UNEP

Depleted Uranium in Serbia and Montenegro

Post-Conflict Environmental Assessment in the Federal Republic of Yugoslavia

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Post-Conflict Environmental Assessment

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Foreword

This report by the United Nations Environment Programme (UNEP) on the environmental impacts of depleted uranium (DU) is a direct follow-up to last year's report, *Depleted Uranium in Kosovo - A Post-Conflict Assessment* (2001), and once more brings additional scientific information on DU.

UNEP's work on DU started in the summer of 1999, when we carried out an assessment of the impacts of the Kosovo conflict on the environment and human settlements. As part of that review, UNEP conducted a Desk Assessment study of the potential effects of the possible use of DU during the conflict. In 2000, the North Atlantic Treaty Organisation (NATO) provided UNEP with new information concerning the use of DU during the Kosovo conflict. This information included maps, amount of DU ammunition used and coordinates of the targeted areas. It enabled UNEP to carry out the first-ever international assessment on the environmental behaviour of DU following its use in a real conflict situation.

Following the publication of the report, the work on DU in the Balkans was, however, not closed. During the Kosovo conflict, a small number of sites outside Kosovo, in Serbia and Montenegro, had also been targeted with ordnance containing DU. To reduce uncertainties about the environmental impacts of DU, it was evident that a second phase of scientific work would be needed.

This second phase has now been carried out in Serbia and Montenegro, starting with a field mission in October 2001 to collect samples, followed by laboratory work during the winter and the early spring.

Our new study provides additional information and reveals important new discoveries on the environmental behaviour of DU. We learn that still, more than two years after the end of the conflict, particles of DU dust can be detected from soil samples and from sensitive bio-indicators like lichen. However, as the levels were extremely low, it was only through the use of state-of-the-art laboratory analyses that detection could be achieved. Based on our findings, UNEP can confirm that contamination at the targeted sites is widespread, though no significant level of radioactivity can be measured.

Furthermore, during this assessment the UNEP team used modern air sampling techniques and detected airborne DU particles at two sites. While all levels detected are still below international safety limits, these results add valuable new information to the scientific body of knowledge concerning the behaviour of DU and have important implications for site decontamination and construction works.

During the mission to Serbia and Montenegro, a serious health concern potentially related to DU was presented to UNEP. This information was forwarded to WHO, as the competent United Nations agency on health issues. The original claim and the formal WHO response are included in this report.

Based on our findings, our recommendations remain the same as those we outlined in the previous Kosovo DU study. Future monitoring is clearly needed, as well as awareness-raising for the local population. Clean-up and decontamination has already started in both Serbia and Montenegro, and detailed recommendations on these issues are given in this report.

Once more, I would like to reiterate the precautionary words already used in our Desk Assessment in 1999 and repeated in the Kosovo report of 2001. The guiding principle for UNEP on the issue of DU is the protection of the environment and human health. Therefore I believe that the information gathered by our team of scientists during this latest assessment will be most useful in further advancing the analysis and understanding of the dimensions and complexity of DU.

During this challenging work, our cooperation with both civil and military authorities, as well as with scientific institutions representing the Federal Republic of Yugoslavia and the republics of Serbia and Montenegro, has been excellent. Their preparations and support during the mission have helped this work in many ways.

UNEP has also been in the fortunate position to cooperate with several excellent research institutes when addressing the challenging task of understanding the environmental impacts of DU. The close cooperation with our colleagues from the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) has been an important factor throughout the process. Without the professional work by the national institutes of Greece, Italy, Norway, Russia, Sweden, Switzerland and the United States, this work could not have been conducted in such an efficient manner, ensuring the highest quality results.

I also have the pleasure of expressing my sincere appreciation to Mr. Pekka Haavisto, who again accepted the demanding task of leading the mission and directing UNEP's work on DU.

Several governments, including those of Greece, Italy, Norway, Russia and the United States, have provided in-kind contributions to this assessment. Above all, my gratitude goes to the government of Switzerland that provided us with both laboratory expertise and generous financial support.

In addition to the recommendations provided in this report, UNEP strongly encourages further assessments to be undertaken in other regions where DU has been used in earlier conflicts in order to reduce uncertainties about its potential environmental impacts in the longer term.

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

Source: Base map coming from the United Nations Department of Public Information, Cartographic Section, New York, 1999, BTF; Times atlas of the world, Bartholomew and Times Books, London, 1994 and Atlas Géographique du Monde, Institut géographique Agostini Novara, 1995.

Introduction

In March 2001, UNEP published the first-ever assessment of the environmental risks associated with the use of depleted uranium weapons in a real combat situation.

The publication, entitled *Depleted Uranium in Kosovo - A Post-Conflict Assessment* (2001), was well received by stakeholders in Kosovo as well as by the international scientific community. The report helped alleviate some of the public concern about DU by scientifically demonstrating the low contamination levels and by providing recommendations to reduce risks at affected sites. The UNEP results were debated in the media and in numerous international seminars and workshops throughout 2001. During this time, five major studies were also published on medical issues and risks arising from DU. None of the studies contradicted the findings of the UNEP study.

Already in autumn 2000, UNEP was invited by Yugoslavian authorities to carry out similar

DU studies at targeted sites in Serbia and Montenegro. UNEP accepted the invitation and the results of the work in Serbia and Montenegro are contained in this report.

This study investigated five of the eleven sites that were struck with DU ordnance in Serbia, the single site that was hit in Montenegro and one targeted military vehicle. The sites were independently selected by UNEP experts based on the quantity of DU used, as well as on environmental and security considerations and population density. In addition, the mission considered safety issues regarding the storage of DU at the Vinca Institute of Nuclear Sciences in Belgrade. A scientific report made by the IAEA regarding the condition of this facility is included in this report.

The assessment team consisted of 14 international experts and the mission was conducted from 27 October to 5 November 2001. During the mission, a total of 161 samples were collected, including 69 vegetation, 54 soil, 17 air, 11 water, and 4 smear samples. Three penetrators and three penetrator fragments were also collected. Sample analyses were conducted by the Spiez laboratory in Switzerland and the ANPA laboratory in Italy.

In terms of improving our understanding of the environmental behaviour of DU, this report contains five new and significant findings.

First, detailed laboratory analyses of soil samples revealed low levels of widespread DU contamination at five of the six study sites. This indicates that during the conflict, DU dust was widely dispersed into the environment following the explosion of DU rounds. No DU was detected at the sixth sample site in Bukurevac.

Second, the penetrators recovered by the UNEP team had decreased in mass by 10-15 % due to corrosion. This has important implications for decontamination approaches as well as for future risks of groundwater contamination and monitoring needs.

Third, the military vehicle investigated during the mission was targeted by DU, but only low levels of contamination were detected. In this specific case, decontamination can be conducted by removing the remaining DU fragments and wet cleaning the interior and exterior using appropriate safety, storage and disposal measures.

Fourth, the mission paid special attention to the quality of groundwater and drinking water in DU targeted areas. Laboratory results showed that DU was not present in any of the water samples. In the short term, this is a positive result. However, in the long term, uncertainty exists regarding DU mobility and future study is needed to measure long-term infiltration rates and to assess potential risks. Annual water quality monitoring is also needed to ensure that sources of drinking water remain risk free.

Finally, the analytical tool box available to the UNEP team was extended through the use of air sampling equipment. Airborne DU particles were detected at two of the six sites measured. While these particles may have become airborne from on-site digging operations, the finding highlights important risks associated with soil disturbance at DU sites. As a result, necessary precautions should be taken during decontamination or construction works at DU sites.

In addition to our key findings, some important remarks must also be made.

First, during our activities in Serbia and Montenegro, the UNEP team observed that excellent work had been conducted concerning signing and fencing of DU-affected sites. The measures taken by the FRY authorities largely reflected the recommendations made in the UNEP Kosovo DU study of 2001.

Second, one of the issues raised during our DU research involves the accuracy of NATO coordinates for targets hit by DU. During the preparations for this study, Yugoslavian authorities identified a single targeted site, Pljackovica, that was not included on the NATO list. Our visit to this site demonstrated that the recovered penetrators were the same type as those from other NATO targets. The missing coordinate stresses the need for accurate and timely information on sites struck with DU.

Third, during the present study, chromosome changes were reported by Montenegrin authorities in 6 of 11 individuals that had worked on DU site decontamination at Cape Arza for four months. At the request of UNEP, WHO was asked to review this claim to determine the likelihood that the changes were related to DU. WHO found no evidence to link the chromosome changes to DU, either by radiological or toxicological pathways. Both the Montenegrin report and the WHO response are included in this study.

The final issue that is touched upon within the context of this report, concerns appropriate measures for site decontamination. While the Cape Arza site in Montenegro had undergone comprehensive decontamination involving the removal of two tons of rock, soil and humus, low-level contamination could still be detected by the UNEP team. This result shows that complete site decontamination is very difficult to achieve when funds are a limiting factor. In addition, it is important to recognize that special care must be taken to prevent the spread of contamination when removing or burning vegetation or disturbing soil at contaminated sites.

In conclusion, the findings of this study in Serbia and Montenegro are consistent with the findings of UNEP's DU study in Kosovo (2001). No alarming levels of DU contamination were detected, but uncertainty exists regarding future potential groundwater contamination from penetrator corrosion. Based on our findings, general and site-specific recommendations are provided to the responsible authorities for prompt implementation.

This study is the second major contribution by UNEP to the scientific debate on the environmental risks and behaviour of DU. UNEP is committed to working with other UN partners to extend DU studies to other post-conflict regions where the long-term effects of DU contamination can be carefully studied. As part of this commitment, UNEP was invited by IAEA to participate in a DU mission to Kuwait in Spring 2002. These results, when available, will give additional new information on the behaviour of DU more than ten years after its use in combat.

I would like to extend my sincere thanks and appreciation to all the national and international experts that worked so hard to contribute to the success of this study. It is my sincere hope that the findings of this study will further contribute to conflict-prevention and to the protection of human health and the environment in the unfortunate event of a future conflict.

Pekka Haavisto
Chairman, UNEP Depleted Uranium Assessment Team
Geneva, 26 March 2002

Background

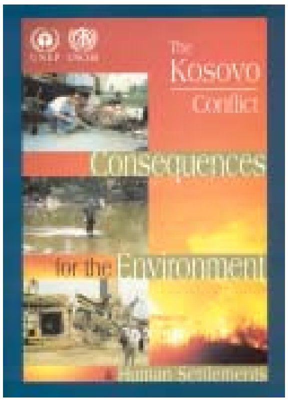
2.1 UNEP's role in post-conflict environmental assessment

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).

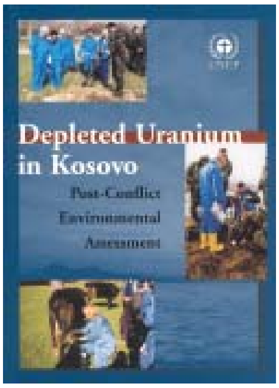
As part of this work, an international expert group on DU – the 'Depleted Uranium Desk Assessment Group' – was appointed to "assess the potential health and environmental impact of depleted uranium used in the Kosovo conflict". However, it should be noted that use of DU in Kosovo had not been officially confirmed at that 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.



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. The mission did not find any widespread contamination of the soil or ground surface, though some localised points of contamination were identified. No contamination of water or milk was found, and there was no evidence to suggest any immediate health problems. However, it was concluded that there could be a risk of DU contamination of groundwater in the future.

A similar mission to Serbia and Montenegro took place from 27 October to 5 November 2001. During this mission, air samples were taken in addition to water, soil, and lichen samples. All the sites investigated by UNEP in Serbia and Montenegro had been visited, cleaned, fenced-off and assessed by the FRY authorities. This had not been the case in Kosovo.

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%).

Penetrator collected by the UNEP team at Pljackovicka

Like naturally occurring uranium, DU is an unstable, radioactive, heavy metal that emits ionising radiation of three types: alpha, beta and gamma. 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 does not change significantly over human lifetimes. The unit for radioactivity is becquerel (Bq), 1 Bq being the disintegration of one atom per second.

When uranium decays, another nuclide or uranium isotope is created, which in turn is also radioactive, leading to a long chain of radionuclides (uranium daughter products) being produced (Appendix O ‘Formulas and Data’, Tables O.8 and O.9). DU is less radioactive than natural uranium and therefore also less radiotoxic.

This is because during the industrial process by which uranium ore is converted to uranium metal, uranium is chemically separated from all its daughter products beyond U-234, i.e. radium, radon and others. Furthermore, in the enrichment process used for production of nuclear fuel the uranium concentration of the isotope U-235 is increased from 0.7 % in natural uranium up to 4 % in the uranium destined for fuel.

The by-product is uranium with a lower concentration of U-235, i.e. depleted uranium (DU). The normal U-235 concentration in the DU produced is 0.2-0.3 %. In enrichment plants, the fact that U-235 is slightly lighter than U-238 is used to separate the two isotopes. This enables the concentration of U-235 to be increased in batches to be used as fuel.

Since U-234 is a lighter isotope still, its concentration is correspondingly higher in fuel uranium and lower in DU when compared with natural uranium. The fact that DU has lower concentrations of U-235 and U-234 than natural uranium also implies that DU is less radioactive than natural uranium. Some basic data on DU are given in Table 2.1.

Table 2.1 Depleted Uranium, DU ($^{235}\mathrm{U}$ 0.2%)

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

Specific gravity theoretically 19.0 Melting point 1,132°C

1) Reference, Browne et al. 1986

Uranium occurs in all rock, soil and water. The normal activity concentration of U-238 in the earth's crust is 5-125 becquerels per kilogram, Bq/kg, (0.5-10 mg/kg, 1 mg/kg = 1 ppm = 1 gram/tonne) and of U-235, 0.2-5 Bq/kg. The activity concentration of U-238 in uranium of good quality (0.5-30% uranium) is $0.6\ 10^5$-$3.6\ 10^6$ Bq/kg. The activity concentration of pure uranium metal in radioactive equilibrium with its immediate decay products is $50.23\ 10^6$ Bq/kg. The ranges of uranium activity concentration in soils, rocks, water and air are given in Appendix O 'Formulas and Data', Tables O.10 and O.11.

The overwhelming part of the radiation emitted from the nuclides in the U-238 series is emitted from the isotopes that follow after U-234. Compared with the sum of the energy of the alpha radiation emitted per transformation from all isotopes in the U-238 series, the isotopes that follow after U-234 emit about 89 % of the alpha energy, about 58 % of the beta radiation energy and about 98.6 % of the gamma radiation energy (Appendix O 'Formulas and Data' Table 8).

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

Metallic DU reacts chemically in the same way as metallic uranium, which is considered to be a reactive material. The general chemical character of uranium is that of a strong reducing agent, particularly in aqueous systems. In air at room temperature, solid uranium metal oxidises slowly. It first assumes a golden-yellow colour. As the oxidation proceeds, the film becomes darker, and at the end of three to four weeks the metal appears black. (Blasch *et al*. 1970).

Upon oxidation, uranium metal forms UO_2. A typical oxidation rate for massive uranium metal would be penetrations of 0.005 mm/day (0.19 mg/cm^2 per day) at 175 ^oC. Significant oxidation of UO_2 does not occur except at temperatures above 275 ^oC (Bennellick 1966). Uranium oxides are sparingly soluble but in a moist environment will gradually form hydrated oxides. Under such conditions, the addition of 0.75 % titanium to DU metal as used in penetrators appears to slow the oxidation rate by a factor of approximately 16 (Erikson 1990).

Microbial action can speed the corrosion of uranium. The corrosion rate is controlled by several variables, including the oxygen content, presence of water, size of metal particles, presence of protective coatings and the salinity of any water present. The principal factor controlling corrosion is the size of the particles. Small particles of uranium metal, produced by abrasion and fragmentation, corrode rapidly. Large masses of uranium metal corrode very slowly. In the long term, all uranium metal will oxidise to U^{4+} and U^{6+} (U.S. AEPI 1994). Studies carried out on penetrators collected by the UNEP DU mission to Kosovo in 2000 showed that impact on the ground causes numerous fine cracks in penetrators (UNEP 2001). This favours corrosion and dissolution. Rapid dissolution has been further confirmed by studies made on penetrators collected during the UNEP mission to Serbia and Montenegro in 2001 (see this report, Appendix K ‘Analyses of DU Penetrators and fragments’).

DU, particularly as a powder, is a pyrophore, which means that it can ignite spontaneously at temperatures of 600-700 ^oC. When DU burns, the high temperatures oxidise the uranium metal to a series of complex oxides, predominately triuranium octaoxide (U_3O_8), but also uranium dioxide (UO_2) and uranium trioxide (UO_3) (RAND 1999).

DU can expose people to radiation from the outside (external radiation) and from the inside (internal radiation) if DU has passed into the body by inhalation or ingestion. The harmful effect of such radiation is mainly an increased risk of cancer, with the magnitude of risk depending on the means of exposure (particularly exposure of the lungs through inhalation) and on the radiation dose.

Like naturally occurring uranium, DU also has a chemical toxicity. This depends on the chemical composition of the uranium and is normally the dominant risk factor to consider in the case of ingestion.

2.3 Assessing the risks

The concept of risk, its meaning and application are discussed in detail in Appendix A ‘Risk Assessment’. The following is a summary, intended to equip readers with the necessary background for interpreting the Findings, Conclusions and Recommendations presented in Chapters 4, 5 and 6 of this report, respectively.

‘Risk’ can refer either to the probability of occurrence of a given 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 unconditional and unacceptable probability of occurrence of a serious illness 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 (see Appendix O 'Formulas and Data', Table O.3). In this report, the consequences are those that might be caused by intake of DU through ingestion or inhalation and/or through 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 (µSv). 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 or guidelines. 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. Because there is an assumption of a linear non-threshold relationship for the biologically detrimental effects of ionising radiation, there is also a decreasing probability of occurrence with decreasing radiation dose. Therefore, an insignificant radiation dose means, in reality, a low and insignificant probability of getting a serious illness from that dose as compared with the overall probability of contracting that illness from all other potential sources.

In relation to chemical toxicity, consequences are treated as insignificant for concentrations or total intakes below applicable health standards or guidelines, and significant for those above.

In the discussions of site-by-site findings in Chapter 7, judgements of risk are made on the basis of measured DU ground contamination and measurements of possible DU contamination of drinking water and air. The relationship between measurements and risks are discussed in Appendix A 'Risk Assessment'. There is also a summary of risk assessment 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/m^2, hereafter referred to as the *Reference Level*.

Some levels of exposure lead to significant risks (consequences, radiation doses, intakes, as compared with chemical toxicity standards), others to insignificant risks. If ground contamination is less than 0.1-1 g/m^2, 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 subsequently be 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’ or ‘points of contamination’), there is a risk of contamination of hands and/or of direct ingestion of contaminated soil. There is also a possible risk of 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 from corroded DU, or fragments of DU, enter the body.

- A large percentage of DU rounds that either hit soft targets, or missed the intended target completely, will have penetrated into the ground and become corroded (to a widely varying degree, depending on site-specific environmental conditions) over time. As a result, there is a risk of future contamination of groundwater 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.

Because more than two years have elapsed since the military conflict in 1999, when DU was used, the conditions influencing the environmental consequences have changed and thereby the risks to people. For instance, the risks of airborne contamination from resuspension of DU dust on the ground surface decreases all the time because of the expected dispersion into the ground by dissolution in water and because of increasing cover of old grass, leaves etc. On the other hand, and for the same reasons, the probability of water contamination increases for a time as DU from surface dust and corroded DU penetrators (either on, or in, the ground), enters the water table.

Furthermore, during the period between the DU attacks and the time when the targeted areas were fenced-off by the FRY authorities, people could have been exposed to any of the risks that are described in Appendix A ‘Risk Assessment’. The possible health consequences of these exposures need to be taken into account by the relevant competent bodies.

The risks of touching a penetrator on the ground increase, given the possibility of hands or clothes becoming contaminated by corroded DU and the risk of subsequent internal contamination through ingestion. However, this increased risk might be neutralised by the decreased probability of finding a penetrator that is hidden by old vegetation. In conclusion, the overall risks from DU decrease with time. This conclusion is discussed further in Appendix A ‘Risk Assessment’.

UNEP Mission

3.1 Mission objectives

More than two years had elapsed since the Kosovo conflict and it could be expected that during this time environmental contamination from DU had probably altered in both quantity and quality (character) owing to natural processes.

Since the end of the military conflict, great efforts have been made by Serbian and Montenegrin experts to localise, measure and remove contamination from DU and DU penetrators on the ground. 11 contaminated sites in Serbia had been surveyed up to October 2001 and, of these, six were investigated by UNEP in cooperation with the Serbian authorities. In Montenegro, one site partly surveyed by Montenegrin experts was also investigated by the UNEP team.

The overall aim of the UNEP mission to Serbia and Montenegro was to examine the possible risks from any remaining DU contamination of ground, water, air and biota and from solid pieces of DU (i.e. intact or fragmented penetrators) still in the environment. The measurements of biota were limited to so called bio-indicators such as lichen, bark and moss to study their use as 'finger prints' of earlier DU dispersion in air.

A second objective was to compare the results of measurements by the various expert groups.

A third objective was to discuss and recommend appropriate principles and methods for management, storage and disposal of the radioactive waste resulting from decontamination work to date and in the future. This task was undertaken by the IAEA representative on the UNEP team and is reported in Appendix F 'Storage of Depleted Uranium Residues at the Vinca Institute of Nuclear Sciences'.

