-238 of 110 µg/l (EU, 1998). Of note is that many bottled mineral waters have high uranium contents, up to about 100 µg/l. No drinking water standards exist for private drinking-water wells. All of the drinking water samples that were collected by the UNEP mission had uranium values of 2 µg/l and below. Of note is that the water samples not filtered contain measurable uranium in some cases, whereas the filtered water samples are below detection limits. This indicates that some of the uranium is transported as colloids. It is possible that uranium concentrations will increase as more of the penetrators and their alteration phases dissolve. From the observations in France, it may be concluded that uranium will be retarded if the penetrator is trapped in soil. According to the observations made by the UNEP mission, most of the rounds penetrated deep into the ground. If the soil cover is very thin or the penetrators go through the soil down to the bedrock, the capacity for uranium retardation is lower than if the penetrator is trapped in a thick soil layer. There is one exception, namely, where the groundwater is over-saturated with respect to calcite, uranium can sorb/co-precipitate with calcite (Kitano and Oomori, 1971; Carroll and Bruno, 1991; Meece and Benninger, 1993). It is also important to consider the depth to the groundwater in drinking water wells.

V.2 Conclusions for sites visited

V.2.1 Planeje/Planeja Village

At Planeje/Planeja village the soil cover is only a few cm thick, the groundwater is at a depth of 2 m, and the rock is limestone. A penetrator was found about 50 metres from a private well. In this water the reducing capacity for uranium is low. The measured Eh (measure of oxygen in the water) is high for all of the waters in Kosovo, indicating that the uranium is oxidised in the water. However, the measured values for iron indicate that the measured Eh may be too high for some of the locations. It is well known that the redox state of water can be deduced from iron concentrations (Grenthe et al., 1992), but Eh is difficult to measure because water reaches equilibrium very quickly with the oxygen in the atmosphere. Therefore a more reliable measure of oxygen dissolved in water comes from iron analysis. From the iron analysis of the water in Planeje/Planeja village it can be seen that the iron concentration is below detection limits, indicating that the iron has oxidised and precipitated as iron(III)hydroxide. This means that uranium is definitely present as uranium (+6) (UO_2^{2+} , uranyl) and the uranyl ion is easily transported as carbonate complexes in limestone waters. The waters are supersaturated with respect to calcite and experimental studies show that the distribution coefficient (K_d) for uranyl-carbonate sorption/precipitation (Carroll and Bruno, 1991) is 1000 for the water composition measured. By assuming a range for hydraulic conductivity in limestone rocks ($K = 10^{-5.5}$ m/s to 10^{-9} m/s), that the porosity of the rocks is 0.1 and the hydraulic head 0.5 m, and that the flow is perpendicular to the mountain-side, and using Darcy's law, it can be estimated that it will take the local groundwater 36 days to 312 years to reach the farm-wells along the ridge (minimum distance to village wells, 50 m). Planeje/Planeja village is therefore a site where uranium values probably need to be monitored in the future.

V.2.2 Vranoc/Vranovac hill

At Vranoc/Vranovac there is apparently 600 kg of depleted uranium embedded in an esker (glacial) ridge that rises about 30 m above the surrounding landscape. The minimum depth to the local well water at the foot of the esker is 2 m.

The esker at Vranoc/Vranovac is composed of fine sand and is thus very permeable. The thickness of the humus-containing sand layer on the ridge was about 0.5 m. If the shooting was primarily at the top of the hill, then the uranium must pass through about 30 m of sand before entering the drinking water. Sand has very low sorption capacity for uranium. Therefore if the DU penetrators were fired deep into the hill, as suggested by the fact that we could not find any on the surface, then they are lying in the sand with a very low buffering capacity for both uranium reduction and sorption. It is therefore possible that the DU penetrators can dissolve and enter the groundwater.

Using laboratory uranium sorption/co-precipitation data for waters that are in equilibrium with calcite (Carroll and Bruno, 1991), it can be calculated that the retardation factor (K_d) for uranium is very low (4-200) for the water at Vranoc/Vranovac hill. Therefore uranium can be transported with this water. By assuming a range for hydraulic conductivity in silty sand ($K = 10^{-3}$ m/s to 10^{-7} m/s), that the porosity of

the rocks is 0.3 and the hydraulic head 1 m, and that the flow is perpendicular to the length of the hill, and using Darcy's law, it can be estimated that it will take the local groundwater 1 day to 27 years to reach the farm-wells along the ridge, if the shooting was aimed at the centre of the ridge (minimum distance to farms, 250 m). The isotopic values for uranium in the local wells show that the depleted uranium has not yet reached the farms. These wells should be monitored in the future. V.2.3 Rikavac

V.2.3 Rikavac

At Rikavac there is evidence of DU on a roadside but no wells could be sampled due to landmines. The land is used for agricultural purposes and is covered with thick soil. If the house next to the road is taken into use again, then nearby wells will need to be monitored.

V.2.4 Irznic/Rznic

The village is about 500 m from the A-10 attack but no evidence of penetrators or radiation was found on the surface. The depth to the closest well is 5 m and the soil thickness is about 4 m. The area shows evidence of a typical karst landscape and the bedrock is composed of limestone. The wells sampled in the village (a farm and the school well) have water compositions that are under-saturated with respect to calcite. Iron values of the waters show that the waters may be reduced and therefore it is possible that uranium will precipitate as UO_2 and reduce the mobility of uranium in the water. There exists, however, the possibility that the water contains some oxygen, allowing uranyl to be transported as carbonate complexes.

By assuming a range for hydraulic conductivity in karst limestone ($K = 10^{-2}$ m/s to 10^{-6} m/s), that the porosity of the rocks is 0.4 and the hydraulic head 0.1 m, and that the flow is towards the village, and using Darcy's law, it can be estimated that it will take the local groundwater 2 days to 63 years to reach the farms in the village (minimum distance to farms, 500 m). As it is still uncertain which parts of the village area were attacked with DU rounds it is recommended that the wells in this area be monitored.

V.2.5 Gjakove/Djakovica garrison

There is no well at Gjakove/Djakovica.

V.2.6 Bellobrade/Belobrod

The depth to the co-op well about 1,000 m from the A-10 attack is 2 m. The water is under-saturated with respect to calcite. Therefore no uranium-calcite co-precipitation is possible. The well has no measurable iron, which indicates that the iron has oxidised and precipitated as $Fe(3+)$ -hydroxide. The rock type in this area is not well known, but, for the purpose of this report, it is assumed that the valley is covered with fine-grained sand. By assuming a range for hydraulic conductivity in sand ($K = 10^{-2}$ m/s to 10^{-5} m/s), that the porosity of the rocks is 0.4 and the hydraulic head is 0.5 m, and that the flow is from the hills and towards the co-op well, and using Darcy's law, it can be estimated that it will take the local groundwater 1 day to 2.5 years to reach the well (distance 1,000 m). Uranyl can therefore be transported in these waters. During the mission's visit to Bellobrade/Belobrod the UNEP mission could not find any evidence of an attack with DU rounds. It is therefore uncertain where this attack really took place. Therefore it is recommended that wells within or close to the area that could have been attacked be monitored.

V.2.7 Bandera and Pozhare/Pozar

The depth to the shallowest well in this area is 11 m. All of the water samples were under-saturated with respect to calcite and therefore no uranium co-precipitation with calcite is possible. However, the iron values indicate that iron is in the form of Fe(2+) and therefore it is possible that uranyl will be reduced and that the concentration of uranium will be controlled by UO₂, which has a solubility of less than 1 ng/L. The location of the attack was not found and therefore it was not possible to assess how long it would take uranium-contaminated water to reach the farms. But it is not likely that these waters will be significantly affected by depleted uranium in the future.

V.3 Overall conclusions

All sites where DU was used need to be visited and samples taken for analyses of contamination by uranium of well water used for drinking. It is recommended that wells within the attacked areas and in the direction of the groundwater transport be monitored. The local situation determines how far from the attacked area the wells may be contaminated by DU. The distance that needs to be considered is of the order of 500 ± 300 m from the edge of the attacked area. The analyses could either be made to establish the total uranium or the isotopic uranium concentrations. In the first case there would be no reasons for action if the uranium concentrations were below established levels. Isotopic analyses will provide information on whether the water is contaminated with DU and if this contamination is likely to increase with time. As the DU contamination is likely to increase with time the monitoring may have to be repeated. Analysis looking for pH, Eh and total alkalinity, and major elements such as calcium, iron and alkalinity can be used to cast light on whether the uranium is in reduced form or oxidized (and mobile), and on the uranium transport capacity of the waters.

If the uranium values are currently found to be at, or will rise in the future to, concentrations above a limit set by the local authorities, two possibilities remain: either to refrain from using this well as source for drinking water, or treatment of the water prior to drinking, by filter systems that remove uranium.

V.4 Uncertainties

These conclusions are based on available scientific data. In evaluating what is known about schoepite dissolution kinetics, it emerged that further study is necessary in order to evaluate the rate of dissolution of this mineral with respect to mineral crystallinity, pH, Eh, soil composition and partial pressure of CO₂. Further studies of the possible link between contaminated soils and water, with the food chain and hence human health are recommended. This will require studies of plant growth in the presence of schoepite and the analysis of plant matter from these soils.

APPENDIX VI

• LICHEN AS A BIO-INDICATOR OF DU

During the UNEP mission to Kosovo, lichens were collected from the bark of living trees in areas close to “targets areas”, in the direction in which the DU rounds were expected to have been fired. Lichens consist of fungi and algae, living together in a mutually beneficial way. Some lichens growing on tree bark are used throughout the world to assess and monitor air quality since they can indicate the real extent of air pollution impact. The lichens morphology does not vary with the seasons and accumulation of pollutants can occur throughout the year, and they usually live for very long periods. Because they lack roots, lichens do not have access to soil nutrient pools and they accumulate substances mainly via trapping atmospheric particulate.

Lichens have a high capacity to accumulate uranium, but there has been very little detailed work done in the field on how uranium is fixed by lichens. Uranium is accumulated in lichen talus under moist and dry condition from airborne particles and dust and even tiny fragments of lichens may contain concentrations that are readily detectable. Unfortunately there is a lack of knowledge concerning the accumulation of depleted uranium in trunk epiphytic lichens.

In the target areas lichens were collected choosing mature trees with the trunk close to vertical (table VI.1). The lichen community did not deviate much on nearby trees of the same species. In addition, in some locations where lichen communities were not found, superficial bark layers were collected.

Table VI.1 Uranium concentrations in lichen and bark

UNEP	Sampling Site	Coordinates	Sample Type	U-238 [Bq/kg]	U-234 [Bq/kg]	U-235 [Bq/kg]	Utot [mg/kg]	U-234 U-238 [Bq/B]
UNEP 033	Vranoc/ Vranovac Hill	DN5266212446	Lichen	2.0±0.2	0.6±0.1	3.2E-02±3.2E-03	0.16±0.03	0.32±0.05
UNEP 046	Irsniq/ Rznic Barracks	DN4660508242	Lichen	39.4±2.5	6.3±0.7	1.0E+00±7.8E-01	3.19±2.53	0.16±0.02
UNEP 060	Pozhare/ Pozar	DN4766009252	Bark	15.4±1.0	2.1±0.2	8.5E-02±1.6E-02	1.24±0.28	0.14±0.02
UNEP 058	Pozhare/ Pozar	DN4766009252	Bark	4.2±0.4	0.5±0.1	1.0E-01±1.7E-02	0.34±0.08	0.11±0.02
UNEP 078	Bellobrade/ Belebrod	DM7397662134	Lichen + Moss	44.6±1.9	10.1±0.7	8.3E-01±8.1E-01	3.60±3.55	0.23±0.02

Table VI.1 reports the activity concentrations of U-238, U-234, U-235 and the total uranium concentration measured in lichen and bark samples collected in Kosovo. The uncertainty estimation for each measurement reported in the table includes: the uncertainty associated with the activity of the tracer (U-232) and the uncertainties

associated with the addition of the tracer to the sample; the uncertainty associated with counting the counting statistics of the sample and the background sample (blank); the uncertainty associated with the weighing of the sample; and the standard deviation of 3 different analytical determinations.