A fourth objective was to discuss possible future activities, such as further research projects, of potential interest for the parties concerned.

Since the UNEP DU mission to Kosovo in November 2000, a great deal of experience has been gained concerning the behaviour of DU in the environment. This was fully taken into account during the mission to Serbia and


New storage of low-level radioactive waste at Vinca

Montenegro. A variety of international studies, covering medical issues and risks from DU, have been published recently (FOI Sweden, August 2001; GSF Germany, January 2001; The Royal Society UK, May 2001: WHO Geneva, April 2001; Italian Ministry of Defence Italy, May 2001). In brief, none of the results or findings of these studies have contradicted the conclusions of UNEP's report concerning DU in Kosovo.

Studies have also been made in Serbia and Montenegro of the possible medical effects of DU.

In comparison with Kosovo in November 2000, certain differences had to be borne in mind when planning the present mission and drawing conclusions from the work conducted:

- a greater number of 'hard' targets, such as tanks, may have been hit by DU ammunition in Serbia and Montenegro causing increased environmental contamination from DU dust;
- any remaining DU contamination (including DU penetrators, jackets and fragments) had been present in the environment for one year longer than at the time of the mission to Kosovo;
- the sites visited had been carefully examined and decontaminated by Serbian and Montenegrin experts prior to the visit of the UNEP expert group;
- the concentration of natural uranium in soil and rock varies from one region to another;
- there was less precise information available from NATO concerning the locations (coordinates) of targeted sites or the quantities of DU used at each site.

In summary, the key questions facing the mission were:

- What are the present levels of DU contamination in Serbia and Montenegro?

- 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 and the results and recommendations of the UNEP mission to Kosovo in November 2000, 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 B 'Prerequisites and Limitations'.

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

- To confirm the presence or non-presence of DU at given locations;

- To determine how widespread was any contamination of soil, water, etc. at the sites investigated;

- To determine the distribution of solid pieces of DU (penetrators, jackets, fragments) in the environment and associated – or other – localised points of (concentrated) contamination (called 'contamination points') at the sites visited;

- To determine the possible presence of DU dust in air caused by re-suspension of

DU from the ground;

- To determine possible DU contamination of groundwater and drinking water at or near the sites investigated;
- To assess the corresponding risks from DU;
- To judge the necessity of maintaining the precautionary measures applied at present or introduce new measures;
- 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.

Mission team gathered around one of the wells at Borovac

3.2 Composition of the team

The team undertaking the UNEP DU mission to Serbia and Montenegro consisted of 14 experts. These came from the International Atomic Energy Agency (IAEA), the Swedish Radiation Protection Authority (SSI), the Finnish Institute of International Affairs, the Norwegian Radiation Protection Authority (NRPA), the United States Army Center for Health Promotion and Preventive Medicine (USACHPPM), the Nuclear Safety Institute of the Russian Academy of Sciences, the Greek Atomic Energy Commission, and two national laboratories: Spiez Laboratory in Switzerland and the National Environmental Protection Agency (ANPA) in Italy. The representative from IAEA took part in the visit to Vinca, but not to the other sites investigated.

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 issues surrounding DU. 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 targeted sites should be investigated was made by UNEP, based on the list previously supplied by NATO and showing locations targeted by DU, together with dates of firing and the numbers of rounds used. One of the investigated sites was not included in the NATO list, and was selected on the basis of information provided by the FRY authorities. Additional information from the FRY authorities concerning the other selected sites was also received upon request. UNEP also asked the FRY authorities whether any vehicles hit by DU could be investigated. Subsequently, members of the team were able to inspect an Armoured Personnel Carrier.

Within each study area, a more detailed selection of specific sites suitable for investigation was made *in situ*, based mainly on instructions from FRY military experts and UNEP's security advisor concerning (a) the presence of mines and unexploded cluster bombs, and (b) estimates of the probable direction of attack during the air strike in which DU was used.

The criteria for selecting sites were as follows:

- the approximate number of DU rounds fired was known;
- the sites taken together should represent a range of environmental conditions and properties;
- the locations taken together should be representative of the region's varied ethnic composition;
- the areas to be examined should be safe from mines and unexploded ordnance.

3.4 Fieldwork, sampling and laboratory analysis

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

- field measurements of beta radiation;
- field measurements of gamma radiation;
- field sampling of soil, water and vegetation (bio-indicators), with subsequent laboratory analysis;
- field sampling of DU air by special air filter samplers.

Starting "Line-up survey" at Borovac

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 C 'Methodology and Quality Control'.

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.

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.

Analyses of the soil, water, biological and air samples were carried out at Spiez Laboratory in Switzerland and at the ANPA laboratory in Italy. Following the Kosovo mission in 2000, a quality control exercise for soil samples was conducted by IAEA (Nahres-60, 2001). Both Spiez and ANPA laboratories passed that quality control test and also made inter-comparison analyses during work for the present report. Three soil samples, two lichen samples and

Sampling of bio-indicators from tree at Borovac

one water sample were analysed, with the results reported in Appendix C 'Methodology and Quality Control'.

The results of field measurements of radioactivity are given as 'counts per second' – abbreviated as 'cps' or microsieverts per hour – abbreviated µSv/h.

The results of laboratory samples (of soil and biota) are given either in terms of weight, i.e. milligrams of 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 becquerels per kilogram, Bq/kg. For samples of water, results are given as micrograms per litre, µg/L or microbecquerels per kilogram, µBq/kg and for air in µBq/m^3.

Water sampling at farm-house situated along the road from Vranje to Pljackovica

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 DU contamination 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;
- 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 biota (e.g. moss, mushrooms, bark and lichen) in order to check for the possible presence of DU as evidence of earlier or ongoing contamination;
- sampling of air at two or three locations within each site.

Air sampling at Borovac

The number of samples taken at 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 3.1.

The results of all the laboratory analyses are given in detail in Appendices E, G, H, I, J and K. The geographical (UTM) coordinates of each sampling position can be found in Chapter 7 ('Site by site findings'), together with corresponding maps. The analytical methods used are described in Appendix C 'Methodology and Quality Control'.

Table 3.1 Summary of samples collected and analysed, and findings in Serbia and Montenegro

Site name	Air	Water	Botanical*	Soil	Smear sample	Fragments of jacket or penetrator	Penetrators found and collected	Contamination points found	DU round
Pljackovica	2	3	5 (19)	11			2	4	Unknown
Vranje Garrison					4	3			
Borovac	3	5	3 (9)	9					300/188
Bratoselce	3	1	5 (11)	8			1	2	2140/1367
Bukurevac	3		2 (4)	4					250/156
Reljan	3	1	4 (7)	9			1		180/113+
Cape Arza decont area	3	1	11 (20)	13			1	2	480/300
Cape Arza cont area							4	5	
Totals	17	11	30 (69)	54	4	3	9	13	

*The first number indicates the number of samples collected. The number of samples analysed is given in brackets. The difference between the number of samples collected and the number analysed is due to the fact that the samples were sub-divided into species sub-samples and bark. The lichen sub-samples have the same number as the original samples with an additional letter, the bark sub-samples have the same number as the lichen sub-samples followed by CORT.

Findings

The findings for the six sites investigated, and for an armoured military vehicle inspected at Vranje Garrison, are summarised below. The corresponding Conclusions and Recommendations are presented in Chapters 5 and 6, respectively. The assessments of risk (where applicable) are based on the approach outlined in Chapter 2.3 and discussed in more detail in Appendix A 'Risk Assessment'.

4.1 Widespread contamination

Soil sample at Cape Arza

If a large number of penetrators hit hard surfaces and become aerosolised on impact, there is a risk that people nearby at the time of the attack may inhale airborne DU dust. As the aerosols disperse and fall out, the resulting contamination of the ground surface may be localised or widespread, depending on the properties of the aerosols and the prevailing meteorological conditions.

The UNEP team could not find any significant contamination of the ground surface or the soil except at localised points of concentrated contamination, referred to as 'contamination points' (see (b) below). These were in the immediate vicinity of penetrators lying on the ground, and around penetrator impact marks/holes. The level of DU detected decreased rapidly with distance from such contamination points and was no longer detectable by field measurements beyond a distance of one metre. However, laboratory analyses of soil samples enabled contamination to be traced for several metres from contamination points.

At all sites, soil samples were taken for analysis at Spiez laboratories in Switzerland. For all except one site (Bukurevac), DU contamination was found in almost every soil sample, indicating widespread contamination of the ground. However, the levels of contamination were low – of the same order of magnitude as natural uranium levels – and could not therefore be detected by field measurements. Such a low level of contamination is insignificant from the point of view of human health.

Undetectable DU contamination of the ground means that any widespread DU contamination at the investigated sites was so small that it could not be differentiated from uranium present naturally in the soil.

Assessment of risk

In Serbia and Montenegro the widespread contamination of the ground surface and upper layer of the ground (from 0-5 cm) is very low. Therefore, the corresponding radiological and chemical risks are insignificant.

4.2 Localised points of contamination

Localised points of ground contamination can occur at the site of a penetrator impact or close to a penetrator that has remained on the surface and been subject to corrosion. The concentration of DU can be very high at these points but the contamination is very localised (normally within a radius of 1 m) and the total amount varies widely, being in the range 0.01-10 g DU/kg soil. The depth of contaminated soil below contamination points was not the subject of special study during this mission but it is known from earlier studies (UNEP DU mission to Kosovo, 2000) that this might be in the range of 10 – 20 cm or more, with declining activity concentration relative to increasing depth. This vertical distribution probably results from dissolution and dispersion of DU from the initial superficial contamination (or from penetrators lying on the surface).

Marking of a contamination point at Pljackovica

All sites investigated in Serbia and Montenegro had been carefully surveyed and decontaminated by Yugoslavian and Montenegrin experts prior to the UNEP mission. Consequently, only 13 contamination points were identified by the UNEP team and all were easily removed or marked for removal. In the part of the Cape Arza site which has not yet been decontaminated (see Chapter 7.6) there might still be contamination points remaining. Further contamination points might also be found outside fenced-off parts of some other sites.

Assessment of risk

The risks associated with contamination points in general are discussed in Chapter 2.3 and Appendix A 'Risk Assessment'. Because there are still a few remaining contamination points in the environment of Serbia and Montenegro, a summary of the possible risks is given here.

One risk relates to the possibility of soil particles from contamination points becoming *airborne through wind action and then being inhaled by people. Another risk is related to the possibility that the DU from the contamination points eventually contaminates groundwater and plants through leakage. However, in both these scenarios, the amount of DU in the contamination points is too low to cause any radiological and chemical problems, either at present or in the future. The corresponding risks are therefore insignificant.*

The only risk of any significance related to contamination points would arise 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 µSv). On the other hand, such exposure might be significant from the point of view of heavy metal toxicity, meaning that the intake of uranium could be higher than applicable health standards.

4.3 Dispersion in ground

Penetrator collected by the UNEP team at Bratoselce

There are reasons for believing that the chemical and physical properties of DU make it more liable to dispersion in soil than is the case for naturally occurring 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 H 'DU in Water'. The possible consequences in terms of contamination of groundwater arising either from DU at contamination points, or from more widespread ground contamination are insignificant, as indicated above. However, for penetrators that remain in or on the ground, that is not necessarily so – see (d) below.

4.4 Penetrators

Corroded penetrator collected at Pljackovica

As outlined in Chapter 2.2, and discussed in more detail in Appendix K 'Analysis of DU Penetrators and Fragments', the fate of a DU penetrator after firing is governed by a wide range of variable factors (e.g. type of target, resistance of surface substrate). Consequently, there are several possible explanations for why penetrators were found at some sites but not at others.

Altogether during the mission, nine penetrators were actually found, and the presence of a further six was indicated by measurements. These findings applied to four of the six sites visited. Yugoslavian and Montenegrin experts had previously found 23 penetrators at four out of five sites and more than 100 penetrators at one site (Cape Arza). Many jackets and DU fragments had also been found prior to the UNEP mission. In most cases, the penetrators were located either on the ground surface, or superficially covered by leaves and grass. Many of them were heavily corroded and, given a similar rate of corrosion, those penetrators still on the surface may have more or less disappeared from the environment – as solid objects – within 10-20 years. What happens in the case of penetrators buried deep in the ground is not yet known.

The general conclusion for the six sites is that there are no penetrators remaining on the surface in the areas that have been searched by the UNEP team. However, at some sites there were indications that penetrators (and contamination points) might be present outside the areas fenced-off by the FRY and Montenegrin authorities. These areas therefore have to be searched and any penetrators and/or contamination points dealt with appropriately.

The soil underneath and adjacent to penetrators on the ground surface was normally found to be contaminated by DU, as described above. This finding is closely related to the observed corrosion of the penetrators, which also illustrates one possible pathway for internal exposure. If corroded penetrators are touched by someone who is not wearing protective gloves, their hands may become contaminated, leading to a risk of DU ingestion.

There are good reasons for believing that most of the DU rounds fired against targets at the investigated sites did not shatter but instead entered the ground more or less intact. In this case, the buried penetrators constitute a source of uranium that might, in the future, influence the concentration of uranium in drinking water. The quantity of additional uranium in the environment of areas affected in this way may, exceptionally, be as much as 10-100 times natural levels. However, a doubling of natural uranium levels is more typical.

Penetrators were also analysed with regard to their content of plutonium (Pu), uranium-236 (U-236) and Np-237, see Appendix K ‘Analysis of DU Penetrators and Fragments’. Analysis of isotopic composition and radiochemical studies confirmed the overall picture for penetrators and fragments that had emerged from the 2000 UNEP DU mission to Kosovo. The depletion level in all samples measured was rather constant, 0.195±0.001% U-235 by weight. In addition, the level of U-236 in penetrators was confirmed to be 0.0027% by weight. Radiochemical analysis also confirmed the very low presence of Plutonium in the penetrators. The concentrations in terms of activity were in the range 0.0134-0.0318 Bq/g penetrator, which corresponds to $5.8\ 10^{-12}$ to $13.8\ 10^{-12}$ g Pu/g penetrator. The concentration of Np-237 was below the limit of detection (<0.002 Bq/g penetrator).

The presence of these radioactive elements in the DU samples analysed indicates that at least some of the depleted uranium had come from material reprocessed from spent nuclear fuel, or from contamination of equipment during the reprocessing of spent nuclear fuel. However, the quantities of plutonium and U-236 were very low, without any significant influence on either the overall radioactivity of penetrators.

Assessment of risk

The risks of penetrators in general are discussed in Chapter 2.3 and Appendix A ‘Assessment of Risk’. Because there are penetrators in the environment of Serbia and Montenegro (some still on the surface but most probably buried in the ground) a summary of the possible risks is provided here.

Penetrators lying on the ground surface may be picked up by people, leading to possible contamination of the hands. Gram quantities of corroded uranium can easily be removed from the penetrators by mechanical contact. This means that there is a potential risk of internal contamination by ingestion. Even if only a small part of the available DU is expected to pass into the body, the resulting radiation dose may be relatively high, though still less than 1 mSv. Furthermore, the intake may be significant in terms of chemical toxicity health standards, at least in relation to annual tolerable intakes. Another risk of exposure from a heavily corroded penetrator is by inhalation. Penetrators have to be handled with care to avoid corroded DU becoming airborne. Based upon conservative assumptions, inhalation might lead to significant radiation doses, i.e. >1 mSv.

A third risk of exposure arises from external beta radiation to the skin if a penetrator is placed in a pocket, or used as an ornament on a neck chain. This could result in quite high localised radiation doses (in excess of radiation safety guidelines) after some weeks of continuous exposure, even though there will not be any radiation skin burns. 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 groundwater and drinking water (see further discussion in Appendix H 'DU in Water'). As discussed in point (g) below, uranium occurs naturally in drinking water, with normal concentrations in the areas investigated being in the range 10^{-5} – 10^{-3} *mg U/l water. Corresponding annual intakes would be in the range 0.01 – 1 mg uranium/year, leading to radiation doses of less than 1 µSv/year.*

At the investigated sites, penetrators buried in the ground could – very locally – lead to increases of 10-100 times the natural uranium content to a depth of one metre from the surface. If that resulted in a corresponding increase in the uranium concentration of water, the radiation dose would still be less than 1 mSv per year, although the uranium concentration might exceed WHO health standards for drinking water. However, there are many uncertainties and it would therefore be desirable to conduct some future checks of uranium in drinking water close to the affected sites. Penetrators currently buried in the ground are liable to be dug up during any future construction work at affected sites. In such cases, there would be corresponding risks of both external exposure from beta radiation and internal exposure through contamination of hands and/or inhalation, as described above. There is no risk of any significantly increased uptake of DU in plants, either at present or in the future, as a consequence of those penetrators that remain in the environment, (compare point (b) above). There is no risk from inhalation of possibly contaminated soil from penetrators, (compare point (b) above).

The highest measured concentration of plutonium in DU was 31.8 Bq/kg DU. This has to be compared with the activity of U-238 in DU which is 12,400,000 Bq/kg DU, i.e. 400,000 times greater. 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 plutonium contained in the penetrators studied is at least 1,000 times less hazardous than the DU itself.

Analysis of uranium-236 content in the penetrators showed a concentration of 0.0027% by weight of the total uranium. This is so low that the radiotoxicity is unchanged when compared to DU containing no U-236 at all.

4.5 Jackets

A jacket is the non-DU part of a weapon projectile that holds the DU penetrator. The projectile is designed so that the jacket stops upon impact against a hard surface, while the penetrator enters the target. A number of jackets had previously been found by Yugoslavian experts at the sites investigated by UNEP, but far fewer than the number of DU rounds that NATO reported to have been fired. The small number of jackets found is a further indication that most of the penetrators missed hard targets and entered the ground with the jacket attached.

Assessment of risk

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

4.6 Contamination of an armoured military vehicle.

An armoured military vehicle that had been hit by DU ordnance was investigated at Vranje garrison for possible DU contamination. No penetrators or jackets were found, but there were some small fragments of DU inside the vehicle, with weak contamination of 20-200 mg DU/m^2. 1-10 % of this was loose enough to contaminate hands upon touch.

APC at Vranje Garrison

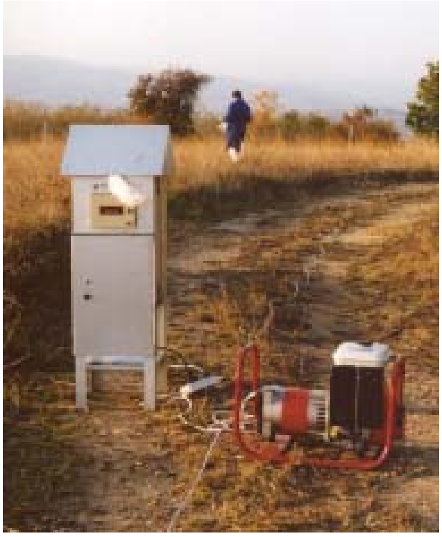
Water sampling from one of the wells at Borovac

Assessment of risk

Even if the risk of contamination is small, certain precautions should be taken to avoid any unnecessary exposure to people entering the vehicle. However, once further decontamination has been completed (by a qualified expert working to relevant safety regulations), the vehicle can be considered safe.

4.7 Contamination of water

In all, 11 water samples, from five of the six sites visited, were taken for laboratory analyses, see Table 3.1. All the water measurements are summarised in Appendix H, Tables H.2 and H.3. The uranium concentration was found to vary from 15 10^{-6} to 2 10^{-3} mg U/kg water, i.e. within the normal range of uranium concentration in drinking water. In seawater from Cape Arza, the concentration was 4 10^{-3} mg U/kg water. There was no detectable DU in any of the water samples.



Air sampling at Borovac

Assessment of risk

At present, there are no significant risks from DU in water.

4.8 Contamination of air

At each site, air samples were taken at two or three locations in line, normally within the fenced-off area, according to wind direction. The concentration of uranium in air varied from 0.14 10^{-6} mg/m^3 (1.7 µBq/m^3) to 3.5 10^{-6} mg/m^3 (42 µBq/m^3). The concentrations are within the range of normal concentrations for uranium in air, even though they are in the upper part of that range.

At two of the sites there was a clear indication of DU in the air sampled, although it is difficult to find an unequivocal explanation for this finding. If the dust and particles on or close to the surface contribute significantly to DU concentration in air, and there is available DU on the ground, there might very well be detectable DU in air (see Appendix I - 'DU in Air'). The measurements are consequently very sensitive to specific local conditions. If natural processes (e.g. wind action) or human activities (e.g. digging) raise dust into the air, it is more likely that DU will be found in air samples. At the two sites where DU was detected in air samples, digging for penetrators was occurring simultaneously during the operation of the filters used for air sampling. This might have caused dust with traces of DU to become airborne and enter the filters. However, at some other sites, DU was not detected in air samples, even though digging also occurred at the time of sampling. In conclusion there is no unambiguous explanation of the findings for DU in air.

Assessment of risks

The natural concentration of uranium in air normally causes very low doses from the uranium isotopes alone, in the order of 0.1-1 µSv/year. This is also the case at the six sites where measurements were taken, including the two sites where DU was detectable in air samples.

Sampling of bio-indicators from tree at Pljackovica

4.9 Contamination of botanical material

At several sites, samples were taken of botanical material such as moss, bark, lichen and mushrooms, in order to search for possible DU uptake and to identify earlier or ongoing airborne contamination. As found by the UNEP DU mission to Kosovo in 2000, lichen appears to be an indicator of airborne DU contamination. This is not a new scientific finding; for instance, studies from fallout of the atomic bomb tests in the early 1960s have shown lichen to be a good indicator of airborne contamination. Of the lichen samples taken in Serbia and Montenegro, only those obtained from Pljackovica, Bratoselce and Cape Arza showed any significant indication of DU.

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

4.10 Contamination checks on UNEP team members

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

Checking for contamination after finished work at Borovac

Conclusions

5.1 Introductory notes

(a) The conclusions and observations in this section refer to the UNEP mission to Serbia and Montenegro from 27 October to 5 November 2001 and to the six sites and one armored personnel carrier that were visited and investigated at that time. The part of the site at Cape Arza not yet searched and decontaminated is not covered by the following conclusions.

(b) During the military conflict of April to June 1999, NATO reports that rounds of DU ammunition were fired at ten sites in Serbia and at one site in Montenegro (Appendix N). Additionally, the FRY authorities have reported the existence of one targeted site that was not included on the NATO list. UNEP experts independently selected six of these sites for investigation (Chapter 3.3) and the FRY authorities supported that selection. The results from the six sites studied are assumed to be 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.

(c) A 'significant' radiological risk is defined in this report to be 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 (WHO 1998A, 1998B). 'Insignificant' radiological risks are those where the corresponding dose or concentrations/intakes are < 1mSv. 'Insignificant' toxicological risks correspond to intakes below WHO health standards (Chapter 2.3 and Appendix A).

(d) In practice, there is no sharply defined boundary at these levels between significance and insignificance. Ultimately, this a personal judgement – as always with regard to risk perception. However, a 'significant' level can be considered as that above which countermeasures to reduce the risks are considered as justified, and below which countermeasures cannot really be justified. In other words, exposures leading to radiation doses, intakes or concentrations lower than the levels given above are considered as tolerable or acceptable.

(e) In comparison with the UNEP mission to Kosovo in 2000, many different conditions applied to the work conducted in Serbia and Montenegro. Nevertheless, the results from the two missions are broadly compatible. One essential difference was that a further year had elapsed since the military conflict. This had led to more apparent corrosion of DU penetrators lying on the ground surface, more covering-over of penetrators and of ground-surface contamination by grass and soil, and to increased possibilities of DU contamination in water. Furthermore, different environmental conditions influenced the performance of the mission and the interpretation of the results.

(f) Based on the findings discussed above in Chapter 4 (and on a site-by-site basis in Chapter 7) and referring to the discussions of risk assessments in Chapter 2.3, the overall conclusions of the UNEP mission are as follows:

5.2 The Conclusions

1. **Widespread contamination:** No significant, widespread contamination of the ground surface by depleted uranium could be detected by portable beta and gamma radiation detectors. The much more sensitive laboratory analyses of soil samples have shown that there is generally widespread, but very low-level, DU surface contamination at all sites except one (which had no indication of DU contamination). This means that any widespread contamination was present at such low levels that it could not be detected or differentiated from natural radiation using state-of-the-art portable detection instruments. The corresponding radiological and toxicological risks from the widespread low-level contamination are insignificant.

2. **Contamination point detection:** Ground surface DU contamination that is detectable by portable beta and gamma radiation detectors is typically limited to areas within 1-2 metres of penetrators and localised points of concentrated contamination ('contamination points') caused by penetrator impacts. A few contamination points were identified during the mission but most of them were only slightly contaminated. They were either removed, or marked for the authorities to deal with.

3. **Contamination point risks:** 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 or guidelines.

4. **Penetrator recovery:** Nine penetrators and three jackets (penetrator covers) were located and removed during the mission. There were also indications from field measurements of a further 13 penetrators hidden in the ground (contamination points). Authorities had earlier found 23 penetrators in Serbia and more than 100 at the single site in Montenegro. Given that more than 2,000 DU rounds were reportedly fired against the investigated target sites (see Appendix N), the number found is very low. It is concluded that there could be four possible explanations:

- the majority of the penetrators are buried in the ground;
- they are spread over a larger (and/or other) area than assumed;
- they have been removed during military-led site clean-up or during clearance of unexploded ordnance;
- they have been removed in circumstances beyond the control of the authorities (for instance by local people).

The most probable and most widely applicable explanation is the first one, but the other three scenarios might also have occurred.

5. **Penetrator corrosion:** There might still be some penetrators lying on the ground surface, probably outside some of the areas that have been fenced-off by the authorities. During the two years that the penetrators have been lying in the environment, they have become corroded. The corroded uranium is loosely attached and easily removable. Consequently, if such a penetrator is picked up, it could easily contaminate people's hands. Even if the probable resulting intake into the body is small, neither the radiological nor the toxicological risks should be neglected.

6. **Penetrator contact:** If a penetrator is put into a pocket or elsewhere close to the human

body, there will be external beta radiation to the skin. After some weeks of continuous exposure, this could lead to localised radiation doses above safety standards. Even so, it is unlikely that there will be any adverse health effects from such exposure.

7. **Penetrator composition:** The transuranic elements, uranium isotope U-236 and the plutonium isotopes Pu-239/240, were found to be present in the depleted uranium of those penetrators analysed. However, the concentrations were very low and did not have any significant impact on their overall radioactivity.

8. **Penetrator detection:** Because of the real and potential risks associated with penetrators, some complementary searching for penetrators lying on the ground is justified, as recommended in the respective site findings, presented in Chapter 7.

9. **Accidental penetrator recovery:** Buried penetrators and jackets may be accidentally brought to the surface in the future through digging as part of soil removal or construction works. The corresponding risks would then be the same as for penetrators and jackets currently lying on the surface.

10. **Water contamination risks:** As concluded in point 4 above, it is probable that the majority of the penetrators and jackets are hidden 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 or guidelines for drinking water.

11. **Water contamination research and monitoring needs:** The inherent uncertainties in the assumptions above justify some long-term research into how rapidly penetrators corrode, dissolve in water and disperse into the environment. They also justify sampling and analysis of drinking water from wells that might become contaminated with DU in the future.

12. **Air contamination risks:** Air samples were taken at all sites and all showed natural uranium concentrations within the normal range of variation. It is common that traces of natural uranium are found in air due to dust stirred up from the ground. However, the possibility of DU occurring in a given air sample depends on wind speed and direction, surface conditions and the quantities and qualities of DU contamination on the ground. The traces of DU contamination detected at two sites were probably caused by natural re-suspension of widespread ground-surface contamination and/or by simultaneous digging for buried penetrators at the time air sampling was conducted. The detected concentrations of DU at both sites do not imply any additional significant risks. However, they raise the possibility of low-level air contamination occurring as a consequence of future soil disturbance, especially major construction works.

13. **Bio-indicators of DU contamination:** As concluded in the UNEP report on DU in Kosovo, there are indications that components of some living organisms such as lichen, and possibly bark, may be good environmental indicators of DU. The detection of DU in some lichen samples taken during the mission to Serbia and Montenegro indicated the earlier presence of DU in air, meaning that at least some of the penetrators had hit hard surfaces, split into dust and dispersed into the air.

14. **Vehicle contamination risks:** The armoured military vehicle inspected during the mission was found to be contaminated to a minor degree. However, some of the contamination was still loose and poses a risk of unnecessary contamination for people entering the vehicle. Decontamination should therefore be conducted as soon as possible by qualified personnel observing applicable safety guidelines. Following decontamination,

all DU-related restrictions on access to and use of the vehicle can be lifted.

15. **Access restrictions and signing:** All sites (except Bukurevac) are at present closed-off from public access by fencing. It is the opinion of the UNEP expert group that at four of the six sites there are no reasons, from either a radiological or toxicological points of view, to retain the fencing. However, it is clearly at the discretion of the authorities to decide whether or not to remove the fences. In any case, signs should be erected with appropriate information, as suggested in the site-by-site findings presented in Chapter 7. At the remaining two sites, complementary survey and measurement work is needed prior to possible removal of the fences.

16. **Assessment methodology:** The survey, measurement and sampling techniques used during the mission worked well. It is concluded that the purposes of, and expectations from, the various technical components were met satisfactorily. These were:

- portable beta and gamma radiation detectors to identify widespread, significant contamination and localised contamination points;
- portable gamma radiation detectors to identify penetrators (on the surface or buried up to about 20 cm below the surface), jackets and fragments;
- laboratory analyses of soil samples to identify soil contamination at levels much lower than those detectable with portable beta and gamma radiation detectors, to study areal distribution and dispersion in the ground at low levels, and to study isotopic composition (including the presence of transuranic elements);
- laboratory analyses of water samples to identify possible contamination of drinking water;
- laboratory analyses of air samples to identify possible contamination of air;
- laboratory analyses of botanical samples to study the possible uptake of DU by biota as a result of dispersal into the environment.

17. **Activities preceding UNEP mission:** The UNEP mission to Serbia and Montenegro had been preceded by surveys, access restrictions, measurements and decontamination of the sites carried out by Yugoslavian, Serbian and Montenegrin experts. The activities were generally conducted in accordance with the risk reduction recommendations contained in the UNEP report on DU in Kosovo. It is concluded that this work was done in a thorough and professional manner. This background, combined with the assistance and support of the in-country experts, allowed the UNEP mission to successfully carry out its objectives.

18. **Constraints to decontamination:** Based on the experience of the in-country experts, as well as on UNEP's sample results, it is very difficult to achieve comprehensive detection and complete decontamination of DU at a given site. Even after thorough decontamination efforts have been conducted, some contamination points may remain. This finding has to be considered in the planning of future DU work and in the selection of decontamination methods and land use planning options at affected sites.

19. **Health concerns:** Results from health examinations on 11 individuals who had worked for four months on DU decontamination in Montenegro were reported to the UNEP team by Montenegrin authorities. This information was handed to WHO as the UN body with competence for medical matters and health-related impacts of DU exposure. The Montenegrin report and the WHO response are contained in an appendix to this report.

Recommendations

These recommendations are valid for all sites in Serbia and Montenegro where depleted uranium (DU) has been used.

1. At all sites in Serbia and Montenegro where DU has been used, the appropriate authorities should undertake investigations using field measurement equipment suitable for (a) making complementary searches for possible widespread ground contamination of significance, and (b) detecting the presence of penetrators, jackets (penetrator covers) and contamination points on the ground surface, as recommended in this report. At the same time, the feasibility of any necessary clean-up and decontamination measures should be assessed.

2. The responsible authorities should consider and decide on the possible and appropriate removal of fences at certain sites, as recommended in Chapter 7 of this report. A similar approach should be taken to other sites that may be searched and decontaminated in the future. At those sites where the relevant authorities decide to remove the fences, signs should be retained indicating that:

- the site has been subject to an attack using DU ammunition; but
- following decontamination, there is no radiological or toxicological risk of concern;
- if, nevertheless, a penetrator or jacket should be found, it should not be picked up, and the local police or health authority should be informed.

3. All penetrators, jackets and fragments that are found should be collected and disposed of safely, as determined by the relevant competent authorities. Special attention should be given to the possible risk of contamination from corroded penetrators.

4. Contamination points should be decontaminated where feasible and justified. Contaminated material should be disposed of safely as determined by the relevant competent authorities. If decontamination is not possible, contamination points should be covered by some durable material, or the area isolated.

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 but once a year might be appropriate.

6. Information should be provided to the local population on the precautions to be taken upon finding material containing DU. This could possibly be linked to ongoing activities to increase awareness about unexploded ordnance.

7. There are reasons to believe that many penetrators remain buried in the ground at DU-affected sites. It is recommended that adequate documentation be kept on each site to avoid unnecessary risks in the future. This documentation should include the position of the site, the possible number of DU penetrators in the ground, information from studies made by in-country experts, and the information contained in this report.

8. Planning for any future decontamination involving soil disturbance or removal of vegetation should consider the risk of DU dispersion in air and inhalation of DU dust. In addition, the potential for subsequent widespread contamination of land from corroded penetrators, should be taken into account. Buried penetrators brought up to the surface and any newly discovered contamination points should be removed and disposed of safely, as determined by the relevant competent authorities.

9. All extensive soil disturbing activities, including the construction of buildings and roads, excavation of soil, or any other uses of land that may imply moving soil may result in possible uncovering penetrators or contaminated soil. As a result, appropriate contingency plans should be developed prior to ground-breaking activities when working in sites where DU weapons have been used.

10. The inspection of the low-level radioactive waste interim storage facility at the Vinca Institute raised concerns regarding the storage site. The recommendations provided by IAEA with respect to storage of DU at Vinca should be implemented as soon as possible to minimise potential risks (Appendix F).

11. The importance of having correct locations and coordinates for DU-affected sites and of obtaining immediate access to these sites for the purpose of conducting surveys and measurements has been clearly demonstrated. The longer the time that has elapsed since the time of the attack, the more difficult it is to find the DU present in the environment and to implement countermeasures, including decontamination.

12. The low levels of transuranic elements, uranium isotope U-236 and the plutonium isotopes Pu-239/240, found in the depleted uranium of those penetrators analysed do not add to the environmental risks posed by DU. In order to confirm that concentrations are consistent with earlier findings, determining transuranic composition during future analyses of DU penetrators is justified.

13. To confirm initial site contamination by airborne DU and to monitor changes in airborne contamination levels over time, environmental bio-monitoring involving lichens and bark can be used.

14. Under certain circumstances some people may have been exposed to very high DU concentrations in air during the military conflict. This is particularly likely to have been the case for the crew in military vehicles that were hit by DU ordnance. These personnel should be provided with medical attention as determined appropriate by the relevant authorities with competence for health matters.

15. All claims regarding health deterioration allegedly caused by exposure to DU should be immediately addressed by the relevant health authorities.

16. The site-specific recommendations contained in Chapter 7 of this report should be implemented without delay at the discretion of the competent authorities.

17. Further scientific work should be carried out to reduce the scientific uncertainties related to assessment of the environmental impacts of DU. These uncertainties relate in particular to corrosion and dispersion of DU in the ground and subsequent contamination of water, as well as to possible contamination of air from DU dust stirred up from the ground surface.

18. In order to reduce scientific uncertainty about the impact of DU on the environment, particularly over time, UNEP recommends that scientific work be conducted in other post-conflict areas where DU ordnance has been used. UNEP, IAEA, and WHO should continue to address this issue jointly.

Site-by-site findings

7.1 Pljackovica

Site description and general information

- Pljackovica (no NATO reference or coordinates).
- Coordinates: EN 57361 71457.
- See map of site.
- Investigated by the UNEP mission on 30 October 2001.

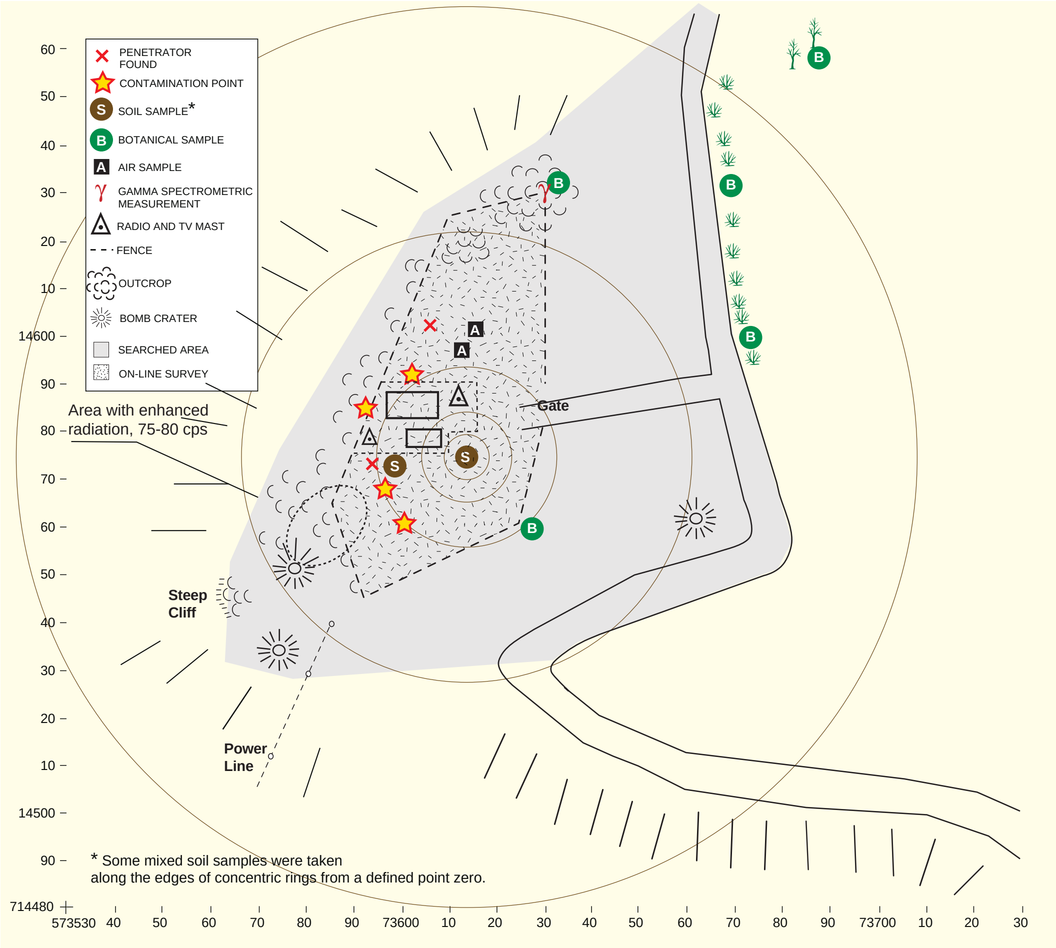
The targeted mast at Pljackovica, with surrounding fence put up by FRY authorities

The targeted site is situated on top of a hill at an altitude of 1,095 m, some 650 m above the town of Vranje and about 3 km north of the town centre. Vranje and the surrounding area hold around 100,000 inhabitants, most of whom are Serbs.

The target was probably the communications mast and associated relay station located on the hilltop. The site is fenced off and DU warning signs have been erected. According to the Federal (FRY) authorities, the site was struck on 29 May 1999. However, at the time of writing, no information concerning this site has been received from NATO and the number of rounds used is therefore unknown. The FRY authorities have found three DU penetrators and a large number of jackets at this site. Several bomb craters were visible at the time of the UNEP visit.

The communications mast is built on low outcropping metamorphic mica gneiss with

Map 3: Pljackovica site



muscovite scales. The soil cover between rock outcrops around the mast is rather thin (0-1 m), and consists of fine-grained sand with stones. According to the result of a gamma spectrometric measurement made for a representative gneiss outcrop, the total gamma radiation is 0.9 µSv/h, the concentration of uranium 4 mg/kg eU (50 Bq/kg eU of U-238), 16 mg/kg Th (69 Bq/kg of Th-232) and 1.6 % K (500 Bq/kg K-40). The area supports sparse vegetation of grass and scattered low bushes, with some trees along the road. The surrounding land is used as pasture for cattle and sheep.

Summary of samples taken at Pljackovica:

- 11 soil samples
- 1 penetrator + 1 collected by personnel from Vinca
- 5 botanical samples[1]
- 3 water samples
- 2 air samples

Field investigation

Inside the fenced part of the site, the beta/gamma radiation survey was made by ‘line-up’ survey, method A. This covered the whole of the fenced area. The line-up survey was

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[1] These samples were subdivided into single-species sub-samples. The sub-samples have the same number as the original samples but with an additional letter.

Table 7.1. Samples taken at Pljackovica

Sample Code	Coordinates	Type of sample	Depth	Lab
NUC-2001-101-01	573614 714576 + 1 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-101-02	573614 714576 + 5 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-101-03	573614 714576 + 10 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-101-04	573614 714576 + 20 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-101-05	573614 714576 + 50 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-101-06	573614 714576 + 100 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-101-07	573599 714559	Soil (above penetrator)	0-5 cm	Spiez
NUC-2001-101-08	573599 714559	Soil (vicinity of penetrators found)	5-15 cm	Spiez
NUC-2001-101-09	573599 714559	Penetrator	8 cm	Spiez
NUC-2001-101-10	573599 714559 + 0.5 m circle	Soil, 8 sticks	0-5 cm	Spiez
NUC-2001-101-11	573599 714559 + 2 m circle	Soil, 10 sticks	0-5 cm	Spiez
NUC-2001-101-12	573829 714 419	Soil, Field blank	0-5 cm	Spiez
Air: 1-1	573613 4714596	Air filter		ANPA
Air: 1-3	573613 4714596	Air filter		ANPA
ANPA-SA01/03	573657 4714594	Lichen		ANPA
ANPA-SA01/03CORT	573657 4714594	Bark		ANPA
ANPA-SA01/04a	573657 4714594	Lichen		ANPA
ANPA-SA01/04aCORT	573657 4714594	Bark		ANPA
ANPA-SA02/03+04	573664 4714632	Lichen		ANPA
ANPA-SA02/04a	573664 4714632	Lichen		ANPA
ANPA-SA02/07	573664 4714632	Lichen		ANPA
ANPA-SA02/08	573664 4714632	Lichen		ANPA
ANPA-SA02/08CORT	573664 4714632	Bark		ANPA
ANPA-SA03/01	573689 4714660	Lichen		ANPA
ANPA-SA03/02a	573689 4714660	Lichen		ANPA
ANPA-SA03/02b	573689 4714660	Lichen		ANPA
ANPA-SA03/02c	573689 4714660	Lichen		ANPA
ANPA-SA03/03a	573689 4714660	Lichen		ANPA
ANPA-SA03/03b	573689 4714660	Lichen		ANPA
ANPA-SA03/06a	573689 4714660	Lichen		ANPA
ANPA-SA03/06b	573689 4714660	Lichen		ANPA
ANPA-SA04/01	573637 4714629	Lichen		ANPA
ANPA-SA05/01	573637 4714562	Lichen		ANPA
ANPA-SA06/02	574041 4713641	Well water		ANPA
ANPA-SA07/01	574796 4713729	Well water		ANPA
ANPA-SA08/02	574707 4713478	Tap water		ANPA

complemented by careful measurements, method C. A qualified ‘at random’ survey, method B, was conducted outside the fence, to a distance of about 50 m.