The U-234/U-238 activity ratios can be used as a fingerprint of natural versus anthropogenic sources of uranium. Natural composition of uranium in soil is characterised by U-234/U-238 and U-235/U-238 activity ratios of about 1 and 0.046 respectively. Particularly, U-234/U-238 activity ratios in soil typically range from 0.5 to 1.2. Depleted uranium has lower U-234/U-238 and U-235/U-238 activity ratios; considering an isotopic abundance of 0.2% for U-235, these ratios become 0.18 and 0.013 respectively. Typical U-234/U-238 activity ratios in natural water samples range from 0.8 to 10, hence values outside these natural limits can be indicative of anthropogenic contributions of uranium.

In the case of the lichen and bark samples collected during the field studies in Kosovo, the U-234/U-238 activity ratios range from 0.11 to 0.32, indicating clearly DU contributions to these samples. The presence of DU in these samples indicates the earlier presence of DU in the air, which means that at least some of the penetrators have hit hard targets and shattered into dust and dispersed in air. In fact, in some locations such as Vranovac Hill, Bandera/Pozar and Belobrod there was no measurable widespread ground contamination. This underlines the possibility of using in the future lichens and barks as sensitive bio-indicators in areas in which DU ammunition has been used.

APPENDIX VII

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ANALYSIS OF DU PENETRATORS FOUND

During the field mission, seven whole penetrators, one fragment (approximately half a penetrator) and six jackets were found and collected. They have been subjected to different forms of analysis: smear tests of the surface coating of uranium oxides on the penetrators and jackets, analyses of the composition of the penetrators and microscopic and spectrometric studies of two penetrators and one penetrator fragment.

VII.1 Studies of transuranic elements

The isotopic ICP MS and alpha spectrometric analysis on some of the soil samples containing high concentrations of depleted uranium (e.g. UNEP 069, UNEP 162 and UNEP 216) revealed traces of uranium-236, which is a non-natural uranium isotope formed when uranium is used as fuel in nuclear reactors. This indicated that some of the depleted uranium came from reprocessed uranium. This finding was confirmed by analysis of smear tests made on penetrators and jackets that had been found, and, at a later stage, by analyses carried out on material from four of the penetrators collected by the UNEP mission.

The activity concentrations of U-236 in the two penetrators (UNEP 213 and UNEP 214) and the penetrator fragment (UNEP 173) studied are in the range of 61–71 kBq/kg (25–31 mg/kg) (Burger and Schmid, 2001). In the penetrators and the fragment the activity concentration of U-236 is approximately 61 kBq/kg (25 mg/kg), which may be compared to the penetrators' U-238 activity concentration, which is 12,400,000 Bq/kg (see table VII.1).

The existence of U-236 in the penetrators triggered further studies of transuranic elements in the penetrators. These studies were performed at the AC Laboratorium Spiez, the Swedish Radiation Protection Institute (SSI), Bristol University's Department of Earth Sciences, and at the Radiation and Nuclear Safety Authority (STUK), Finland. The studies at the AC Laboratorium Spiez, SSI and STUK laboratories were carried out by alpha spectrography after the material from the penetrators had been dissolved in acid (HCl and HNO₃). Accounts of the analytic and radiometric methods used by the AC Laboratorium Spiez and SSI laboratories for the study of the penetrators are given in Appendix III, and from STUK in "Report of a projectile composed of depleted uranium" (Pöllänen et al., 2001). The results of these studies are presented in table VII.1.

The diagram in Figure VII.2 shows the result of the alpha spectrometric measurement on material from the penetrator collected by SSI at Ceja Mountain. The

activity concentration of Pu-239 and Pu-240, in the penetrators examined is from <0,8 to 12.9 Bq/kg. With the alpha spectrometric method used by the laboratories it is not possible to measure separately the activity of Pu-239 and Pu-240. The plutonium concentrations are very low and constitute impurities at the level of detection. The laboratories also analysed the penetrators for other elements formed in nuclear reactors, for example Tc-99, Np-237 and Am-241. However, the concentrations of these elements were all below the detection limit.

At Bristol University samples of alteration products from the surface of two penetrators and fragments of penetrators were dissolved and analysed by ICP-MS. The analytical method is described in Appendix III. In these samples the concentration of the radioelements Pu-239, Pu-240, Tc-99, Np-237, Am-241, Am-243 and Cm-244 were all below the detection limit.

Table VII.1. Studies on penetrators

Sample no./ Found at	Laboratory	U-238, [Bq/kg]	U-235, [Bq/kg]	U-234, [Bq/kg]	U-236, [Bq/kg]	Pu-240 + Pu-239, [Bq/kg]
ZA/R-00-505-01 Ceja Mountain	AC Laboratorium Spiez	12.37E+06	1.60E+05	1.16E+06	6.10E+04	<0.8
ZA/R-00-505-02 Ceja Mountain	AC Laboratorium Spiez AC Laboratorium Spiez	12.37E+06 12.37E+06	1.61E+05 1.62E+05	1.39E+06 1.62E+06	6.19E+04 6.10E+04	3 1
ZA/R-00-500-16 (fragment) Gjakove/ Djakovica						
Kokovce Ceja Mountain	STUK SSI 1)	12.70E+06	2.00E+05	1.55E+06	5.72E+04	<0.8 12.9

1) SSI did not make any measurements of the uranium isotopes of the penetrator.

Figure VII.1. Alpha spectrum of plutonium from a DU penetrator

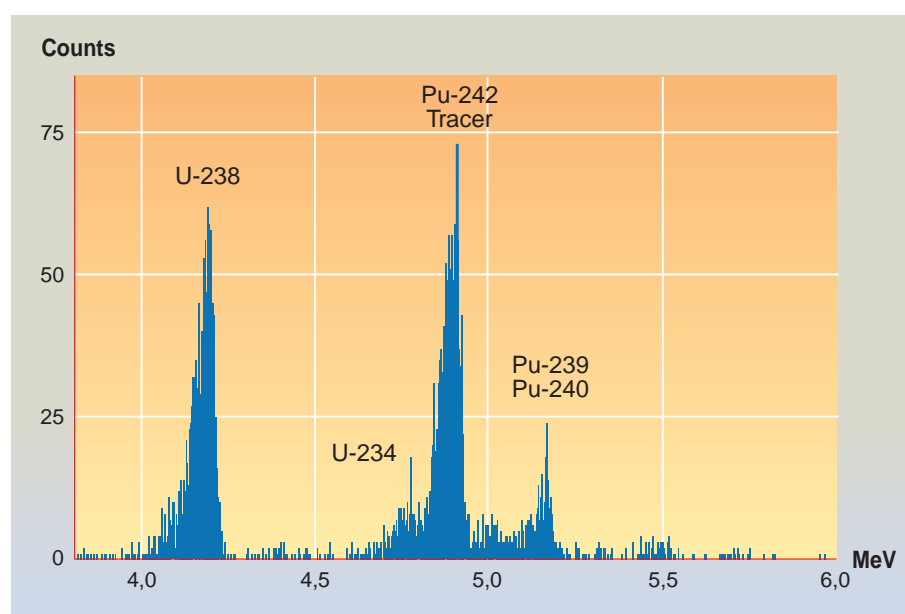


Figure VII.1 shows the alpha spectrum after chemical separation of Pu from 0.8 g of uranium from a DU penetrator found at Ceja Mountain, November 2001. The separation of uranium was not complete and the alpha spectrum shows traces from U-238 and U-234 that slightly interfere with the alpha from the Pu-242 tracer. The chemical yield was 19% and the sample was measured for more than 7 days. (SSI, 2001). The analysis results were that the DU penetrator contained 12 Bq/kg of Pu-239/240.

VII.2 Origin of transuranics

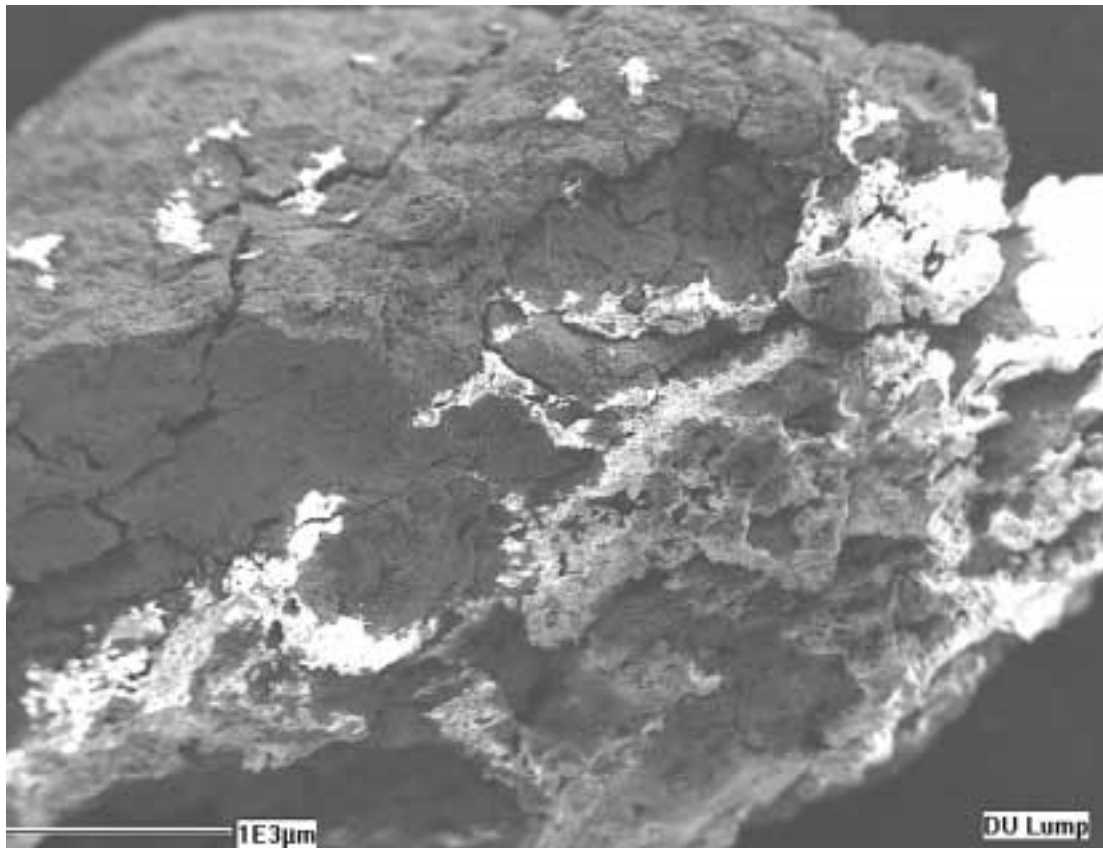
The U-236 and plutonium in the penetrators come from the reprocessing of nuclear fuel. In uranium fuel, the concentration of U-235 is enriched by up to 4%. When the reactor fuel is spent, the removed fuel still contains uranium-235. By reprocessing, the uranium-235 can again be concentrated up to 4% and used as uranium fuel. At the chemical reprocessing, the transuranic elements are separated from the uranium. However a small part of the transuranic elements will remain in the uranium fraction. If reactor uranium is reprocessed, some of the transuranics may contaminate some of the equipment in the enrichment plant (DOE, 2000). Consequently uranium that was processed in the plant is contaminated with transuranics, even if the uranium was new uranium received from mines.