“Line-up survey” at Pljackovica

Soil samples were taken along the edges of concentric rings from a defined point zero (see Table 7.1 and Map 7.1), as well as from the immediate vicinity of a penetrator. Botanical samples were taken outside the fenced area, while air sampling was conducted at two locations within the fence.

Water samples were taken from a farmhouse and from a hotel, both situated along the road between Vranje and the hilltop, at a distance of about 1 km from the mast. The water was collected from small reservoirs, both of which could theoretically contain DU-contaminated water transported by pipelines from the target area or water from nearby wells that might be contaminated.

Summary of results and site-specific conclusions

■ General contamination

No widespread contamination was detected by the field measurements inside or outside the fenced area, meaning that any contamination was less than 10 % of the *Reference Level* (or less than 1 g DU/m^2 assuming superficial deposition on the ground surface and absorption of 90 %). Because of the tall, dense stands of old grass encountered during the line-up survey, it is possible that the beta and gamma measurements may be underestimates. However, similar measurements, made with great care, on cleared ground (i.e. where grass was removed from the surface) also showed no detectable contamination.

The soil sample analyses indicate widespread, low-level contamination by DU up to a distance of 100 m around the probable target of the DU attack. Within this area, and from 0 to 5 cm depth, uranium was found to increase by an average factor of 2 (maximum 3.3) due to the presence of DU. At 100 m no DU was found. However, there is no relationship between the distance from the mast and the degree of contamination, suggesting that it may have been caused by dispersal of DU dust from several scattered impacts.

In spite of the difficult terrain, the line-up measurements worked satisfactorily. The speed of forward movement had to be decreased somewhat after it was concluded that the team had initially missed two buried penetrators. Because of the thick grass cover mentioned above, the line-up survey was complemented with more precise measurements, using method C. Given that two years had elapsed since the Kosovo conflict, it was decided to generalise this approach, which was applied at each of the sites subsequently investigated by the UNEP team.

The low level of contamination detected suggests one or more of three possible scenarios:

The possibilities

1. Very few rounds with DU were fired against the target. There is no official information on the number of rounds used, though given that the target was evidently the communications mast, there seems to be no clear reason to have used DU ammunition at all. However, since penetrators were found, DU ammunition had apparently been used. It may be that only a small number of DU rounds were fired (many fewer than 100) and that those which split and dispersed over a large area are not detectable by field measurement, even if the DU is still on the ground surface (as shown by the soil analyses).

2. DU rounds were fired against the target in large numbers (100-1,000 or more) but most were split into fine dust by impact on the very rocky surface. This dust was dispersed by wind action (whether at the time of impact or during the last two years), over areas so large that the activity is no longer detectable by field measurement.

3. DU rounds were fired against the target in small or large numbers, some splitting and dispersing over a limited area (<1,000 m^2), after which the DU dispersed vertically into the ground over a two-year period, rendering it undetectable by external beta/gamma measurements.

Comments on the three possibilities

Possibility 1.

The practical limit of detection of DU, which is not dispersed more than a few mm depth into the ground, is about 10 % of the *Reference Level*, i.e. 1 g DU/m^2. The possible contaminated area is 1,000-10,000 m^2 and the total DU spread over these areas would therefore be 1-10 kg, respectively corresponding to 3-30 DU rounds assuming each round has a weight of 300 g of DU.

The results of the soil sample measurements do not contradict these conclusions. The soil samples were taken from a mixture of 0-5 cm depth, which means that a possible superficial layer of DU is distributed in this 0-5 cm sample. The DU concentration in the samples up to 100 m distant from the presumed target was, on average, of the same level as the natural uranium concentration. This corresponds to about 0.3 g DU/m^2 which means a maximum 0.3 kg DU fired if dispersed over 1,000 m^2 and 3 kg if dispersed over 10,000 m^2, corresponding to 1-10 DU rounds. Both cases equate to less than the limit of field detection and the superficial layer would contain less (or much less) than 1 g DU/m^2.

Possibility 2.

In this case nothing can be concluded about how many DU rounds were fired at the target. However, the scenario set out in possibility 2 is not very plausible.

Possibility 3.

If, on the other hand, the DU is dispersed deeper in the ground, for example evenly to a depth of 10 cm, the level of ground contamination recorded during the field measurements should not have been less than a factor of 2-5 times the activity of the *Reference Case*, i.e. not less than 20-50 g DU/m^2. Once more assuming an overall contaminated area of 1,000-10,000 m^2, the total amount of DU would need to be 20-500 kg, corresponding to 70-1,700 DU rounds.

However, the soil measurements show that the total amount of DU in a soil layer 1 cm thick and over an area of 1,000-10,000 m^2 would be less than 0.6-6 kg, which corresponds to a concentration far below the field detection limit, equating to a much lower total number of DU rounds fired, possibly in the range of 2-20.

Conclusion

The widespread contamination is probably derived from around 10 kg of DU.

■ Penetrators and jackets

Field measurements indicated the presence of two buried penetrators and/or jackets inside the fenced area. One of these was dug up by Vinca personnel from just outside the inner fence around the mast (see Map 7.1). It was found at 8 cm depth at position 573599 714559. The penetrator was heavily corroded and coated by yellow uranium oxide.

Field measurements suggested the presence of a further four buried penetrators outside the inner fence (but inside the outer fence) and one of these was collected by the UNEP group from a position to the south west of the mast.

At the points where hidden penetrators were indicated by field measurements, gamma measurements were 50-150 cps, while beta measurements gave no result significantly above the background (0.1-1 cps) as long as there was no digging to retrieve the penetrator.

Altogether, two penetrators were collected, four penetrators (or, possibly, jackets) were indicated by gamma measurements, three of them within the fence and one outside. Three penetrators and a large number of jackets had been found during earlier searches by Yugoslavian experts. The penetrators were of the same kind as those used by the NATO forces. The penetrators that were collected showed clearly advanced corrosion and the soil nearby was contaminated with corroded DU.

Because there is no information on the total number of DU rounds fired against the target it is not possible to say how many penetrators are still present in the environment. On the basis of clear evidence from the survey conducted, it is nevertheless concluded that there are penetrators and jackets outside the fenced area.

Sampling of a penetrator at Pljackovica

Localised points of contamination

Four points of localised surface contamination were found through field measurements, one of which related to a penetrator that had been dug up. The soil just around the penetrator was contaminated (as shown in Appendix G ‘DU in Soil’, Tables G.2 and G.3). The uranium concentration close to the penetrator was found to reach about 25 g/kg soil, more than 99 % of which was DU.

It is concluded that there are no remaining unidentified measurable points of contamination, at least within the fenced area.

Soil

Samples were taken along the edges of concentric rings from the mast (zero position: 573614 714576) at 1, 5, 10, 20, 50 and 100 metres. The samples were taken at 0-5 cm depth, and at 12 positions from each ring. The 12 samples for each ring were then mixed. Soil samples were also taken at and around the position where the penetrator was dug up.

The results of the soil analyses are shown in Appendix G ‘DU in Soil’, Tables G.2 and G.3. There are clear indications of DU contamination but the concentrations – except when close to a penetrator – are low, not differing significantly from those of natural uranium.

As was the case for UNEP’s studies of DU in Kosovo, it is concluded that there is localised DU contamination within an area of a few metres of the impact point of a penetrator. As was also concluded for Kosovo, using soil sampling, chemical analyses and measurements in the laboratory, it is possible to identify widespread DU contamination at a much lower activity level than is possible with direct field measurements (lower by a factor of 10-100 depending on the vertical distribution of DU in the soil).

Drinking water

Water samples were collected at a farmhouse and at a hotel both situated along the road from Vranje to the mast. The farmhouse obtains water from a small reservoir 1 km north west of the mast, with the water travelling a total distance of 3.5 km to the farmhouse.

The results of the water analyses are shown in Appendix H 'DU in Water', Tables H.2 and H.3. The uranium concentration is normal and there is no indication of DU. However, the drinking water source might theoretically become affected by DU in the future, even if only in small concentrations.

■ Botanical samples

Botanical samples such as lichen, bark, moss etc. are used as bio-indicators of the possible earlier presence of DU in air. The conclusions in this report derived from botanical samples are based on the value of the ratio between U-234 and U-238 concentrations.

Samples of bio-indicators were taken outside the fence. No samples were taken inside the fence. The results are shown in Appendix J 'Bio-indicators of DU', Tables J.2 – J.5 and J.8-J.9.

The presence of DU in some lichen samples indicates the earlier presence of DU in the air which means that at least some of the penetrators have hit hard surfaces, split into dust and dispersed in air.

■ Air samples

Within the fenced area, two air samplers were placed 2-3 m from each other at the position 573613 714596 and operated for 115 minutes. The air volume for each sample was 156 m^3. It should be noted that, at the time of sampling, FRY personnel were digging for penetrators at a contamination point situated about 5-6 m from the air samplers but perpendicular to the prevailing wind direction.

The results presented in Appendix I 'DU in Air', Table I.2 show an increased concentration of uranium in the air sampled and significant contamination by DU. This is seen from the deficit of U-234 as well of U-235. The ratio indicates that DU constitutes about 80 % or more, which is remarkably high. Nevertheless, the recorded concentration is low in terms of radiation and chemical risks. For example, the radiation dose to a person exposed continuously to such air for one year would be less than 1 µSv.

It is always difficult to identify with certainty the source of airborne activity. It could come from the ground by resuspension, even though this is difficult to explain considering the low level of ground contamination and the fact that two years have elapsed since the conflict. The air contamination could also be wholly or partly derived from the simultaneous digging a few metres from the air samplers during their operation. The soil measurements show that the contamination of soil very close to a penetrator buried in the ground may be very high, i.e. 25 g DU/kg soil.

■ Residual risks

The area within the fence has been searched carefully by both FRY and UNEP experts and some penetrators and jackets have been identified. Of these, some have been dug up with the remainder left in the ground. There are no penetrators or jackets remaining on the ground surface and therefore easily available to anyone walking around.

There are no unmarked localised points of contamination still remaining inside the fence.

With regard to residual risks in this area there are two possible risk scenarios to consider:

The first concerns the possibility of penetrators and jackets on the ground surface outside the fenced area. There are indications of buried penetrators/jackets outside the fence and it is possible that there may be some remaining on the surface also. If a penetrator is picked up and put in someone's pocket there will be a small external beta radiation dose to the skin adjacent to the pocket. There is no risk of any radiation damage, but the radiation dose is unnecessary and should be avoided. Pieces of DU should not be put into pockets.

Furthermore, by touching a penetrator or a jacket with bare hands there is an obvious risk of direct contamination and, via the hands, contamination of food and/or mouth, which could lead to internal contamination. Assuming a normal standard of hygiene, there is only a small risk that this will happen and even then the resulting dose will be very small – a few µSv or less. Nevertheless, considering the chemical toxicity of uranium, such a level of intake by ingestion would certainly fail to meet applicable WHO standards.

The other possible risk scenario regards the possible short- and long-term consequences of ground contamination from penetrators and jackets still buried in the ground and undetectable surface/soil contamination of dispersed DU. From observations made, it is known that solid DU corrodes and may be dissolved in water, with a risk of eventual contamination of groundwater. As discussed above, there are no indications or information that a large number of DU rounds were used at this site. 'Normal' numbers are a few hundred, while a 'large number' would be a few thousand DU rounds against the same target. In the discussion above under 'General contamination' the probable maximum amount of dispersed DU was given for different assumptions.

Irrespective of that, if a maximum 300 DU rounds are assumed to have been fired at the area, this would correspond to about 100 kg of DU distributed over 1,000-10,000 m^2. If the natural uranium concentration of the soil is assumed to be the same as that of the gneiss, i.e. 4 mg uranium/kg soil, the amount of natural uranium in soil over 10,000m^2 and 1 m depth would be about 60 kg.

This amount of uranium is assumed to be the source of the natural uranium content of groundwater in that area which might be in contact with, or be the source of, drinking water further down the hill (where the water samples were taken). The conclusion is that the possible additional uranium in the form of DU will not change the uranium source more than by a factor of 2-20. Intake of uranium by drinking water is normally very low, leading to radiation doses in the order of 0.1 µSv per year. The possible extra uranium from DU would not lead to any significant doses, i.e. far below a dose of 1 mSv per year.

However, there are uncertainties in the assumptions made. These justify application of the precautionary principle and the implementation of selected monitoring to better understand the environmental behaviour of DU in the future. For example, in the case of possible future contamination of groundwater used as drinking water, neither the rate of erosion and dissolution of DU in water is known, nor the dilution in groundwater before this becomes drinking water.

■ Need for mitigation. Recommendations.

The following conclusions and recommendations refer to the risk of radiation and the chemical risk of DU.

1. Once the soil at the contamination points has been removed there is no need to retain the outer fence surrounding the assumed target area.

2. The area outside the presently fenced area should be surveyed once more, extending up to 100 m away from the fence, to find any additional penetrators and jackets on the surface, as well as those buried in the upper part of the ground. Those easily removable should be taken away and stored as radioactive waste until further guidance is issued by the competent authorities.

3. Neither the area inside nor outside the fence requires general decontamination (by this is meant extensive decontamination by removal of soil to some depth over the whole area).

4. An information sign should be erected to indicate that while the area had been subject to an attack using DU ammunition, it has subsequently been cleaned and there is no risk of radiation or any chemical risks of concern. The sign should also give clear instructions that if, nevertheless, a penetrator or jacket should be found by accident, it should not be picked up but the local police or health authority should be informed.

5. In line with the precautionary principle and as part of scientific research, water samples should be taken once a year from the farm and hotel sampled during the UNEP mission. This would enable detection of any possible increase of the uranium concentration in the drinking water.

7.2 Vranje garrison – investigation of a DU-targeted military vehicle

Description and general information

- Military vehicle at Vranje garrison.
- Coordinates: EN 574649 711861.
- Investigated by the UNEP mission on 30 October 2001.

Investigating of a DU-targeted military vehicle at Vranje Garrison

A small delegation from the UNEP team visited Vranje Garrison to study an armoured military vehicle that had been hit by a single DU penetrator fired from an A10 ‘Warthog’ aircraft. The vehicle was an Armoured Personnel Carrier (APC), type BOV1, carrying Yugoslavian army number 13038.

The APC had been hit at the village of Urosevac at Kamena Glauathe in Kosovo during the military conflict of 1999. It had not been used after the attack and afterwards it had been towed to Vranje. According to Serbian army officers, the crew had survived.

At the time of the UNEP mission, the APC was standing in the tank yard of Vranje Garrison. It had been roped off and there were radiation warning signs. Serbian army officers asked for UNEP’s advice on what to do with the APC.

Summary of samples taken from the inside of the APC:

- 2 samples of fragments from the penetrator
- 1 sample of fragments from the jacket
- 4 smear samples

Table 7.2 Samples taken at Vranje Garrison.

Sample Code	Coordinates	Type of Sample	Lab
NUC-01-102-01	574649 711861	Penetrator fragment in tank, front / left	Spiez
NUC-01-102-02	574649 711861	Jacket fragment in tank, front / left	Spiez
NUC-01-102-03	574649 711861	Smear sample Blank	Spiez
NUC-01-102-04	574649 711861	Smear sample 20 x 20 cm inside tank, left side	Spiez
NUC-01-102-05	574649 711861	Smear sample 20 x 20 cm inside tank, front / middle	Spiez
NUC-01-102-06	574649 711861	Smear sample around penetrator hole in tank	Spiez
NUC-01-102-07	574649 711861	Penetrator fragment inside of tank	Spiez

Field investigation

When investigating the APC, it could be seen that the penetrator had hit the front of the vehicle at an angle of about 45°. The penetrator had made a small hole in the roof of the APC and entered the interior of the vehicle.

The inside of the APC was investigated by measuring the radiation with the *SRAT* instrument (see Appendix C ‘Methodology and Quality Control’) and the *Inspector* instrument. Four smear samples were taken from the inside. A thorough search of the inside of the APC was carried out, but no penetrator could be found. However, there was a hole showing where the penetrator had entered the APC. Some fragments of the penetrator were found on the floor, but there were no large pieces of DU.

Gamma measurements (using the SRAT) were conducted beneath the APC. No hole was found through which the penetrator could have exited the APC. The only enhanced gamma radiation to be measured came from the penetrator fragments found on the floor inside the APC. This indicates that the penetrator had either shattered into small pieces, and that the fragments on the floor constituted the remaining parts of the penetrator, or that the larger parts of the penetrator had already been removed.

Summary of results

■ Penetrators and jackets

No penetrator was found, but fragments of the penetrator and jacket were found. Samples of the fragments were taken. The results from analyses of the penetrator fragments are given in Appendix E 'Military Vehicle at Vranje Garrison' and Appendix K 'Analysis of DU Penetrators and Fragments'.

■ General contamination, localised points of contamination, smear samples

Through continuous use of the *Inspector* instrument, the area was searched for possible DU contamination both inside and outside the vehicle. Nothing could be detected, which means < 100 mg/m^2 or about 1,000 Bq/m^2, i.e. less than the clearance level for contaminated material in many countries.

Four smear samples from inside the APC were taken. The results are shown and discussed in detail in Appendix E 'Military vehicle at Vranje Garrison', Tables E.2-E.4. In summary, some loose low level DU surface contamination was found.

■ Residual risks

The APC itself was slightly contaminated on its inner surfaces and small, heavily corroded fragments of the penetrator were found. When entering the vehicle it is still necessary to follow specific safety rules to avoid external and internal contamination.

■ Need for mitigation. Recommendations.

1. Through clearing-up of remaining DU fragments and careful wet cleaning of the APC (taking precautions to avoid any further contamination of the environment and respecting safety regulations through proper waste disposal/storage) the vehicle could be restored to the extent that no precautionary measures related to DU should be necessary thereafter.

2. With regard to the crew that were in or close to the vehicle during the DU attack, they might have been exposed to a very high instantaneous DU concentration in air during the attack itself. The crew members should be provided with medical care and health monitoring, as determined by the competent medical bodies.

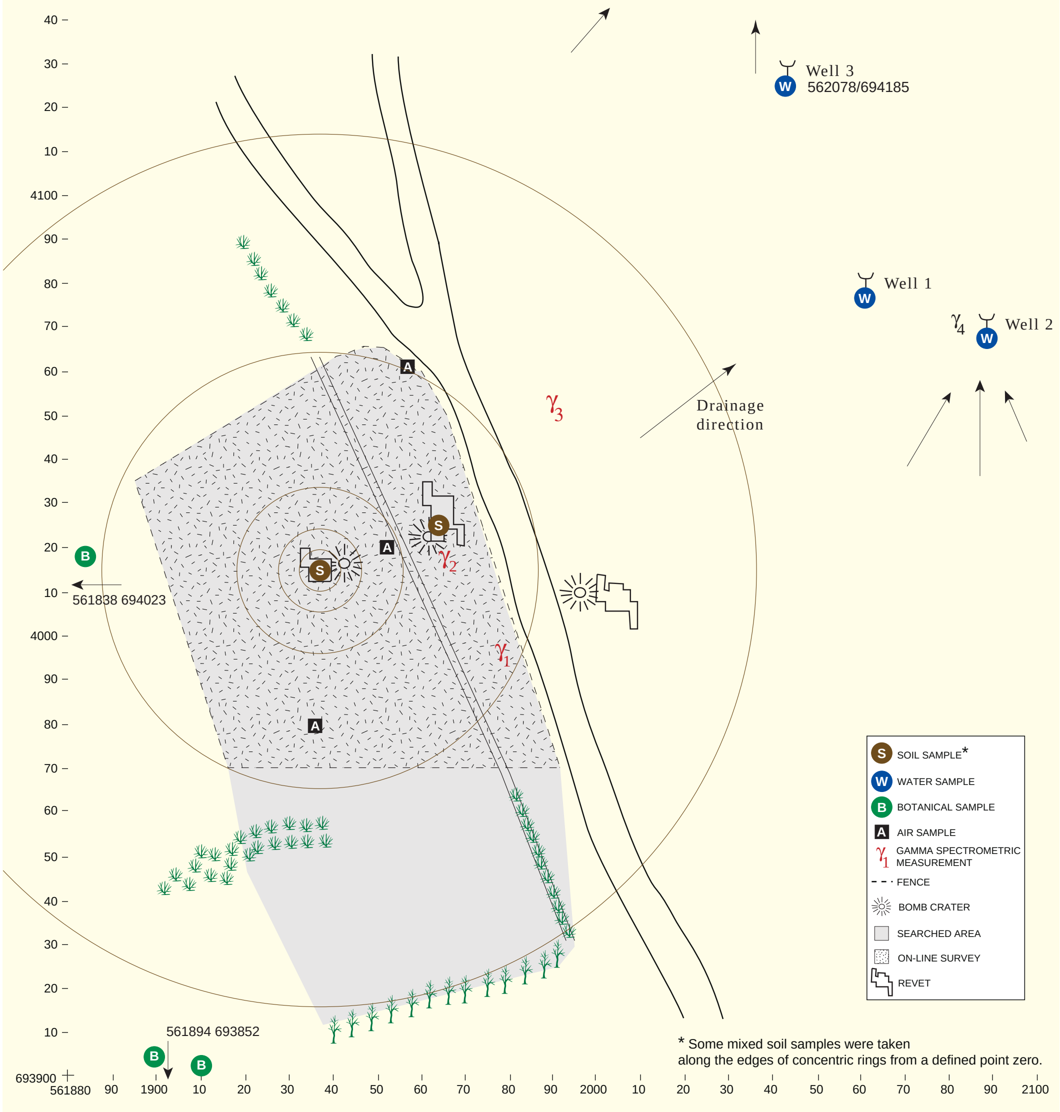
7.3 Borovac

Site description and general information

- ➢ Borovac (NATO reference no. 41).
- ➢ Coordinates: EM 620 945.
- ➢ See map of site.
- ➢ Investigated by the UNEP mission on 31 October 2001.