In January 2000, the United States Department of the Army reported that investigations of transuranics in depleted uranium armour used in tanks had that shown this kind of armour does contain some transuranics (U.S. Army Material Command, 2000). The concentrations were low - the average Pu-239 and Pu-240 activity concentrations were 85 Bq/kg and the highest 130 Bq/kg. Since the uranium for both armour and ammunition comes from the same source, these contaminations can be expected in both armour and ammunition.

VII.3 Microscopic and spectroscopic studies of penetrators

Surface studies under a microscope of two penetrators were done at Bristol University. There were also studies done on the penetrator fragment found at the Gjakova/Djakovica Garrison. The studies included observation of the penetrator fragment surface, scanning electron microscopy (SEM) (see Figure VII.2), electron diffraction spectrometry (EDS), and x-ray photoelectron spectroscopy (XPS). The studies show that the penetrators had many visible cracks and two new alteration phases, a yellow and a black, primarily uranium (6+) solids. This indicates that the alteration and the weathering of the penetrators may be of orders of magnitude faster than that of uranium minerals.

Figure VII.2. Image of a penetrator fragment with scanning electron microscopy (SEM)



The fragment surface is fractured and the surface contains solids that have much lower mass density than the uranium metal as indicated by the light colours in the SEM image. The density of uranium decreases when the metal reacts with oxygen and water to form uranium oxides. The spots that are identified as A, B, C, D, and E were analysed by electron diffraction spectrometry (EDS). These analyses demonstrate that the uranium metal contains impurities or small phases intermingled with uranium oxides. These impurities are probably from the soil (aluminium, silicon and iron, and also contain iron, chrome and titanium).

APPENDIX VIII

LIST OF NATO COORDINATES

NATO UNCLASSIFIED

Data concerning the possible locations of depleted uranium ordnance expanded
in Kosovo (grid coordinates)

Site Number	Date	Location (UTM)	Total Number of Rounds
1	6-Apr-99	34TDM717863	UNKWN
2	7-Apr-99	34TDM551901	110
3	8-Apr-99	34TDN665117	150
4	8-Apr-99	34TDN834190	UNKWN
5	15-Apr-99	34TEM580880	250
6	15-Apr-99	34TEM680995	UNKWN
7	16-Apr-99	34TEM643964	UNKWN
8	17-Apr-99	34TEM1885	200
9	27-Apr-99	34TDM433974	UNKWN
10	27-Apr-99	34TDM680690	UNKWN
11	30-Apr-99	4203N02030E	UNKWN
12	30-Apr-99	34TEM208935	UNKWN
13	30-Apr-99	34TDN402102	UNKWN
14	5-May-99	34TDM515938	210
15	6-May-99	34TDM717863	UNKWN
16	7-May-99	34TDM503893	400
17	7-May-99	34TDN387039	500
18	7-May-99	34TDM771627	100
19	9-May-99	34TDN416092	200
20	10-May-99	34TEN148478	200
21	11-May-99	34TEN187470	700
22	11-May-99	34TEM019990	150
23	11-May-99	34TDN505044	65
24	12-May-99	34TDN505044	110
25	13-May-99	34TDN7735	570
26	14-May-99	34TDM723693	170
27	14-May-99	34TEM105920	UNKWN
28	14-May-99	34TDM525911	300
29	14-May-99	34TEM126888	90
30	15-May-99	34TDM7462	210
31	15-May-99	34TDN514102	320
32	15-May-99	34TEM1995	200
33	15-May-99	34TEM6496	130
34	15-May-99	34TDN719403	UNKWN

Site Number	Date	Location (UTM)	Total Number of Rounds
35	15-May-99	34TDM741622	UNKWN
36	16-May-99	34TDM745682	90
37	17-May-99	34TDM755619	170
38	17-May-99	34TEM540821	120
39	22-May-99	34TEM209103	UNKWN
40	25-May-99	34TDM624931	120
41	25-May-99	34TEM620945	300
42	25-May-99	34TEM632934	150
43	26-May-99	34TDM588998	UNKWN
44	26-May-99	34TDM5597	170
45	28-May-99	34TEN472112	100
46	28-May-99	34TEM625882	200
47	28-May-99	34TDM43159425	300
48	28-May-99	34TDM659950	50
49	28-May-99	34TEM189923	90
50	29-May-99	34TEN178432	350
51	29-May-99	34TDM695654	190
52	29-May-99	34TEM335844	UNKWN
53	29-May-99	34TDM580994	UNKWN
54	29-May-99	34TDM659950	50
55	29-May-99	34TCM01479634	230
56	29-May-99	34TEM335844	80
57	30-May-99	34TEM1691	480
58	30-May-99	34TCM01479634	250
59	31-May-99	34TDM54938	200
60	31-May-99	34TDM6573	970
61	1-June-99	422550N0202630E	200
62	1-June-99	34TDM663705	540
63	1-June-99	34TDM597858	400
64	1-June-99	34TDM782603	500
65	1-June-99	34TEM625882	970
66	2-June-99	34TDM728675	80
67	2-June-99	34TDM728675	70
68	2-June-99	34TDM5892	600
69	2-June-99	34TDM743720	400
70	2-June-99	34TDM503893	400
71	2-June-99	34TDN387039	500
72	2-June-99	34TDM771627	100
73	3-June-99	34TEN362171	150
74	3-June-99	34TDM503893	470
75	3-June-99	34TDM740590	370
76	3-June-99	34TDN59223216	700
77	5-June-99	34TDN393005	280
78	5-June-99	34TDN4002	120
79	5-June-99	34TDN389042	400
80	5-June-99	34TDN393005	200
81	5-June-99	34TDN387005	560