Targeted area at Borovac, with surrounding fence

➤ Map 4: Borovac site



* Some mixed soil samples were taken along the edges of concentric rings from a defined point zero.

The targeted site is situated 1.5 km from the village of Borovac. The target was probably an artillery position. Two gun emplacements were found in the middle of the fenced-off area.

NATO information confirms that the area was targeted once on 25 May 1999. The number of rounds fired was 300/188, based on a 5/8 mix.

Prior to the UNEP visit, the FRY authorities had found 16 penetrators and a large number of jackets at this site. The FRY authorities had also erected a fence with warning signs around the area where penetrators and jackets had been found. The surface area enclosed by the fence is 5,000 m^2. The site is situated at an altitude of 605 m on the crest of a ridge in hilly grassland used for grazing.

There are few trees and bushes. About 300 m north of the site stands a large radio mast. 1.5 km to the north lies the village of Borovac, which has around 200 inhabitants, mostly Serbs. During the military conflict, this area was part of the main line of defence. The site was also heavily attacked using cluster bombs. After hostilities ceased, the area was cleared of unexploded ammunition. The area has a silty sandy soil, which was found to be about 0.5 to 1.5 m thick within the fenced area, and up to 2 m thick in the valley to the east. In one of the bomb craters the bedrock had been exposed. It consisted of a coarse-grained granitic rock mainly composed of quartz and feldspar. Three gamma spectrometric measurements were made in the area. They showed that the total gamma radiation was about 0.02-0.04 µSv/h and the natural uranium concentration in the soil was 2-3 mg/kg eU (25- 35 Bq of U-238/kg soil eU). The thorium concentration was 3-4 mg/kg (12-16 Bq/kg Th-232) and the potassium concentration 0.5-1 % (150-310 Bq/kg K-40). Two wells have been dug into the hillside about 100 m east of the fenced area, with a third well fed by a natural spring at the end of a small creek. At least one of these wells was situated directly in line with the direction of drainage from the fenced area. The water from these wells is transported through pipes to the village of Borovac.

Summary of samples taken at Borovac:

- 9 soil samples
- 3 botanical samples[2]
- 5 water samples
- 3 air samples

Field investigation

Inside the fenced area a beta/gamma radiation survey was made by ‘line-up’ survey, using method A. This survey covered the whole area. The line-up survey was complemented with careful measurements, using method C. A qualified ‘at random’ survey, method B, was conducted outside the fenced area on the hill to the south of the fence.

Soil samples were taken along the edges of concentric rings around a defined point zero. Botanical samples were taken outside the fenced-off area.

Water samples were taken from the three wells in the slope to the east of the fenced area, and two samples were taken in the village: one tap-water sample and one well-water sample.

Air sampling was made at 3 locations inside the fence.

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[2] These samples were subdivided into single-species sub-samples. The sub-samples have the same number as the original samples but with an additional letter.

Table 7.3. Samples taken at Borovac.

Sample Code	Coordinates	Type of sample	Depth	Lab
NUC-2001-103-01	561935 694013 + 1 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-02	561935 694013 + 5 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-03	561935 694013 + 10 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-04	561935 694013 + 20 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-05	561935 694013 + 50 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-06	561935 694013 + 100 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-07	561935 694013 + 200 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-103-08	563178 693024	Soil, Field blank	0-5 cm	Spiez
NUC-2001-103-09	561963 694025	Soil, 10 sticks, 2x2 m	0-5 cm	Spiez
Air : 2-1	561953 694025	Air-filter		ANPA
Air : 2-2	561969 694064	Air-filter		ANPA
Air : 2-3	561935 693979	Air-filter		ANPA
ANPA-SA09/01a	561910 693899	Lichen		ANPA
ANPA-SA09/01c	561910 693899	Lichen		ANPA
ANPA-SA10/01a	561894 693852	Lichen		ANPA
ANPA-SA10/04a	561894 693852	Lichen		ANPA
ANPA-SA12/01a	561838 694023	Lichen		ANPA
ANPA-SA12/01c	561838 694023	Lichen		ANPA
ANPA-SA12/02a	561838 694023	Lichen		ANPA
ANPA-SA12/02b	561838 694023	Lichen		ANPA
ANPA-SA12/02c	561838 694023	Lichen		ANPA
ANPA-SA13/01	561577 695276	Tap water		ANPA
ANPA-SA14/01	561162 694635	Well water		ANPA
ANPA-SA15/02	562061 694078	Well water		ANPA
ANPA-SA16/02	562087 694072	Well water		ANPA
ANPA-SA17/01	562028 694185	Well water		ANPA

Summary of results and site-specific conclusions

■ General contamination

No widespread surface contamination was found by field measurements either inside or outside the fenced-off area. The results of laboratory analyses of soil samples show weak contamination by DU within and beyond the fenced-off area.

If it is assumed that the number of DU rounds fired according to NATO data is correct, i.e. 188, the amount of DU would be about 60 kg, which is six times more than the *Reference Case*. However, the target area might be larger than 1,000 m^2 (the area in the *Reference Case*) and 10,000 m^2 seems more reasonable. If a large proportion of the penetrators split on impact and the dust spread evenly over 10,000 m^2 , the surface contamination would be 6 g per m^2 which should have been easily detectable. Even if the DU dust had dispersed vertically and was evenly distributed down to about 10 cm, it would still be detectable. Therefore, the amount of ground contamination would be less than 60 kg.

Furthermore, because there was no indication of surface DU contamination shown by the field measurements, the contamination was certainly less than 10 % of the *Reference Level*, i.e. less than 1 g DU/m^2 if the DU contamination is limited to the near-surface layer (a few mm thick). This would correspond to less than 10 kg DU dispersed over an area of 10,000m^2.

The analysis of soil samples showed low contamination of DU in the soil, but this did not change the total uranium concentration significantly, meaning less than 0.2 mg DU/kg in a soil layer 5 cm thick. If this result is representative over 10,000 m^2, it would equate to a total of 0.15 kg DU. Even if the results were representative for soil to a depth of 10 cm, the total amount of DU would not be more than about 0.3 kg, i.e. corresponding to one penetrator only.

In conclusion, the observed contamination of the ground is too small to result from any large-scale shattering of DU rounds and it is probable that most of the penetrators did not split but remain buried in the ground. A contributing factor might be that the ground surface is very soft at the site, which would have reduced the likelihood of penetrators splitting on impact.

■ Penetrators and jackets

No penetrators or jackets were found. Field measurements gave one possible indication of a buried penetrator (or jacket) to the south of the fence and some digging attempts were made, though without any positive result. 16 penetrators and a large number of jackets had been found and removed as a result of earlier searches by Yugoslavian experts.

It is concluded that the major part of the penetrators fired remain buried in the ground, corresponding to about 50 kg uranium.

The content of natural uranium in the ground down to a depth of 1 m and over an area of 10,000 m^2 would be roughly the same amount, i.e. 30 kg, and the presumably buried penetrators therefore represent a doubling of the uranium content in this part of the ground profile.

■ Localised points of contamination

No points of localised surface contamination were indicated by field measurements. It is concluded that there are no such contamination points, at least within the fenced-off area.

■ Soil samples

Soil samples were taken along the edges of concentric rings from a defined point zero at 1, 5, 10, 20, 50, 100 and 200 meters. The samples were taken at 0-5 cm depth, and at 12 positions from each ring. The 12 samples were then combined, to give a single mixed sample for each ring.

The soil measurements showed weak contamination by DU inside and outside the fenced area. It is likely that the targeted objects were located within the fenced area and that the contamination beyond the fence has been caused by dispersion in air.

One soil sample was taken from inside a rocket impact crater. The sample was mixed, being composed of ten sub-samples taken within an area of 2 x 2 m. The results are shown in Appendix G ‘DU in Soil’, Tables G.2 and G.3. This soil was found to be slightly contaminated by DU (circa 15 % of the total uranium concentration), possibly due to the washout of DU by rainwater having collected in the depression formed by the rocket.

■ Drinking water

Water samples were taken from the three wells east of the fenced area, together with single tap-water and well-water samples from the village of Borovac. The results are shown in Appendix H ‘DU in Water’, Tables H.2 and H.3. The uranium concentration is within the normal distribution of values for drinking water. In natural water the activity ratio U-234/U-238 is 1. In DU containing 0.2 % U-235 by weight, the activity ratio U-234/U-238 is 0.2. In DU with 0.35 % U-235 by weight, the corresponding value is 0.33. As seen from the Tables, there are two values of less than 1.0 (0.66 and 0.82). However, the uncertainties make it impossible to draw any conclusions from these observations concerning contamination by DU. In any case, the concentrations are so low that the corresponding radiation doses are insignificant (<0.1 µSv per year).

■ Botanical samples

Samples of bio-indicators were taken outside the fence. No samples were taken inside the fence. The results are shown in Appendix J ‘Bio-indicators of DU’, Tables J.2 – J.3.

There were no significant indications of DU in any sample taken (based on U-234/U-238 ratio).

■ Air samples

The three air samplers were placed in a line parallel to the wind direction. The air samplers were operated for 110 minutes. The air volume for each sample was 150 m^3. The results are shown in Appendix I ‘DU in Air’, Table I.2. One of the values of the activity ratio U-234/U-238 could be understood as lower than 1.0 (0.67) and to be indicative of DU in air. However, because of the uncertainties involved, the result is on the limit of significance. The concentrations of U-235 are not detectable and therefore nothing can be said about the U-235/U-238 ratio.

In conclusion, the concentrations are normal for air above land, there was no clear indication of DU, and the corresponding radiation doses are very low (~0.1 µSv per year) and insignificant.

■ Residual risks

The area inside the fence was searched carefully. 16 penetrators and a large number of jackets had previously been found and dealt with by Yugoslavian experts. No further penetrators and jackets were found within the fence by the UNEP group. There are no penetrators or jackets still on the ground surface or otherwise easily available to a person walking around.

There are no localised points of contamination still inside the fence, no indication of widespread contamination of significance from a health point of view, and no contamination of water or air.

Outside the fence a number of measurements were made but there were no indications of any abnormal activity on the ground.

With regard to residual risks in this area there are two possible risk scenarios to consider.

The first one regards the possibilities of penetrators and jackets on the ground surface outside the fenced area. However, the UNEP group did not find any indications of penetrators and jackets on the surface or buried in the ground outside the fenced area. With regard to the risks related to penetrators, reference is made to the discussion for Pljackovica (see Chapter 7.1) and to Appendix A ‘Risk Assessment’.

The other risk scenario regards the possible short- and long-term consequences of ground contamination derived from penetrators and jackets still buried in the ground. The very low contamination of the surface and soil by dispersed DU can be disregarded as a source of concern.

From observations made, it is known that solid DU corrodes and may dissolve in water, perhaps eventually contaminating the groundwater.

The amount of DU still present in the ground may be about 50 kg, which will not increase the total amount of uranium in the affected area by more than a factor of two (i.e. a doubling of natural uranium levels).

Intake of uranium through drinking water is normally very low, leading to radiation doses in the order of 0.1 µSv per year and the possible addition from DU would not lead to any significant doses, i.e. far below 1 mSv per year.

However, there are uncertainties in the assumptions made. These justify application of the precautionary principle and the implementation of selected monitoring to better understand the environmental behaviour of DU in the future. For example, in the case of possible future contamination of groundwater used as drinking water, neither the rate of erosion and dissolution of DU in water is known, nor the dilution in groundwater before this becomes drinking water. Furthermore, precautions are justified as at least one of the wells used for collecting groundwater from the area is situated in line with the direction of drainage from the targeted area and the three wells are situated within a distance of not more than 150 m from this area.

■ Need for mitigation. Recommendations.

The following conclusions and recommendations refer to the risk of radiation and the chemical risk from DU.

1. There is no need to retain the fence surrounding the assumed target area.

2. The area outside the present fenced area should be surveyed once more, extending up to 100 m away from the fence, to find possible additional penetrators and jackets on the surface and those concealed in the upper part of the ground. Those easily removable should be taken away and stored as radioactive waste until further guidance is issued by the competent authorities.

3. No area needs general decontamination except in the case where localised contamination is found (outside the fence).

4. An information sign should be erected at the site, indicating that while the area had been subject to an attack using DU ammunition, it has subsequently been cleaned and there is no risk of radiation or any chemical risks of concern. The sign should also give clear instructions that if, nevertheless, a penetrator or jacket should be found by accident, it should not be picked up but the local police or health authority should be informed.

5. In line with application of the precautionary principle and as part of scientific research, water samples should be taken once a year from the wells to the east of the targeted area and in Borovac village where this water is used.

7.4 Bratoselce

Site description and general information

- Bratoselce (NATO reference no. 46, 65 and 106).
- Coordinates: EM 625 882.
- See map of site.
- Investigated by the UNEP mission on 31 October 2001.

Investigation of the targeted site Bratoselce

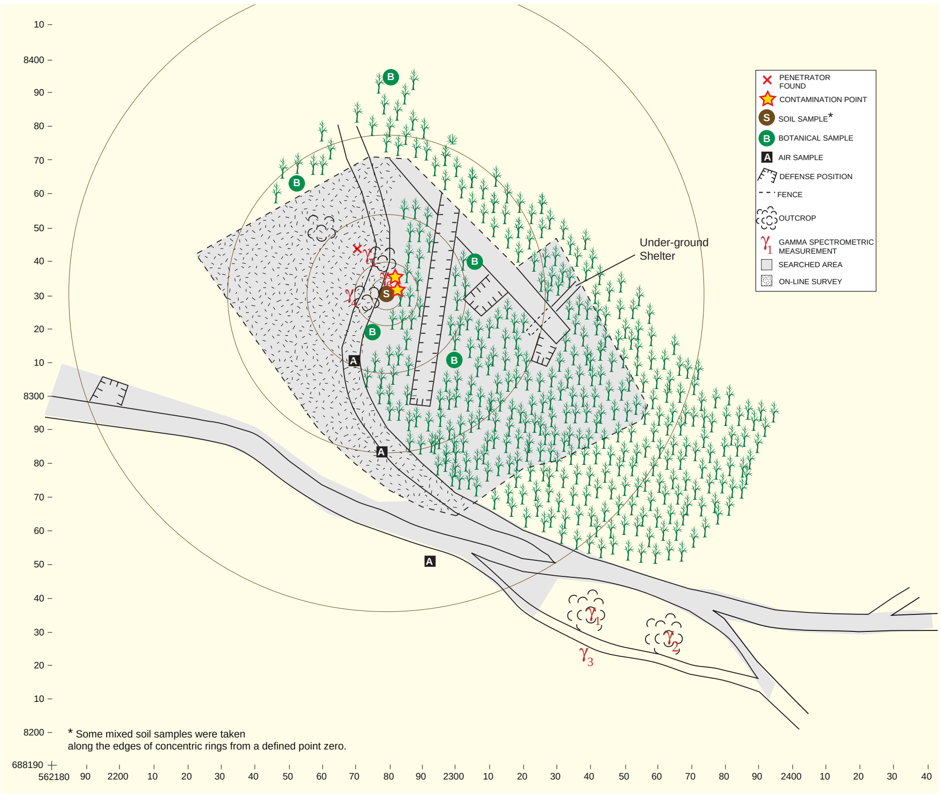
The targeted site is situated about 700 meters from the village of Bratoselce. The area where the FRY authorities had previously found penetrators and jackets is fenced-off, and equipped with warning signs. The surface of the fenced area is 8,500 m^2. The target was probably formed by fortified shelters for Armoured Personnel Carriers (APCs). NATO information confirms that the area was attacked three times on 28 May, 1 June and 11 June 1999. The numbers of rounds used were, respectively, 200/155, 970/606 and 970/606, giving a total of 2140/1337, based on a 5/8 mix. More DU ammunition was fired at this site than at any other site in Serbia. A total of almost 400 kg DU was reportedly used.

The FRY authorities have found eight penetrators and six jackets at this site. They were found on the surface, and in the ground (to a depth of 60 cm). The penetrators found at 60 cm below the ground surface were found because the entry holes could still be seen shortly after the attack. New penetrators have reportedly always been found after heavy rain.

The site is situated on the crest of a ridge elongated in a north-west to south-east direction. The surrounding areas are hilly grassland used as pasture. About half of the fenced area is densely covered with thorny bushes and small trees. This forested area continues to the east and south-east of the fenced area. Inside the fence there are several fortified positions used for APCs and probably also tanks. There is also an underground shelter. Outside the fenced area, on the slopes of the ridge, there are several excavations for army positions.

Within and immediately around the fenced area, the soil cover was found to be thin, i.e.

Map 5: Bratoselce site



* Some mixed soil samples were taken along the edges of concentric rings from a defined point zero.

within the range 0-1 m, though on the slopes running down from the crest it reaches a thickness in excess of 2 m. The bedrock consists of mica (muscovite) gneiss, which is exposed in several outcrops. Gamma spectrometric measurements were made at six locations. The total gamma radiation from the bedrock was 0.10-0.15 µSv/h and the concentration of radionuclides 2.5-7.3 mg/kg eU (30-90 Bq/kg eU U-238), 16.6-23.7 mg/kg Th (66-95 Bq/kg Th-232) and 3.2-4.0 % K (990-1240 Bq/kg K-40). These are higher concentrations of natural radionuclides than is normal for rocks in this part of Yugoslavia.

The village of Bratoselce is situated about 700 m west of the site and has around 200 inhabitants, mostly Serbs. The inhabitants use water from a shared, dug well in the village, lying about 80 m below and 700 m west of the targeted area.

Summary of samples taken at Bratoselce:

- 8 soil samples
- 1 penetrator
- 5 botanical samples[3]
- 1 water sample
- 3 air samples

Field investigation

A 'line-up' survey, using method A, was conducted on the open area inside the fence with beta and gamma measurements taken. The line-up survey was complemented with careful measurements, using method C. A qualified 'at random' survey, using method B, was made in the densely forested part of the site. No survey was conducted outside the fenced area.

[3] These samples were subdivided into single-species sub-samples. The sub-samples have the same number as the original samples but with an additional letter.

Table 7.4 Samples taken at Bratoselce

Sample Code	Coordinates	Type of sample	Depth	Lab
NUC-2001-104-01	562279 688324 + 1 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-02	562279 688324 + 5 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-03	562279 688324 + 10 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-04	562279 688324 + 20 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-05	562279 688324 + 50 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-06	562279 688324 + 100 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-07	562279 688324 + 200 m circle	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-104-08	561693 688083	Soil, Field blank	0-5 cm	Spiez
NUC-2001-104-09	562272 688343	Penetrator	40 cm	Spiez
Air : 3-1	562271 688310	Air-filter		ANPA
Air : 3-2	562278 688285	Air-filter		ANPA
Air: 3-3	562292 688251	Air-filter		ANPA
ANPA-SA18/01	562274 688318	Lichen		ANPA
ANPA-SA19/01a	562305 688342	Lichen		ANPA
ANPA-SA20/01a	562305 688312	Lichen		ANPA
ANPA-SA21/02a	562258 688363	Lichen		ANPA
ANPA-SA21/02aCORT	562258 688363	Bark		ANPA
ANPA-SA21/03a	562258 688363	Lichen		ANPA
ANPA-SA21/03aCORT	562258 688363	Bark		ANPA
ANPA-SA21/04	562258 688363	Lichen		ANPA
ANPA-SA21/04CORT	562258 688363	Bark		ANPA
ANPA-SA22/01a	562282 688396	Lichen		ANPA
ANPA-SA22/01b	562282 688396	Lichen		ANPA
ANPA-SA23/01		Well water		ANPA

Soil samples were taken along the edges of concentric rings around a defined point zero. Botanical samples were taken both inside and outside the fenced area. Water samples were taken from the village well. Air sampling was conducted at two locations inside the fenced area and one outside. Unfortunately, there was some simultaneous digging for penetrators nearby that might have contaminated the air.

Summary of results and site-specific conclusions

■ General contamination

The field measurements using methods A and C worked well in the open part of the fenced area. However, these methods could not be used in the area covered by trees and bushes and even method B (qualified 'at random' measurements) could be performed only to a very limited extent because of the rough vegetation.

The beta and gamma field measurements did not reveal any widespread contamination of significance (< 10 % of the *Reference Level*). While laboratory analyses showed significant DU contamination in the soil samples taken, the concentrations were lower than for natural uranium concentrations and were therefore not detectable by field measurements.