Site Number	Date	Location (UTM)	Total Number of Rounds
82	5-June-99	34TDN603245	320
83	5-June-99	34TDM67256935	286
84	6-June-99	34TDM409873	UNKWN
85	6-June-99	34TDM412883	907
86	6-June-99	34TDN4002	120
87	6-June-99	34TDM936785	970
88	6-June-99	34TDN474090	745
89	6-June-99	34TDM396948	100
90	6-June-99	34TDM396948	100
91	6-June-99	34TDN474090	200
92	6-June-99	34TDN464082	440
93	7-June-99	34TDM7439471956	140
94	7-June-99	34TDM545937	225
95	7-June-99	34TDN886168	370
96	7-June-99	34TDM592764	610
97	7-June-99	34TDN465083	530
98	7-June-99	34TDN534026	655
99	7-June-99	34TDN4310	560
100	8-June-99	34TDN528123	1320
101	8-June-99	34TDM771631-DM762600	400
102	8-June-99	34TDN863422	670
103	8-June-99	34TDN528123	1000
104	9-June-99	34TDM755645	200
105	11-June-99	34TDM772630	500
106	11-June-99	34TEM625882	970
107	17-Apr-99	34TEM170852	UNKWN
108	-	34TEM6308785128	UNKWN
109	-	34TEN17012908	UNKWN
110	-	34TDM5359283702	UNKWN
111	27-May-99	34TEM397979	UNKWN
112	28-May-99	34TEM631852	180

APPENDIX IX

FORMULAS AND DATA

IX.1 The isotope ratio

IX.1.1 Natural uranium

Table VII.1. Studies on penetrators

U-238	99.2745 %
U-235	0.7200 %
U-234	0.0054 %
U-235/U-238	0.00725
U-234/U-238	5.54E-5

IX.1.2 Depleted uranium

**Table IX.2 Composition of depleted uranium by weight
(defined as U-235 is 0.2% by weight)**

U-238	99.8000 %
U-235	0.2000 %
U-234	0.0010 %
U-235/U-238	0.00200
U-234/U-238	1.00E-5

The definition of DU varies. In some definitions U-235 is less than 0.7, some less than 0.35%, some less than 0.3%.

The table below shows the composition by weight if 0.35% is taken as the max. value in the definition of DU.

IX.1.1 Natural uranium

**Table IX.3 Composition of depleted uranium by weight
(defined as U-235 is 0.35% by weight)**

U-238	99.6500 %
U-235	0.3500 %
U-234	0.0018 %
U-235/U-238	0.00351
U-234/U-238	1.76E-5

In a mixture of natural uranium and DU the ratio U-235/U-238 will vary as follows. Assume an amount M (mg) of uranium of which X is the part of DU and 1-X the part of natural uranium.

The ratio $R = U-235/U-238$ in the amount M with DU defined as $U-235 = 0.2\%$ is estimated with the formula:

$$\frac{0.72-0.52X}{99.2745 + 0.5255X}$$

given in table IX.4

Table IX.4 The relation between the fraction X of DU of total amount of uranium in a sample and the ratio $R = U-235/U-238$ in the sample

X	1-X	R = U-235/U-238 in the sample M	1/R
0	1	0.00720	139
0.1	0.9	0.00673	149
0.2	0.8	0.00620	161
0.3	0.7	0.00567	176
0.4	0.6	0.00515	194
0.5	0.5	0.00462	216
0.6	0.4	0.00410	244
0.7	0.3	0.00357	280
0.8	0.2	0.00305	328
0.9	0.1	0.00253	396
1.0	0	0.00200	499

With DU defined as $U-235 = 0.35\%$ the formula is

$$\frac{0.72-0.37X}{99.2745 + 0.3755X}$$

given in table IX.5.

Table IX.5 The relation between the fraction X of DU of total amount of uranium in a sample and the ratio $R = U-235/U-238$ in the sample

X	1-X	R = U-235/U-238 in the sample M	1/R
0	1	0.00720	139
0.1	0.9	0.00688	145
0.2	0.8	0.00650	154
0.3	0.7	0.00613	163
0.4	0.6	0.00575	174
0.5	0.5	0.00538	186
0.6	0.4	0.00501	200
0.7	0.3	0.00463	216
0.8	0.2	0.00426	235
0.9	0.1	0.00389	257
1.0	0	0.00351	285

Tables IX.4 and IX.5 show that if the measured value of R is compared with table IX.3 assuming U-235 is 0.2% it might be an underestimation of max 30% of the DU content of the sample if in fact the U-235 content is 0.35% in DU instead of 0.2%.

IX.2 Half-lives, specific activities and decay schemes

Table IX.6 The specific activity of some radio-nuclides of interest

Radio-nuclide Natural = N Artificial = A	Occurrence	Half-life (years) Bq/mg of respective radio-nuclide	Specific activity
U-238	N	4.468E9	12.4
U-236	A	2.3415E7	2,400
U-235	N	7.038E8	80
U-234	N	2.445E5	231E3
Pu-239	A	24065	2.3E6
Pu-240	A	6537	0.84E7
Pu-241	A	14.4	0.38E10
Pu-242	A	3.763E5	0.145E6
Pu-244	A	8.26E7	6.57E2

Table IX.7 Specific activity of some common radio-nuclides in depleted Uranium, DU (235U 0.2%) in terms of activity of a radio-nuclide per mg DU

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°C

1) See Browne et al., 1986.