There was no indication of any widespread surface contamination in the part of the area covered by trees and bushes (except as indicated by soil analysis in the laboratory).

There were some small areas in the open part of the fenced-off target area where the gamma background was relatively high, 50-80 cps gamma. That might reflect the partial contribution from hidden penetrators and jackets but could also solely depend on natural activity, see above. One penetrator was found during the UNEP mission, and others had been found previously by Yugoslavian experts.

The total number of DU rounds fired against the targeted area (according to data from NATO) was about 400 kg. The size of the fenced area is 8,500 m^2. If all the rounds were fired against that area and all penetrators were split, the ground contamination would be 47 g DU/m^2, which is more than four times the *Reference Level* and would be very easily detectable, even if covered by old leaves, or dispersed vertically and evenly to a depth of about 10 cm.

The results from analyses of the soil samples do not contradict these conclusions. The corresponding total DU in the area where DU was detectable is only 0.2 kg.

Therefore, with the given assumptions, the most probable conclusion is that most of the penetrators did not split but are still buried deep in the ground.

■ Penetrators and jackets

One penetrator was located at 40 cm depth in the open area. It was dug up by the FRY authorities, but collected by UNEP. Results of analyses on this penetrator are presented in Appendix K ‘Analysis of DU Penetrators and Fragments’. The penetrator had been rubbing against a stone and was heavily corroded. Field measurements also gave an indication of a buried penetrator (or jacket) a few metres away from the first penetrator, and another in a hole at the edge of the bushy area. Yugoslavian experts had earlier found three penetrators, five cores and six jackets. In summary, very few have been found.

If the number of DU rounds was of the order of magnitude that was given by NATO (1,337), around 99 % of them may still be buried in the ground, both inside and outside the fenced-off area. Some of them might still be on the surface, either outside the fenced-off area, or in the densely vegetated zone inside the fence.

The content of natural uranium in the ground to a depth of 1 m and over an area of 1,000-10,000 m^2 would be 10-100 kg (assuming 5 ppm). An addition of uranium in the form of 400 kg of DU in this area, down to a depth of 1 m, would increase the amount by approximately one to two orders of magnitude.

■ Localised points of contamination

Two localised points of contamination were identified in the open area with 5-10 cps beta/gamma corresponding to 10-100 % of the *Reference Level*. By taking away 1 cm of the upper part of the surface layer and re-measuring, it was concluded that the contamination was superficial and probably caused by a partial split of a penetrator in contact with the ground or some nearby object. There may be several similar contamination points in the part of the fenced-off area covered by trees and shrubs, and perhaps also some outside the fence.

■ Soil samples

Soil samples were taken along the edges of concentric rings from a defined point zero at 1, 5, 10, 20, 50, 100 and 200 metres. The samples were taken at 0-5 cm depth, and were mixed for 12 positions from each ring. The results are shown in Appendix G 'DU in Soil', Tables G.2 and G.3. The percentage of DU in the samples decreased from 27 % to 4 % at 20 m distance from point zero within the fence. This was a clear indication of ground-surface contamination from the impact of a penetrator. The relatively restricted area that was found to be contaminated supports the conclusion that there was probably a very limited shattering of penetrators at this site, which is remarkable considering the large number of DU rounds reported to have been fired in the area.

■ Drinking water

One water sample was taken from the well in Bratoselce village. The results of laboratory analysis are shown in Appendix H 'DU in Water', Tables H.2 and H.3. The uranium concentration was relatively high at 22 mBq/l, and could be related to the higher natural uranium background. However, the uranium concentration was within the range of normal values (1-60 mBq/l or 0.1-5 µg/l) and there was no indication of DU. The corresponding radiation doses are very low (~1µSv/year).

■ Botanical samples

Samples of bio-indicators were taken both inside and outside the fence. The results are shown in Appendix J, Tables J.2-J.3 and J.6-J.9.

The detection of DU in some lichen samples (based on U-234/U-238 ratio) indicates the earlier presence of DU in the air which means that at least some of the penetrators hit hard targets, split into dust and dispersed in air.

■ Air samples

The three air samplers were placed in a line parallel with the wind direction, two in the open part of the fenced area and one outside this area. The air samplers were operated for 85 minutes. The air volume for each sample was 116 m^3. The results are shown in Appendix I 'DU in Air', Table I.2. As can be seen, all values are within the normal range of air concentration, 0.01-20 $\mu Bq/m^3$, except one, which is around 40 $\mu Bq/m^3$. This might be due to the fact that this air sampler was placed close to the dirt track so that dust from passing cars was collected on the filter, or it could reflect dust from digging for penetrators that occurred at the same time the air sample was taken.

However, there is no significant indication of DU and the concentration as such would correspond to very small radiation doses, about 1 µSv per year in the case of a continuous stay in such air for a period of one year. Because there is no indication of any surface contamination, there are no reasons to believe that there will be any airborne DU arising from this area now or in the future.

■ Residual risks

The open area inside the fence has been searched carefully. A few penetrators and jackets have been found and taken care of. There are no further penetrators and jackets still on the surface of the ground easily available for a person walking around. There are no localised points of contamination still in the environment inside the fence except those already identified and marked, no indication of widespread DU contamination of significance from a health point of view, and no DU contamination of water or air.

In the densely vegetated part of the area the current environmental situation with regard to DU is uncertain. There might be some penetrators and jackets still on the ground surface and some localised contamination points but virtually no significant widespread contamination.

The same conclusion might be drawn concerning the adjacent area outside the fenced area.

In conclusion, the residual risk situation might be summarised as follows:

The possibility of penetrators and jackets on the ground in the vegetated part of the fenced-off area and the adjacent area outside the fence (up to a few hundred metres from the fence) justifies consideration of the related risks. The risks include picking up the objects, contamination of hands and unintentional ingestion of DU residues. See the discussion for the Pljackovica site and Appendix A 'Risk Assessment'.

The other residual risk regards the possible short- and long-term consequences of contamination resulting from penetrators and jackets still buried in the ground. The low surface/soil contamination of dispersed DU can be ignored.

From observations made it is known that solid DU will erode and may dissolve in water, perhaps eventually contaminating the groundwater.The amount of DU possibly still in the ground may be about 400 kg which will increase the total amount of uranium in the affected area by a factor in the range 10-100, down to a depth of 1 m.

Intake of uranium via drinking water is normally very low, leading to radiation doses of the order of 0.1 µSv per year. If the additional DU behaves as natural uranium it should not lead to any significant doses, i.e. below 1 mSv per year.

However, there are uncertainties in the assumptions made. These justify application of the precautionary principle and the implementation of selected monitoring to better understand the environmental behaviour of DU in the future. For example, in the case of possible future contamination of groundwater used as drinking water, neither the rate of erosion and dissolution of DU in water is known, nor the dilution in groundwater before this becomes drinking water.

■ Need for mitigation. Recommendations.

The following conclusions and recommendations refer to the risk of radiation and the chemical risk of DU.

1. It is justified to maintain the fence surrounding the assumed target area.

2. The densely vegetated part of the fenced area and the adjacent area outside the presently fenced area, to a distance of approximately 100 m, should be re-surveyed to locate possible additional penetrators and jackets on the surface, those hidden in the upper part of the ground and any localised points of contamination. Those easily dealt with should be removed and stored as radioactive waste until further guidance is provided by the competent authorities.

3. No areas require general decontamination unless any localised contamination is found (either in the vegetated part of the fenced-off area, or outside the fence).

4. An information board should be maintained in the area stating that the site has been attacked by DU ammunition, but that this has been or will be cleared. If a penetrator or jacket should be found by accident it should not be picked up but the local police or health authority should be informed. When the entire area has been carefully searched and decontaminated a sign should be erected with text similar to that

suggested in Chapter 7.3 for Borovac.

5. The nearest well is situated about 700 m away from the site and it is very unlikely that the water could ever become contaminated by DU from the target area. However, in line with the precautionary principle and as part of scientific research, consideration should be given to taking regular water samples from the well in the adjacent village (i.e. the one sampled during the UNEP mission) to study any possible increase of the uranium concentration in the drinking water.

7.5 Bukurevac

Site description and general information

- Bukurevac (NATO reference no. 5).
- Coordinates: EM 580 880.
- See map of site.
- Investigated by the UNEP mission on 1 November 2001.

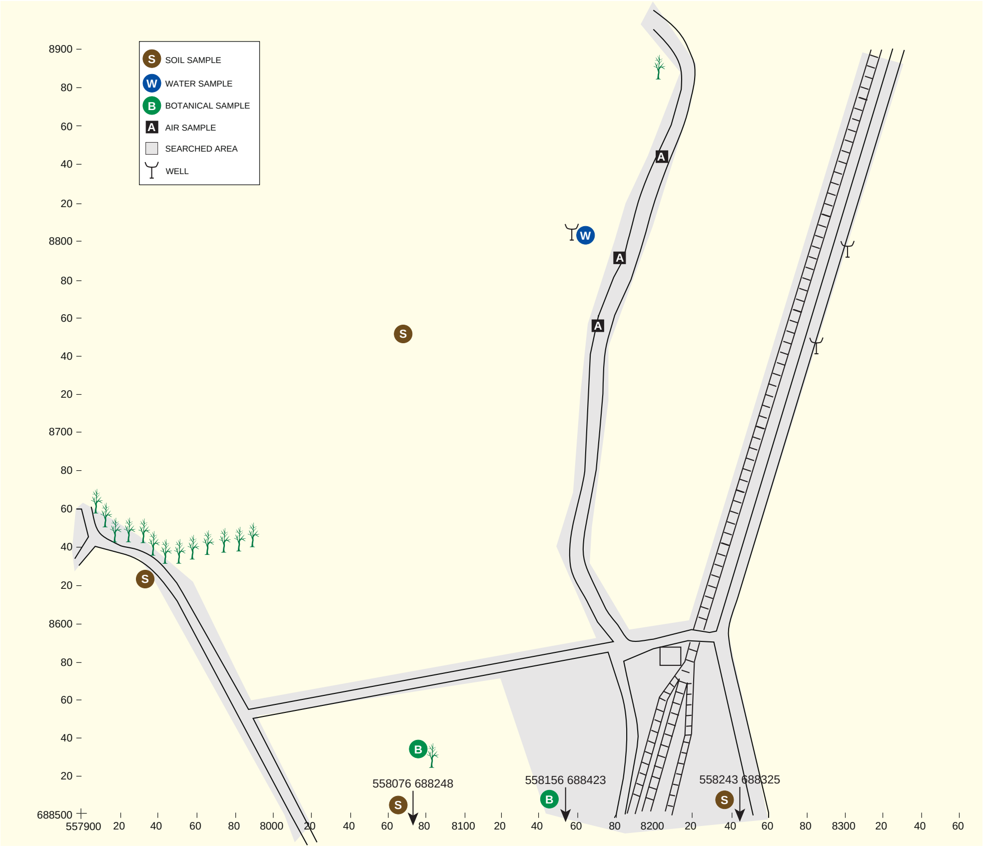
FRY authorities sampling bio-indicators close to the railway at Bukurevac

The targeted site is situated at the railway station of Bukurevac, 1.5 km from the village of Crnotince. A vehicle was probably the target. NATO information confirms that the area was targeted once on 15 April 1999. The number of rounds fired was 250/156, based on a 5/8 mix. Crnotince is an Albanian village, which has 800-1,000 inhabitants. The railway from Thessaloniki to Skopje and Belgrade passes through the targeted area.

This site was the only one visited in the vicinity of the demilitarised ‘safety zone’ close to the border with Kosovo. The FRY authorities did not have this site on their list of DU-targeted sites, and they did not have any information of their own about where the attack occurred. However, they had earlier searched this area within a radius of 300 metres from the railway crossing. No DU contamination had been found.

They had also searched at the position of the NATO coordinates, which is located about 500 m south of the railway crossing, but no DU was found here either. The UNEP team considered

Map 6: Bukurevac site



that the most likely place for the attack would have been the road close to the railway crossing north of the railway station. Thus, this position was chosen as a centre for the new investigation.

The area is flat land used for farming. Some of the fields are cultivated, some not. There may still be mines in those fields that are presently uncultivated. The soil in the area consists of silt and is at least several meters thick.

The gamma radiation, as measured by the '*SRAT'* instrument, is about 50 cps and the beta/gamma radiation measured by the '*Inspector'* instrument 0-1 cps. The groundwater table lies at about 1-1.5 m depth. There are some wells used for drainage of the fields. Local people showed where an unexploded rocket had landed 700 metres from the railway crossing.

Summary of samples taken at Bukurevac:

- 4 soil samples
- 2 botanical samples[4]
- 1 water sample
- 3 air samples

Field investigation

A search for DU by directed individual survey (method D) was made along the four roads, along the railway, around the railway station and in the fields adjacent to the station (not

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[4] These samples were subdivided into single-species sub-samples. The sub-samples have the same number as the original samples but with an additional letter.

Table 7.5 Samples taken at Bukurevac.

Sample Code	Coordinates	Type of sample	Depth	Lab
NUC-2001-105-01	558063 688746	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-105-02	557933 688628	Soil , 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-105-03	558076 688248	Soil , 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-105-04	558243 688325	Soil , 10 sticks, 5x5 m	0-5 cm	Spiez
Air : 4-1	558190 688787	Air-filter		ANPA
Air: 4-2	558209 688831	Air-filter		ANPA
Air : 4-3	558165 688761	Air-filter		ANPA
ANPA-SA25/02a	558156 688423	Lichen		ANPA
ANPA-SA25/02b	558156 688423	Lichen		ANPA
ANPA-SA26/01a	558084 688527	Lichen		ANPA
ANPA-SA26/01aCORT	558084 688527	Bark		ANPA
ANPA-SA27/01	558184 688800	Well water		ANPA

shown on the map).

Four mixed soil samples were taken at different locations. A zero point could not be defined here, since the target location was unknown. Two samples of bio-indicators (lichen and bark) and a single water sample from a well were also taken. Air samples were collected at three different locations along one of the roads.

Summary of results and site-specific conclusions

■ General contamination

No widespread contamination was found in the searched area, either by field measurements or by laboratory analysis of soil samples.

■ Penetrators and jackets.

No penetrators or jackets were found, and no buried penetrators or jackets were indicated by field measurements.

■ Localised points of contamination

No localised points of contamination were found or indicated.

■ Soil samples

Four mixed samples of soil were taken at different locations. Each sample consisted of samples taken from ten points within an area of 5 x 5 metres. The samples were taken at 0-5 cm depth. The results are shown in Appendix G ‘DU in Soil’, Tables G.2 and G.3. There was no indication of DU and the uranium concentrations were normal.

■ Drinking water

Water samples were taken from a well. The results of the laboratory analysis are shown in Appendix H ‘DU in Water’, Tables H.2 and H.3. The concentration of uranium is very low and there is no indication of any DU.

■ Botanical samples

Samples of bio-indicators were taken in the area. The results are shown in Appendix J 'Bio-indicators of DU', Tables J.2-J.3 and J.8- J.9. There are no significant indications of DU in any of the samples taken (based on U-234/U-238 ratio).

■ Air samples

The three air samplers were placed along the road in a line parallel to the wind direction. The air samplers were measured for 95 minutes. The air volume for each sample was 130 m^3. The results are shown in Appendix I 'DU in Air', Table I.2. The concentrations are within the range of normal distribution of natural uranium in air and there is no significant indication of DU in any of the samples.

■ Overall conclusion

With the exception of one lichen sample, none of the measurements resulted in any indication of the presence of DU in the environment. NATO information indicated that 156 DU rounds had been fired at this area but it was not clear exactly where. The UNEP mission did not elucidate this question. Normally, if an area had been the target for that number of DU rounds, it would be expected for some to be lying on the surface. If the UNEP team had been working in the right locality, something ought probably to have been found.

However, because the area was not clear from land mines and cluster bombs, the survey was quite limited in terms of the area covered by measurements. Therefore, the conclusions are also very limited and unspecific.

■ Residual risks

Because of the unclear situation outlined above, nothing certain can be said about residual risks in this area. Along the roads that were measured, there is no risk from DU whatsoever. In the surrounding environment, there might be some penetrators and jackets on the surface and these should be avoided by the public. The total amount of DU that might have been used in this area is not so large that it is expected to cause any environmental problem.

As usual, there is always an uncertainty with the possible contamination of drinking water, even if the concentration is expected to be small and insignificant from both a radiological and chemical point of view.

■ Need for mitigation. Recommendations.

1. As the results of lichen analysis indicate that DU had at some time been present in the air at this site, it is recommended that the whole area should be searched more thoroughly after having been cleared of unexploded ordnance. If possible, confirmation should be sought regarding the exact coordinates of the target.

2. It is also recommended that the public living in this area are informed that DU might be found in the environment, and that any observation of penetrators or similar should immediately be reported to the authorities.

3. In case later surveys by Yugoslavian experts lead to findings of localised contamination and penetrators and/or jackets on/in the ground, complementary actions might be justified, to be taken at the discretion of the Yugoslavian authorities.

7.6 Reljan

Site description and general information

- Reljan (NATO reference no.108 and 112).
- Coordinates: EM 631 852.
- Investigated by the UNEP mission on 1 November 2001.

The targeted site is situated on the crest of an elongated hill at an altitude of 655 metres. The village of Reljan lies 3 km west of the targeted area. A communications mast was destroyed sbout 0.5 km from the site. However, there was no indication from field measurements of any DU.

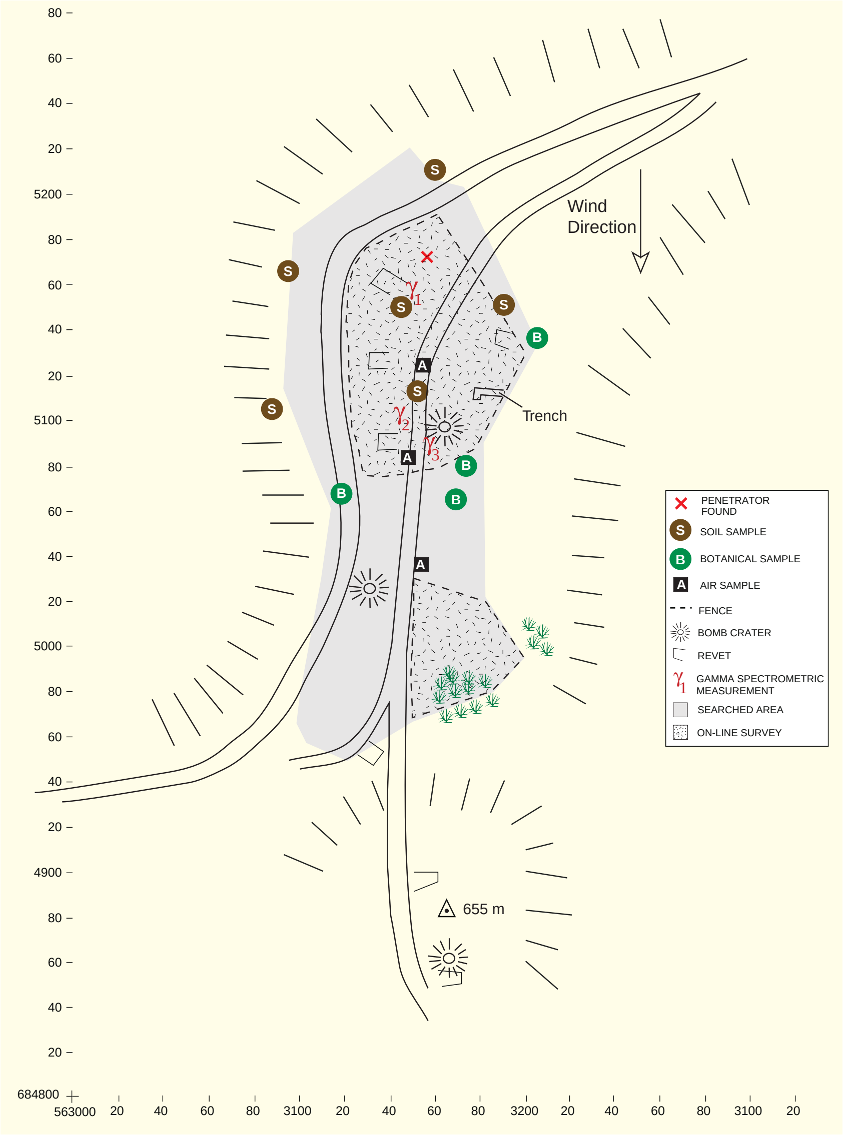
NATO information confirms that the area was targeted once on 28 May 1999, and once more on an unknown date. The number of rounds fired during the attack of 28 May was 180/113, based on a 5/8 mix. The number of rounds fired during the second attack is not known. The targets were probably armoured vehicles on both occasions. The airstrikes were carried out along a south-north trajectory. The area was also targeted with 'conventional' (i.e. non-DU) weapons. Prior to the UNEP visit, the FRY authorities had found one penetrator and a large number of jackets in two adjacent parts of the site.

The FRY authorities had also erected fences and warning signs around both of these areas. The surface areas of the two fenced-off sites are 4,000 m^2 (northern site) and 2,000 m^2 (southern site). UNEP was informed by the FRY authorities that the fenced area next to the road (the northern site) would be most interesting since some DU projectiles had been found on the ground surface.

The village of Reljan has 6,000 inhabitants, mostly Serbs. The land at the site and on the surrounding hills is grassland used for pasture. The soil in the area is sandy and gravelly. The soil layer is mostly rather thin (0-50 cm thick) consisting of granitic gneiss weathered *in situ*, which is exposed in a few outcrops and in excavations. Three gamma spectrometric measurements were made on outcrops of deeply weathered gneiss and on gravelly sand. The total gamma radiation was 0.11-0.13 µSv/h. The uranium concentration was 2.1-3.2

One of the fenced areas at the targeted site of Reljan

Map 7: Reljan site



mg/kg eU (26-40 Bq/kg eU U-238), the thorium concentration 18-22 mg/kg (72-88 Bq/kg Th-232) and the potassium concentration 3.7-4.2 % K (1,150-1,300 Bq/kg K-40).

There are no wells in the area close to the targeted sites.

Summary of samples taken at Reljan:

- 9 soil samples
- 1 penetrator
- 4 botanical samples[5]
- No water samples
- 3 air samples

Field investigation

A ‘line-up’ survey, using method A, was made in both areas. Measurements showed the

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[5] These samples were subdivided into single-species sub-samples. The sub-samples have the same number as the original samples but with an additional letter.

gamma background to be 60-75 cps, and the beta background to be 0-2 cps, at maximum 3 cps. The line-up survey was complemented with careful measurements, method C. A qualified 'at random' survey, method B, was made outside the fenced area, on the asphalt that FRY authorities said had been contaminated. Soil samples were taken inside and outside the fence. The samples were mixed. Botanical samples were taken both inside and outside the fenced area. There was no well in the area and thus no water sample was taken. Two air samples were taken inside the fenced part of the northern site and one outside the fence to the south.

Table 7.6 Samples taken at Reljan.

Sample Code	Coordinates	Type of sample	Depth	Lab
NUC-2001-106-01	563147 685117 Distance inside, 1m to fence	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-106-02	563147 685117 Distance inside, 10 m to fence	Soil, 12 sticks	0-5 cm	Spiez
NUC-2001-106-03	563142 685109	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-106-04	563136 685149	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-106-05	563191 685151	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-106-06	563163 685209	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-106-07	563096 685167	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-106-08	563087 685104	Soil, 10 sticks, 5x5 m	0-5 cm	Spiez
NUC-2001-106-09	562605 684538	Soil, Field Blank	0-5 cm	Spiez
NUC-2001-106-10	563151 685160	Penetrator	80 cm	Spiez
Air : 5-1	553168 685120	Air filter		ANPA
Air : 5-2	553155 685074	Air filter		ANPA
Air : 5-3	553150 685032	Air filter		ANPA
ANPA-SA28/01a	563208 685137	Lichen		ANPA
ANPA-SA29/01a	563173 685079	Lichen		ANPA
ANPA-SA29/01aCORT	563173 685079	Bark		ANPA
ANPA-SA30/01a	563171 685063	Lichen		ANPA
ANPA-SA30/01b	563171 685063	Lichen		ANPA
ANPA-SA31/01a	563123 685073	Lichen		ANPA
ANPA-SA31/02	563123 685073	Moss		ANPA

Summary of results and site-specific conclusions

■ General contamination

The field measurements using methods A and C worked well with more than 50 careful measurements made in the two parts of the site. Furthermore, a number of measurements were made using method B.

No widespread contamination was found by the field measurements inside or outside the fenced area; i.e. any such contamination was less than 10 % of the *Reference Level* (<1 g DU/m^2 assuming deposition distributed in the superficial layer of the surface with an absorption of 90 %). The soil sample analyses showed widespread contamination by DU within the fence but nothing outside. The DU concentration was up to 77 % of the total uranium concentration, 13 mg/kg soil, which is about four times the normal level for that area.

NATO reported the number of DU rounds fired during the first strike to be 113, with an unknown number of rounds fired during the second strike. If it is assumed that the target area covered 6,000 m^2, that the same number of rounds were fired during the two attacks, i.e. a total of about 250 DU rounds, and all were split and dispersed over the target area, the average ground surface contamination should be 12 g DU/m^2.

This activity should have been easily detectable if it was in the form of widespread contamination, even if part of it had dispersed down into the ground (0-5 mm). However, there was no indication from the field measurements of any DU on the ground, which means that the DU had either not been split in the amounts estimated, or that it had dispersed deeper than 5 mm during the two years since the time of the strikes and been transported from the area by groundwater.

Laboratory analyses of soil samples showed the presence of DU to be of the same order of magnitude, on average, as the natural uranium concentration, i.e. less than 0.2 g DU/m^2 in the upper 0-5 cm of soil. This does not contradict the conclusions above.

Therefore, with the given assumptions and available information, the most probable explanation is that most of the penetrators did not split but entered the ground more or less intact.

■ Penetrators and jackets

A corroded penetrator, located at 80 cm depth, was dug up by the FRY authorities and handed over to the UNEP team for laboratory analysis. The results of this analysis can be found in Appendix K 'Analysis of DU Penetrators and Fragments'.

Including findings prior to the UNEP mission, a total of two penetrators and a large number of jackets have been found in the area. The presence of jackets is a strong indication that the investigated area was indeed the targeted site. If most penetrators are still buried in the ground, as concluded above, this means that at least 34 kg (and perhaps 75 kg or more) of uranium in the form of DU has been added to the local environment. An area of 6,000 m^2 and 0.5 m depth would contain about 15 kg of natural uranium, meaning that DU accounts for an increase of up to five times natural levels. Because very little DU was found in the soil samples, and given the assumptions discussed above, the majority of the DU must either still be in solid form (i.e. as intact penetrators), or already corroded, dissolved in water and disappeared into the wider environment.

■ Localised points of contamination

No localised points of surface contamination were indicated by field measurements.

■ Soil samples

Soil samples (mixed samples of ten points within an area (5 x 5 m)) were taken inside and outside the fence. Samples were also taken along the inside of the fence at a distance of 1 m and 10 m from the fence, with 12 sticks taken at each of these distances. The results are shown in Appendix G 'DU in Soil', Tables G.2 and G.3. There are significant indications of DU in the soil samples taken inside the fence. The level of contamination varies and it is difficult to estimate a reliable average value, but DU contamination of 50 % is assumed for the fenced area, which probably is an overestimation. That translates into an average doubling of the uranium concentration of the soil at a depth of 0-5 cm depth, when compared with natural levels. The results are a clear indication of DU dispersal in air due to the impact of one or more penetrators on hard surfaces.

None of the samples taken outside the fence had any measurable DU contamination.

■ Drinking water

No water samples were taken. There is no drinking water nearby and no information that the area might be a source of water for the village.

Botanical samples

Samples of bio-indicators were taken both inside and outside the fence. The results are shown in Appendix J ‘Bio-indicators of DU’, Tables J.2-J.11.

There are no significant indications of DU in any sample taken (based on U-234/U-238 ratio).

Air samples

The three air samplers were placed in a line parallel to the wind direction and operated for 95 minutes. The air volume for each sample was 130 m^3. The wind was blowing rather strongly from north to south. During the air sampling the FRY authorities dug up the penetrator referred to above. It was found 40 m north of the air sampler with the filter Air:5-1 (see Appendix I ‘DU in Air’, Table I.2). The concentration of uranium found in the air samples is not exceptional and there is no significant indication of the presence of DU. While digging for penetrators occurred nearby at the time of air sampling, there is no indication that this affected the results.

The concentration of uranium in air is within the range of normal distribution of concentrations in air. The corresponding radiation doses are very low, of the order of 1 µSv per year.

Because there is no indication of any significant widespread surface contamination, there is no reason to believe that there will be any significant airborne DU in this area, either now or in the future.

Residual risks

The area inside the fence has been searched carefully by Yugoslavian and UNEP experts. Other than those penetrators and jackets already found, there are no penetrators or jackets still lying on the surface and easily available to a person walking around.

The widespread surface contamination inside the fence is insignificant from the point of view of human health.

There are no localised contamination points in the environment. The amount of possible additional uranium in the ground because of buried penetrators could be almost one order of magnitude larger than the natural uranium content. However, there are no wells or other sources of drinking water nearby the target areas. Consequently, there are no reasons to believe there will be any contamination of drinking water from DU now or in the future unless new wells are dug in the area.

Measurements outside the fence have shown no indications of DU contamination whatsoever. The conclusions concerning residual risks are therefore the same.

Need for mitigation. Recommendations.

The following conclusions and recommendations refer to the risk of radiation and the chemical risks associated with DU.

1. There is no need to retain the fence surrounding the assumed target areas.

2. The area outside the present fenced areas should be surveyed once more up to a distance of 100 m from the fence to locate any penetrators and jackets still lying on the surface, together with those buried in the upper part of the ground. Those easily removable should be taken away and stored as radioactive waste until further guidance is issued by the relevant authorities.

3. No part of the site area needs general decontamination. Limited decontamination would be needed if localised contamination were to be found outside the fence.

4. An information sign should be erected stating that the area was subject to an attack using DU ordance but has since been cleared and there is no risk of radiation or any chemical risks of concern. If, nevertheless a penetrator or jacket should be found by accident it should not be picked up, and the local police or health authority should be informed.

7.7 Cape Arza

Site description and general information

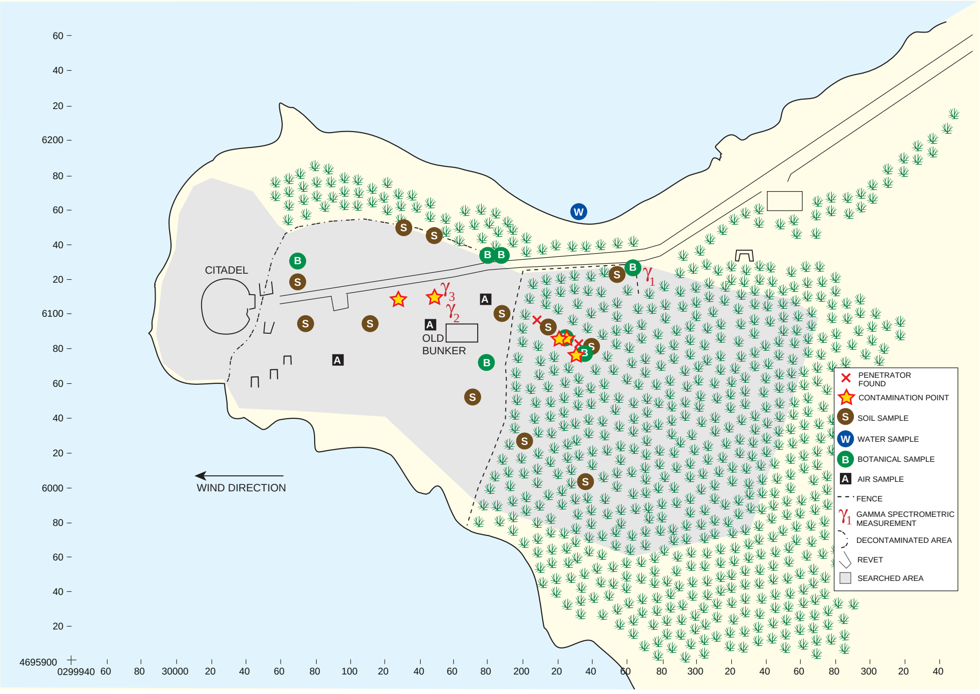
- Cape Arza (NATO reference no. 55 and 58).
- Coordinates: CM 0147 9634.
- See map of site.
- Investigated by the UNEP mission on 3 November 2001.

The targeted site of Cape Arza

The targeted site is situated on a cape of the Montenegrin coast.

NATO information confirms that the area was targeted twice, once on May 29 and once on

➤ Map 8: Cape Arza site



May 30 1999. The number of rounds fired was respectively 230 and 250. Of the total of 480 rounds, 300 rounds were DU (based on a 5/8 mix).

In the middle of the targeted area a small fortified emplacement for an anti-aircraft gun was found.

Cape Arza is the site of a 19th century citadel and has been an important area for tourism. A small stony beach is situated along the northern coast of the cape. The whole area inland from the citadel is virtually inaccessible as it is covered by dense vegetation of bushes and trees, although some areas have been cleared as part of decontamination efforts since the military conflict (see below). About 700 metres north-east of the targeted site is a small village with about 100 inhabitants.

The Government of Montenegro has financed decontamination of the area closest to the citadel (Vukotich et al., 2002, not yet published). 'Phase 1' of this work was carried out between 1 February and 15 June 2001. During this time, a total of 30,000 m^2 was surveyed and, of this, 10,000 m^2 was decontaminated (see Map 7.7).

About 25 persons took part in the survey and decontamination work. Among these were radiation experts from the Centre for Ecotoxicological Research of Montenegro, the Faculty of Science at the University of Montenegro, the Vinca Institute of Nuclear Sciences in Belgrade, and NBC (Nuclear, Biological and Chemical warfare) officers from the FRY Army. This work took about 2,500 person days (i.e. 25 x 100). The whole area was surveyed by grid technique, i.e. the area was divided into rectangular areas, each of which was searched using beta and gamma instruments. During this work, 188 contamination points (maximum radius 1 m) were located and 102 whole penetrators, 28 penetrator fragments and a few tens of jackets were found. The penetrators, penetrator fragments and jackets were collected and put into barrels for storage. In addition, the contaminated soil around the penetrators and at the contamination points was removed. Some 10 kg of highly contaminated soil (1,450-7,000 Bq uranium/kg soil sample) was taken away to be stored securely. The soil that was very close to penetrators contained up to 3.5 10^6 Bq/kg.

In addition, two tons of soil, rock, humus etc. with low radioactivty was removed and collected. The uranium concentration of this soil was two to five times higher than the natural levels found in soil at Cape Arza. The threshold for soil decontamination was 400 Bq/kg, i.e. soil with activity less than 400 Bq/kg was left where it was. 400 Bq/kg is about twice the maximum natural uranium background level for red soil at the site. Typical values for the natural uranium-238 concentration in the soil at Cape Arza are around 30 Bq/kg in grey soil, while samples of red lateritic soil can contain up to 200 Bq/kg.

The penetrators and highly contaminated soil removed from the site are now stored at Vinca Nuclear Research Laboratory in Belgrade, while the soil with only low radioactivity has been stored in a First World War bunker situated within the decontaminated area (see Map 7.7).

During the whole of the decontamination work the participants wore protective half masks, overalls and gloves.

As part of ‘Phase 2’ of the decontamination work, some searching for DU has been carried out in the densely vegetated sector to the east of the area decontaminated during ‘Phase 1’. Several penetrators have been found, but this part of the site is considered far from being cleared of DU. The total area to be covered by ‘Phase 2’ is judged to be about 30,000 m^2. It has been fenced-off from the already decontaminated part of the site and warning signs have been erected. The coastal side has not been fenced as the Montenegrin authorities consider it to be almost inaccessible.

‘Phase 3’ of the process is planned for implementation after all decontamination work has been completed. It is projected to extend over ten years and to comprise a range of follow-up monitoring of environmental and health parameters.

The strategies, findings and observations, experiences and conclusions of the Montenegrin experts can be summarised (in no particular order and not being complete) as follows.

The measurement strategy:

- an experienced army officer first conducts reconnaissance of the area of interest, on his own, to guide the work of the following team survey;
- the survey team walks in line, 10 m across, making very careful measurements, using instruments sensitive to gamma and beta radiation and at a speed of 20 m/h on average;
- a maximum of two impact holes are examined per day;
- visual observations and measurements of possible contamination points are made on rock surfaces;
- the work is conducted pragmatically, tending towards use of practical rather than sophisticated means and methods;
- the team members are well protected with overalls, gloves and breathing masks.

Some observations, experiences and conclusions:

- no regular pattern in the occurrence of jackets and penetrators;
- localised contamination points less than 1 m radius;
- no DU activity found on the beach;
- when increased gamma radiation levels are detected and a buried penetrator/jacket is suspected, digging takes place and the radiation level is observed. If this does not increase, digging is stopped and it is concluded that only background radiation is involved;
- a penetrator’s trajectory along a rock surface can be identified by observation of the

contamination pattern up to a distance of 90 cm;
- the maximum practical depth for finding a penetrator by gamma measurements is about 17 cm; beta measurements are only used for detection of surface contamination;
- it is expected that at least another 100 penetrators will be found in the area not yet surveyed;
- the penetrators that can not be found are assumed to be concealed among the rocks and not considered to be of any current or future concern from a health viewpoint;
- all personnel are checked for contamination at the end of each day;
- some medical observations are made on personnel;
- conducting medical examinations of members of the public has been discussed but it is recognised that this is a highly sensitive issue;
- the cost of survey, decontamination, laboratory measurements and equipment has, to date, been 400,000 DM;
- financial support is required for the work to continue.

The bedrock in the area is Cretaceous grey limestone, which is exposed along the shoreline and in many parts of the Cape itself. The limestone is covered by a layer of soil, mostly less than 1 m thick and normally 10-20 cm deep. There are three types of soil: one grey, one red lateritic and one greyish-blackish, all of which consist of humus to a large extent. There are no wells in the area. The UNEP team made five gamma spectrometric measurements in the area. A measurement on limestone showed concentration of radioactive elements to be very low. The total gamma radiation measured was 0.02 µSv/h, the uranium concentration 3.1 mg/kg eU (38 Bq/kg eU U-238), the thorium concentration <0.2 mg/kg (<1 Bq/kg Th-232) and the potassium concentration <0.2 % K (<60 Bq/kg K-40).

Two measurements were made on red soil, which also contained sand and small stones of limestone. The total gamma radiation as measured on the red soil was 0.06-0.08 µSv/h and the uranium concentration 5.7-8.0 mg/kg eU (70-100 Bq/kg eU U-238), the thorium concentration 8.6-9.4 mg/kg (40-50 Bq/kg Th-232) and the potassium concentration 0.8-0.9 % K (240-300 Bq/kg K-40). One measurement was made of grey humus-rich soil. The total gamma radiation measured was 0.004 µSv/h and the uranium concentration 4.1 mg/kg eU (50 Bq/kg eU U-238), the thorium concentration 4.6 mg/kg (20 Bq/kg Th-232) and the potassium concentration 0.4 % K (120 Bq/kg K-40).

Summary of samples taken at Cape Arza:

- 7 soil samples in the decontaminated area and 5 soil samples in the still-contaminated area
- 11 botanical samples[6]
- 1 water sample from the sea
- 3 air samples

Field investigation

Both the decontaminated area and parts of the area to the east of this, were searched by qualified 'at random' surveys (method B). The search was supplemented with careful measurements (30 seconds to one minute in each place, compare method C) within the decontaminated area and at several points within the adjacent non-decontaminated area, especially where marks from penetrators could be seen. Approximately 30 % of the decontaminated area was searched by the UNEP team. The search in the non-decontaminated area was rather limited because of the very rough vegetation.

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[6] These samples were subdivided into single-species sub-samples. The sub-samples have the same number as the original samples but with an additional letter.

Table 7.7 **Samples taken at Cape Arza.**

Sample Code	Coordinates	Type of sample	Depth	Lab
NUC-2001-107-01	300110 696093	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-02	300077 696097	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-03	300069 696116	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-04	300124 696155	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-05	300149 696145	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-06	300185 696095	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-07	300171 696054	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-08	300210 696090	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-09	300231 696081	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-10	300200 696031	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-11	300218 696005	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-12	300251 696 134	Soil, 10 sticks, 5x5 m area	0-5 cm	Spiez
NUC-2001-107-13	300796 696439	Soil, Field Blank	0-5 cm	Spiez
Air: 6-1	300146 696097	Air filter		ANPA
Air: 6-2	300119 696100	Air filter		ANPA
Air: 6-3	300174 696120	Air filter		ANPA
ANPA-M01/01a	300180 696077	Lichen		ANPA
ANPA-M02/01a	300180 696077	Lichen		ANPA
ANPA-M03/01a	300187 696137	Lichen		ANPA
ANPA-M03/01aCORT	300187 696137	Bark		ANPA
ANPA-M04/01	300188 696136	Moss		ANPA
ANPA-M05/02a	300257 696122	Lichen		ANPA
ANPA-M05/02b	300257 696122	Lichen		ANPA
ANPA-M06/01a	300065 696128	Lichen		ANPA
ANPA-M06/02a	300065 696128	Lichen		ANPA
ANPA-M06/02aCORT	300065 696128	Bark		ANPA
ANPA-M07/01a	300222 696092	Lichen		ANPA
ANPA-M07/01b	300222 696092	Lichen		ANPA
ANPA-M07/01c	300222 696092	Lichen		ANPA
ANPA-M08/01	300234 696084	Lichen		ANPA
ANPA-M08/01CORT	300234 696084	Bark		ANPA
ANPA-M09/01a	300234 696084	Lichen		ANPA
ANPA-M09/01aCORT	300234 696084	Bark		ANPA
ANPA-M10/01a	300234 696084	Lichen		ANPA
ANPA-M11/01	300234 696084	Lichen		ANPA
ANPA-M12/01	300239 696157	Sea water		ANPA

Mixed soil samples were taken in the decontaminated and non-decontaminated areas (outside and inside the fence respectively). Soil samples were taken in areas of 5 x 5 m randomly or around contamination points or penetrators. Botanical samples of lichen and bark were taken both in the decontaminated and the adjacent area. One water sample was taken from the sea. Air measurement was carried out with three air samplers placed in the decontaminated area.