Table IX.8. Uranium-238 series (ICRP,1983)

Isotopes existing in depleted uranium

Nuclide	Type of decay	Half-life	Average emitted energy per transformation		
			Alpha energy	Beta energy	Gamma energy
			MeV	MeV	MeV
Uranium-238 238U ↓	α	4.468 10 ⁸ y	4.26	0.010	0.001
Thorium-234 234Th ↓	β	24.1 d	-	0.059	0.009
*Protactinium-234m 234mPa (99.84%) + *Protactinium-234 234Pa (0.16%) ↓	β β	1.17 m 6.7h	-	0.820	0-013
Uranium-234 234U	α	2.45 10 ⁵ y	4.84	0.013	0.002
↓					
Thorium-230 230Th ↓	α	7.54 10 ⁴ y	4.74	0.013-	0.002
Radium-226 226Ra ↓	α	1600 y	4.86	-	0.007
Radon-222 222Rn	α	3.824 d	5.59	-	-
Polonium-218 218Po ↓	α (99%) + β (0.02%)	3.05 m	6.11	-	-
↓					
*Astatine-218 218At 0.02%	α	1.6 s	6.82	0.04	-
*Lead-214 214Pb 99.98 % ↓	β	26.8 m	-	0.291	0.284
Bismuth-214 214Bi ↓	β (99%) + α (0.04%)	+19.9 m	-	0.648	1.46
↓					
*Polonium-214 214Po 99.98%	α	1.64 10 ⁻⁴	7.83	-	-
*Thallium-210 210Tl 0.02% ↓	β	1.3 m	-		
↓					
Lead-210 210Pb ↓	β	22.3 y			0.047
↓					
Bismuth-210 210Bi ↓	β	5.01 d	-	0.389	
↓					
Polonium-210 210Po ↓	α	138.4 d	5.40	-	-
↓					
Lead-206 206Pb		Stable			

* Branched decay

Table IX.9. Uranium-235 series (ICRP,1983)

Nuclide	Type of decay	Half-life	Average emitted energy per transformation		
			Alpha energy	Beta energy	Gamma energy
Uranium-235 ²³⁵ U	α	7.04 10 ⁸ y	MeV	MeV	MeV
↓ Thorium-231 ²³¹ Th			4.47	0.048	0.154
↓ Protactinium-231 ²³¹ Pa	β	25.52 h	-	0.163	0.026
↓ Actinium-227 ²²⁷ Ac	β	3.28 10 ⁴ y	5.04	0.063	0.048
↓ * Thorium-227 ²²⁷ Th (98.6%) + * Francium-223 ²²³ Fr (1.38%)	α (1.38%) + β (98.6%)	21.77 y	0.069	0.016	-
↓ Radium-223 ²²³ Ra	α	18.72 d	5.95	0.046	0.106
↓ Radon-219 ²¹⁹ Rn	β	21.8 m	-	0.391	0.059
↓ Polonium-215 ²¹⁵ Po	α	11.43 d	5.75	0.133	-
↓ Lead-211 ²¹¹ Pb	α	3.96 s	6.88	-	0.058
↓ Bismuth-211 ²¹¹ Bi	α	1.78 10 ⁻³ s	7.52	-	-
↓ * Polonium-211 ²¹¹ Po (0.28%)	β	36.1 m	-	0.454	0.053
↓ * Thallium-207 ²⁰⁷ Tl (99.7%)	α (99.7%) + β (0.28%)	2.14 m	6.68	-	0.047
↓ Lead-207 ²⁰⁷ Pb	α	0.516 s	0.021	-	-
	β	4.77 m	-	0.492	-
		Stable			

* Branched decay

Isotopes existing in depleted uranium

IX.3 Health standards, limits and levels

IX.3.1 Chemical: Health standards

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 $\mu\text{g}/\text{kg}$ body weight per day was established by the WHO (WHO, 1998).

The United States maximum contaminant level for Uranium in public watersystems that provide water for human consumption is 30 $\mu\text{g}/\text{l}$ (U.S. EPA, 2000)

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 for insoluble uranium of 0.2 mg/m^3 for chronic occupational exposure and 0.6 mg/m^3 for short-term exposure. When these occupational guidelines are converted for exposure of the general public they are 0.05 mg/m^3 for chronic exposure and 0.15 mg/m^3 for short-term exposure. For soluble uranium the levels are 0.5 mg/m^3 and 10 mg/m^3 , respectively (NIOSH, 1994).

The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) derived a Minimal Risk Level (MRL) for chronic inhalation exposure of 8 $\mu\text{g}/\text{m}^3$. For oral exposure, an intermediate MRL of 2 $\mu\text{g}/\text{kg}$ body weight per day was established (ATSDR, 1999).

IX.3.2 Radiation: Limits and action levels

- Trivial dose <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.

IX.4 Natural levels of uranium (UNSCEAR reports)

- Activity of U-238 is 12.4 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 7.4 μSv per year caused by only U-238 + U-234 (in equilibrium and

- each contributing about 50%) in the body.
- Total effective dose 120 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 $\mu\text{Bq m}^{-3}$ each of U-238 and 234 ($8 \cdot 10^{-5} \mu\text{g m}^{-3}$, 99.8% U-238 by weight).
 - Inhaled 7 mBq per year each of U-238 and 234 ($\sim 0.6 \mu\text{g}$ 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;
 - 5.3 μSv per year from uranium and its daughters as they are in air (major part caused by Pb/Po –210);
 - 0.02 μSv per year from U-238 solely and 0.03 μSv per year from U-234 solely.
 - Normal dust load 50 $\mu\text{g m}^{-3}$.
 - Natural uranium in soil 33 Bq kg^{-1} of each U-238 and U-234 (3 mg per kg).
 - Uranium in dust as in soil i.e. 1.7 $\mu\text{Bq m}^{-3}$ air of each U-238 and U-234.
 - Ingested by food 5.7 Bq per year (0.46 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 and U-234.
 - Effective dose caused by ingested (by food and water) uranium 0.3 μSv per year from each of U-238 and U-234 Therefore: 33 Bq/kg soil (each of U-238 and 234) leads to a total annual intake by food and water of 6.2 Bq of each of U-238 and U-234 which leads to an effective dose of 0.3 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 15 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).

IX.5 Dose conversion factors for DU

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 IX.10 Committed effective dose per unit intake via ingestion for members of the public [Sv Bq⁻¹]

Uranium-238

Half-life	Age ≤ 1a		Age	1-2 a	2-7 a	7-12 a	12-17 a	> 17 a
	f_1 for $g \leq 1$ a	$h(g)$	f_1	$h(g)$	H(g)	$h(g)$	$h(g)$	
4.47 10 ⁹ a	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 $g \leq 1$ a	$h(g)$	f_1	$h(g)$	H(g)	$h(g)$	$h(g)$	
2.44 10 ⁵ a	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 $g \leq 1$ a	$h(g)$	f_1	$h(g)$	H(g)	$h(g)$	$h(g)$	
7.04 10 ⁸ a	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 IX.11 Committed effective dose per unit intake via inhalation for members of the public [Sv Bq⁻¹]

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	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	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	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 IX.12 Effective dose coefficients for workers [Sv Bq⁻¹]

Uranium-238					
Type	Inhalation			Ingestion	
	f _i	h(g) _{sum}	h(g) _{sum}	f _i	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					
Type	Inhalation			Ingestion	
	f _i	h(g) _{sum}	h(g) _{sum}	f _i	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					
Type	Inhalation			Ingestion	
	f _i	h(g) _{sum}	h(g) _{sum}	f _i	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 IX.13 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 IX.14 Compounds, lung absorption types and f_1 values for the calculation of inhalation dose coefficients:

Adsorption type	f_1	Compound Uranium
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 newborn babies than for adults (ICRP Report No. 23 Report of the Task Group on Reference Man 1974). Therefore with a given concentration ($Bq\ m^{-3}$ or $Bq\ g^{-1}$) 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 IX.15 is an example of lung clearance after an intake of 100 Bq U-234 as 5 μ S-particles to an adult.

Table IX.15 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	$2.7 \cdot 10^{-5}$
10	7.8	$1.1 \cdot 10^{-4}$
100	4.6	$4.0 \cdot 10^{-4}$
1000	1.9	$6.9 \cdot 10^{-4}$
10.000	0.12	$9.2 \cdot 10^{-4}$

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 a long time exposure the child is a child only for 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.

Table IX.16 and table IX.17 show chosen committed effective dose per unit intake ($Sv\ Bq^{-1}$) of various uranium isotopes and of depleted uranium ($Sv\ mg^{-1}$), respectively.

Table IX.16 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 IX.17 Committed effective dose per unit of intake of depleted uranium [Sv mg⁻¹]

Mode of intake	Intake of DU [Sv/mg]
Ingestion	6.7 10 ⁻⁷
Inhalation	1.2 10 ⁻⁴

APPENDIX X

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TABLE OF RESULTS

The following are explanatory notes on the Table of Results from laboratory analyses of samples collected during the UNEP mission to Kosovo in November 2000. Information is also provided on the laboratory quality control exercise that was carried out. For ease of reference, the actual Table of Results is provided as a separate, pull-out document.

Following the mission every sample taken in Kosovo was given a unique UNEP code number. Altogether 355 samples were taken. Some of the samples were not analysed, others were divided into sub-samples, e.g. grass+roots and soil (these sub-samples are counted as one sample but as two analyses). A description of the sampling and the analytical methods used is given in Appendix III.

With the exception of some analyses performed on penetrators and jackets, the table includes the results from all uranium analyses of the samples.

For each sample the following information is given:

- the code of the institution/laboratory responsible for the analytical work
- the sampling date
- the name of the site where the sample was taken
- UTM coordinates for the place where the sample was taken (usually correct to 10 m)
- the type of sample and often a description of the sample
- the depth at which the sample was taken (most samples were taken at 1 – 10 cm depth)
- % of ignition residue of the sample (mineral fraction after oxidation at 550°C)

The following uranium isotopes have been analysed: U-238, U-234, U-235 and U-236. For each of these, the results are given as Bq/kg and mg/kg including the analytical uncertainty (if provided by the laboratory). In the case of the ANPA results, the uncertainty estimation of each measurement includes: (a) the uncertainty associated with the activity of the tracer (^{232}U) and the uncertainties associated with the addition of the tracer to the sample; (b) the uncertainty associated with the counting statistics of the sample and the blank; (c) the uncertainty associated with the weighing of the sample; (d) the standard deviation of replicate analytical determinations.

In the Table of Results empty cells indicate that no analysis was made of that particular isotope.

The table includes also results of the analyses of the total uranium concentration, U_{tot} , the calculation of the ratio U-234/U-238 and U-235/U-238 and the percentage of DU calculated from the ratio of the different isotopes. Low U-234 and U-235 values combined with large standard deviations can introduce large errors to these calculations.

Quality control exercise

During the mission it was decided that a quality control exercise should be organised by IAEA for the laboratories that participated in analyses of the samples. Four of the five laboratories whose data are presented in the Table of Results participated in the quality control exercise. Due to lack of time, a quality control exercise was only made for soil samples. One laboratory that only analysed the leachable fraction of uranium did not pass the quality control exercise. The UNEP codes used by this laboratory, as well as the codes used by the laboratory that did not participate in the quality control exercise, are marked with + UNEP codes for water and biological samples are marked with * as no quality control exercise was made for the analytical methods used for these samples.

In the Table the following abbreviations are used:

ANPA	Italian National Environmental Protection Agency
BS	Bristol University, Department of Earth Science, United Kingdom (soil samples)
BW	Bristol University, Department of Earth Science, United Kingdom (water samples)
IAEA	International Atomic Energy Agency, Seibersdorf Laboratory, Austria
ZA/R	AC Laboratorium Spiez, Switzerland
SSI	Analytica Laboratory, Lulea, Sweden
NA	Not Analysed
ND	Not Detected, i.e. below the minimum detection limit for the method used

APPENDIX XI

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APPENDIX XII

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In November 2000, following confirmation by NATO that depleted uranium (DU) had been used during the Kosovo Conflict, UNEP organised a scientific field mission to investigate the possible environmental consequences.

The mission visited 11 sites, taking hundreds of measurements and collecting more than 300 samples for laboratory analysis.

This report presents UNEP's findings and conclusions on:

- the presence and extent of DU contamination at the study sites;
- corresponding risks to the environment;
- possible mitigation actions.

UNEP urges a precautionary approach and recommends a series of measures to minimise risks to the environment and people of Kosovo and the wider Balkans region, both now and in the future.