Summary of results and site-specific conclusions

■ General contamination

The overall conclusion of the field measurements using the beta/gamma equipment is that there is no measurable widespread surface contamination, meaning less than 10 % of the *Reference Level* i.e. less than 1g DU per m^2. The radiation background measured by the beta-gamma instruments was 0-1 cps and by the scintillometers it was 30-50 cps (gamma).

The soil sampling and subsequent analyses showed widespread DU contamination of the soil in both parts of the site. The level of contamination varied from virtually zero to about 20 mg DU/kg soil (at 0-5 cm depth) and the pattern of contaminated areas was quite scattered.

Because of (a) the special character of the environment, (b) the fact that the area had already been searched carefully by Montenegrin experts, and (c) the limited time available for the survey, the field measurements were organised in an optimised manner considering the circumstances. In this way, about 30 % of the decontaminated area or 3,000 m^2 was searched carefully within a period of 1.5 hours. During that time, a number of contamination points and indications of buried penetrators were recorded. Consequently, the conclusions in terms of quantities should be multiplied by three.

Assuming that 300 DU rounds in total were spread over the affected area, of which 100 have already been removed, the maximum amount of DU that could possibly have been split and scattered over the area is about 60 kg DU. The total affected area might be about 60,000 m^2 and consequently the contamination of the ground would be 1g DU per m^2 on average, which corresponds to the limit of detection using field measurements. If the affected area is smaller, the contamination level will be correspondingly higher and should be easily detectable using field measurements.

However, the true value of ground contamination with DU dust is probably much lower because many penetrators are still expected to be found and many remain concealed in the ground (in soil and rock). Furthermore, as the concentration of DU does not exceed the natural uranium concentration (with one exception), the level of DU contamination is so low that it is not expected to be detectable by field measurement techniques.

If the contaminated area was much smaller, the fact that no widespread contamination could be detected by field measurements leads to the conclusion that the total amount of DU split and scattered over the affected area must have been even less than 60 kg.

The results of the soil analyses do not contradict these conclusions. The analyses showed contamination levels up to 20 mg DU/kg soil. If this value is assumed to be representative over 1 % (maximum 10 %) of the area, it would correspond to 1-10 kg DU. 20 mg DU/kg soil corresponds to 1.5 g DU/m^2, which is at the limit of detection for field measurements, even if the DU contamination is very superficial (i.e. to a depth of only a few mm).

The overall conclusion is therefore that most of the penetrators probably did not split but are present more or less intact, either on the surface in the non-decontaminated area or concealed in the soil/rock of both parts of the site.

■ Penetrators and jackets

No penetrators were found in the decontaminated area except one that was dug up by Montenegrin experts at one of the hot spots (defined as excessive gamma radiation without excessive beta radiation, indicating a buried penetrator or jacket) identified by the UNEP team. Two such hot spots were identified (150 cps and 75 cps respectively, background 25 cps). A ‘false’ hot spot was also identified (50 cps as compared with background 25 cps in other parts of the area). But there was a special red soil in this part of the area and the background there was 50 cps.

Four penetrators were found on or just below the surface in the non-decontaminated area, adjacent to the decontaminated area.

More than 100 penetrators had earlier been found by the Montenegrin experts in the decontaminated area, which is a remarkable number. That so many have been found is probably a consequence of the area’s thin soil layer. Rounds that missed the target have ricocheted up to the ground surface or are hidden among the rocks depending on the angle of impact.

No, or very few, additional penetrators are expected to be found in the future inside the decontaminated part of the site.

■ Localised points of contamination

Two localised points of contamination were found in the decontaminated area. The activity was low (10-15 cps beta/gamma, corresponding to 0.01-10 g DU depending on the size of absorption, 0-90 %, and the size of the contaminated area, 0.01-1 m^2).

Five localised points of contamination were found in the non-decontaminated area. The activity was of the same order of magnitude as given above.

The contamination points were most often quite superficial and could easily be cleared if the upper layer of soil was removed.

The size of the contaminated areas was small, less than 1 x 1 m, and may indicate that these were residues of penetrators or jackets that had been removed previously. There are reasons to believe that there might be more such contamination points in the decontaminated area and particularly in the non-decontaminated area.

■ Soil samples

Mixed soil samples were taken randomly in both the decontaminated and the non-decontaminated area. 10 sticks were taken in an area of 5 x 5 m. The samples were taken at a depth of 0-5 cm.

Soil samples were also taken 3 m and 5 m around penetrator findings in the non-decontaminated area.

The results are shown in Appendix G ‘DU in Soil’, Tables G.2 and G.3. As can be seen there are clear indications of DU in some of the soil samples (up to 90 % of DU in the sample) and in others no DU could be found. However, the activity is low, of the same order of magnitude as natural levels.

In the area that had been decontaminated by the Montenegrin experts, several soil samples were nevertheless still found to be contaminated, with up to 60-70 % of DU. These relatively high values were found in those parts of the site where there had been intensive decontamination through digging up and removal of buried penetrators and clearance of soil around localised contamination points. It is possible that the remaining contamination can be considered as ‘residue’ from the clean-up process. During decontamination, the Montenegrin experts removed a large quantity of contaminated soil (about two tonnes), taking it away for storage. The limit at which soil was considered as ‘clear’ and left on the ground was 400 Bq/kg, which corresponds to about 10 mg U-238/kg soil. This soil could possibly have been included in the samples taken by the UNEP team.

In the undecontaminated part of the site, the DU contamination was sometimes even higher, up to 90 % of DU in soil containing up to 20-25 mg uranium/kg soil. The highest levels were found within 1-2 m from penetrators lying in/on the ground. However, samples taken at random, and not close to a penetrator, showed no contamination. This would indicate that contamination in the area is very localised.

■ Sea water

There is no spring water in the area and surface runoff of rainwater flows into the sea.

A sample of sea water was taken and the results of laboratory analysis are given in Appendix H ‘DU in Water’, Table H.2 and H.3. The concentration is within the normal range of natural uranium in sea water. There is no indication of DU in the water.

■ Botanical samples

Samples of bio-indicators were taken in both parts of the site. The results are given in Appendix J ‘Bio-indicators of DU’, Tables J.2-J.3 and J.6-J.11.

The presence of DU in almost all of the lichen, bark and moss samples indicates the earlier presence of DU in the air (based on U-234/U-238 ratio) which means that at least some of the penetrators hit hard surfaces, split into dust and dispersed in the air.

■ Air samples

The three air samplers were placed in a line parallel to the wind direction in the decontaminated area and operated for 130 minutes. The air volume for each sample was 192 m^3. The results are given in Appendix I ‘DU in Air’, Table I.2. The concentrations are low but there are clear signs of DU dust in the air, indicated by the values of U-234/U-238 (but not by the values of U-235/U-238), which is an interesting observation. As at the other investigated sites where DU was detected in air samples, the explanation might be one or several of the following: resuspension by wind, simultaneous digging for penetrators at the time of air sampling, movement of many people in the vicinity of the air samplers.

■ Residual risks

The risk in the decontaminated area is essentially different from that in the undecontaminated area.

With regard to the decontaminated area, there is no reason to believe there are any further penetrators and jackets still lying on the surface and easily available for a person walking around. There may still be some contamination points, which, once identified, should be easy to remove. The risk of a contamination point is that someone comes into physical contact with the contaminated soil, thereby contaminating their hands and subsequently ingesting part of it. With reasonable assumptions the resulting radiation dose will be much less than 1 mSv and less than the amount that could be problematical from the point of view of chemical toxicity. Therefore, the corresponding risks are insignificant but should nevertheless be eliminated if reasonably possible.

In summary, there are no significant risks to the soil, water and air.

As regards the non-contaminated area the situation is quite different. A number of penetrators on the ground surface and contamination points can be expected and these have to be removed, see below.

■ Need for mitigation. Recommendations.

The following conclusions and recommendations refer to the risk of radiation and the chemical risks of DU.

1. The already decontaminated area is practically clean but in line with the precautionary principle there should be a final check made through surveying for contamination points. If any localised contamination is found the contaminated soil should be removed.

2. Following implementation of Recommendation 1. above, the decontaminated area can be considered fit for unrestricted public access.

3. However, an information sign should be erected, stating that the area has been subject to a strike using DU ordnance, but that it has subsequently been decontaminated and there is no risk of radiation or any chemical risk of concern. If, nevertheless, a penetrator or jacket should be found by accident, it should not be picked up but the local police or health authority should be informed.

4. The as yet undecontaminated part of the site should be surveyed and decontaminated in a way that minimises the risk of spreading contamination and that maintains ecological values. For that reason, it would be preferable to cut the bushes instead of burning them if it is considered necessary to remove them. Once these measures have been implemented, Recommendations 2. and 3. above will be applicable.

5. From a scientific point of view it would be of interest to measure the uranium (and possible DU) concentration in air when no people are present.

APPENDIX A

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RISK ASSESSMENT

A.1 The concept of the '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, in 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 of 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' (µSv 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 O 'Formulas and Data'.

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 O 'Formulas and Data'.

A.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 in terms of 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 a given assessment 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.

A.3 The application of the risk assessment methods to Serbia and Montenegro

The objectives of the mission to Serbia and Montenegro are defined in Chapter 3. Measurements in Serbia and Montenegro were judged necessary in order to verify the theoretical results given in the UNEP/UNCHS Balkans Task Force (BTF) Report of October 1999 – 'A preliminary assessment'. The assessments were based on conservative safety assumptions with regard to conditions of exposure to DU but with realistic assumptions about the 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 a 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 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 current 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 respects, 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. Theoretical environmental dispersion models are used only exceptionally because of insufficient measurement data and knowledge of the local geochemical and geohydrological properties.

A.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 m^2. The impact of DU on soldiers and civilians in the vehicles and on the affected area during the attack is not considered specifically. The chemical and radiological impact during the attack is probably small as compared with the consequences of explosions and fire. However, the survivors may have been seriously exposed to depleted uranium, 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 m^2. 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/m^3 air is assumed.*
>
> *After some time people may enter the area which will then be cultivated. By entering the area people cause resuspension 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 October/November 2001 mission to Serbia and Montenegro, 2.5 years after the military conflict, the conditions have changed. Rain and snow have partly washed away the superficial ground contamination; there may have been some DU 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 from both short- and long-term perspectives. Therefore, many of the possible exposures in 1999 are irrelevant.

Table A.1 Comparison of possible means of DU exposure in 1999 and from late 2001 onwards

Means of exposure in 1999	Means of exposure from late 2001 onwards
(a) Solid pieces of DU picked up	(a) Same + risk of inhalation of corroded DU (dust)
(b) Rounds that passed or missed the target and might contaminate groundwater	(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	(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

Table A.1 below summarises the changes concerning issues of interest. The inclusion of 'Same' in the 2001 column of Table A.1 does not mean that the risks are the same quantitatively as in 1999, but that the means of exposure are the same 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 as described in the Reference Case are ambiguous or close to limits, standards, or any other value of relevance, the actual values of contamination at the visited sites in Serbia and Montenegro at the time of visit (October/November 2001) must be at least a factor of ten below the values in the Reference Case. This is to be confident that the contamination does not exceed any limits or standards or that the consequences are of no concern.

A.5 The risks in the Reference Case

The means of exposure refer to table A.1 above. The comparisons to natural levels, limits etc. refer to Appendix O 'Formulas and data'. All radiation doses refer to pre-teenage boys (7-12 years), which means that the doses to children less than one year old may be up to five 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 two times lower than that to pre-teenagers per unit of intake.

(a) Picked up solid pieces of DU
The only significant exposure may be by external beta (ß) 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. If a piece of DU is placed in a pocket, the beta radiation is somewhat reduced; 50 % reduction 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 a 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 tissue close to a piece of DU kept in a pocket. The gamma dose rate at different distances from a penetrator, containing about 300 g DU, has been measured and the approximate dose rates are as shown in Table A.2. Considering 0.1 m as the closest distance of significance, it would need more than 1,000 hours of continuous exposure until the organ dose approached the natural annual gamma radiation dose to that organ.

Table A.2 External gamma dose rate from a penetrator

External dose rate (Sv/h)	Distance from the penetrator (m)
2.7	0.05
0.85	0.1
0.25	0.2

Another means 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 during 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 dependent 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 µSv, which is an insignificant dose. Probable doses are 10 to 100 times less. An intake of 10 mg DU is considerably above generic standards for daily intake (WHO, 1998) but less than the 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.

In case a penetrator is heavily corroded there is a risk that in picking up the penetrator the hands become contaminated with more than 10 mg of DU. Still assuming very bad hygiene, the highest probable intake would be 1 g of DU (compare point (c) below) which would result in radiation doses up to 1 mSv effective dose but would lead to acute heavy metal toxic effects. Furthermore, if the penetrator is placed in a pocket there is a risk of contamination of the pocket. The consequences of that would be a continuous exposure of the skin under the pocket, although less than with a penetrator in the pocket, and a repeated contamination of the hand every time it is put into the pocket followed by a risk of ingestion and internal contamination. The radiological consequences are repeated exposures of less than 1 mSv each day, which is an unacceptable scenario, particularly from a chemical toxicological point of view.

The conservatism lies even more in this case in the assumption of an intake of 1 g of DU. The probable intakes would be much less than 1 g.

Another risk of exposure from a heavily corroded penetrator is by inhalation. One has to be careful in handling such a penetrator to avoid corroded DU becoming airborne. Inhalation of 10 mg of DU might lead to significant doses (>1 mSv).

The conservatism lies in the assumption that the corroded DU is easily airborne and the amount of inhaled DU.

(b) Inhalation of resuspended DU

In the Reference Case it is assumed that 10 kg DU is spread over 1,000 m^2, i.e. 10 g/m^2. Through wind action, walking about in the area, or digging etc., dust from the ground may become airborne and be inhaled. All DU is assumed to be present in the form of small particles (<10 µm) and to be in the form of insoluble oxides (Type S), which are cleared from the lungs only slowly.

DU is mixed with soil on the ground and – for the purpose of assessment – it is assumed that a soil layer 1 mm thick includes all the DU contamination, all of which will become airborne dust. With the assumption of 10 kg DU spread over 1,000 m^2, the top 1 mm of soil in this area contains 1 m^3 of soil, weighing 1,500 kg. The DU concentration in the dust will therefore be 6 µg DU per 1 mg dust.

Normal dust concentration in outdoor air is 50 µg/m^3 and under very dusty conditions may reach 5 mg/m^3, which would result in DU concentrations of 0.3 µg/m^3 and 30 mg/m^3 of DU respectively. From a toxicological point of view, these levels are lower than, or within, the range of given hygiene standards for chronic exposure.

A two-hour stay in a dusty area, such as a field being ploughed, with a respiration rate of 1 m^3 per hour, would lead to an intake of 60 µg of DU, corresponding to an effective dose of 7 µSv.

Even a continuous stay night and day for a year, and under the most dusty conditions, would not lead to a dose of more than a few tens of mSv. Normal dust conditions would result in a dose 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 to a depth of 10 cm instead of 1 mm, the consequences (radiation doses) would be 100 times less with the same area of deposition (10 kg over 1,000 m^2) – i.e. a few µSv per year, which is 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 µSv. Acute heavy-metal toxic effects from uranium might occur with amounts about ten times higher than this.

The same conclusions can be drawn in the case of a contamination point 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 layer of soil only 1 mm thick. If it is found to be thicker the corresponding doses are proportionally smaller.
2. In the case of a contamination point, the conservatism is in the assumption that someone (a child) digs soil out of the hole and eats it (a low probability).

(d) Contaminated hands
Hands can be contaminated by touching contaminated objects, clothes etc., and then ingesting the contamination during meals etc. However, as in the case of contamination from a penetrator, see (a) above, the intake is more dependent on poor hygiene than intentional ingestion, which more or less was the case in row (e) of Table A.1 above. Therefore, the amount is assumed to be 10–100 times less than in row (e) of Table A.1 and correspondingly the doses 10–100 times less; i.e. less than 1 µSv, with 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 groundwater that serves a well nearby, or a larger drinking water reservoir. An estimation of the short- and long-term levels of DU contamination of water caused by initial ground-surface contamination and by buried penetrators needs more data concerning the specific situation in Serbia and Montenegro than is at present available. The information required concerns the geochemical and geohydrological properties of the ground that are relevant

for estimating the rate of oxidation, solubility and transport to ground water or drinking water, of uranium. Some data and discussion of uranium behaviour in natural environments is provided in Appendix D ‘Military use of DU’and Appendix G ‘DU in Soil’.

It is therefore necessary to make more robust calculations – that are conservative in nature – in order to minimise the possibility of underestimating possible short- and long-term health problems. At the same time, the calculations should not be unrealistic in order to avoid raising unjustified concerns and/or recommending unjustified mitigation measures.

With regard to short- and long-term perspectives, there are different conditions concerning the radioactivity of DU. At present, there is only one radionuclide of any significance from the point of view of radiation dose, namely U-238. In the long term (assumed to be 1,000 years), other radionuclides might be added because of the build up of activity. These other radionuclides may also have higher radiotoxicity, i.e. a higher dose per unit of intake (Sv/Bq). Table A.3 shows in Column 1 the radionuclide (only alpha radiation emitters are considered); Column 2 the activity (Bq/mg uranium) in relation to U-238 (the activity of which is 12.4 Bq/mg uranium); and Column 3 the dose factor (Sv/Bq) in relation to U-238 (the dose factor of which is 4.5 10^{-5} Sv/Bq ingested, for adults). As can be seen from Table A.3 Column 4, even after 1,000 years the relative contribution of radionuclides other than uranium isotopes is negligible.

Table A.3 The relative activity and dose factor for alpha radiation emitting uranium daughter products at present and after a period of 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

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 through which the water is passing. A number of measurements of uranium in drinking water and in soil were made in Serbia and Montenegro. The arithmetic mean of U-238 in water is 40 10^{-5} mg/l and in soil 3.34 mg/kg. Therefore, the relation between concentration of uranium in water and soil is about 10^{-4} by weight.

In the Reference Case it is assumed that 10 kg of DU is spread over 1,000 m^2. Assuming 3 m depth to the water table, the total volume of soil that might be contaminated by dissolved DU will be 3,000 m^3, which is about 5,000 tons. In this amount of soil the natural uranium content will be 17 kg, corresponding to the measured water uranium concentration of 40 10^{-5} mg/l water. 10 kg DU over this area would mean an increase of about 50 % and a corresponding increase of uranium in drinking water.

An uncertainty here is the solubility of DU in comparison with natural uranium. If it is more soluble, the uranium concentration in water will increase by more than 50 %.

The number of penetrators fired at any one site in Serbia or Montenegro was about 1,400 at most. If this number of penetrators were hidden in the ground over an area of 1,000 m^2 , the increase of uranium would be 420 kg. That would mean a substantial increase of the uranium concentration in the ground, by a factor of 25. A much higher solubility of DU than for natural uranium would make the DU concentration in drinking water even higher and would clearly exceed the WHO guidelines for uranium in water (0.002 mg/l) by more than a factor of five. The resulting radiation dose would still be insignificant.

The conservatism in the assumptions is an area of 1,000 m^2 in the case of 1,400 penetrators fired. It is not unreasonable to assume that in such exceptional circumstances the target area would be at least ten times larger, which would make all values calculated ten times less (assuming there is a simple correlation between concentration in soil and water). Another element of conservatism is the assumption that the size of the uptake area for water is limited to the soil volume immediately below the affected ground surface. The true uptake area is likely to be much larger, therefore making concentrations even 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.

Through rainfall, DU deposited on the ground may be transferred downwards, eventually reaching the groundwater that serves a nearby well. The soil depth between the groundwater table and the surface of the bedrock is assumed to be 3 m, the contaminated area 1,000 m^2, the total amount of DU 10 kg, the leakage of DU 10 % per year of the total amount of DU deposited, the water content of the ground 30 %, and the outtake from the well 40 m^3 per year.

The available water volume for dilution of the leakage of DU is accordingly 900 m^3 and the concentration will be 1 g DU/m^3. During one year, the rainfall is approximately 0.5 m leading to a total of 500 m^3 over the area of interest, which means there is a more or less complete renewal of the water column. The concentration of DU in the well will therefore not increase with time.

A concentration of 1g DU/m^3 water (1 mg per litre of water) is considerably 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 are proportionally greater.

The conservatism is probably the leakage rate of 10 % per year, and the assumed water dilution. Other calculations might give a DU concentration in water that is ten times less. Even so, the resulting concentration may be higher than the WHO guideline for drinking water.

An alternative means of assessment is given in Appendix H ‘DU in water’and Appendix 5 in the Kosovo report.

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 with these, the normal values of uranium in drinking water in Serbia and Montenegro are low (at the places visited).

Conclusion: if the amount of DU dispersed over an area of approximately 1,000 m^2 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, contamination in the area is much higher than the Reference Case or the number of penetrators is much higher than 30 (e.g. more than 100) over an area of 1,000m^2, there should be special consideration of the possibility of future DU contamination of drinking water in adjacent wells.

(f) Contaminated food
More than two years after ground contamination by DU, there may still be an intake of DU (although very small) through ingestion of contaminated food assuming there is some cultivation there. This may be from vegetables, fruit etc. which are contaminated indirectly by root uptake of DU, or from milk and meat from animals that have eaten contaminated plants and soil. These long-term consequences can be assessed in comparison with natural levels of U-238.

With regard to the contamination of plants (and then meat) by root uptake, the following relationship can be used (UNSCEAR 2000):

35 Bq/kg soil of U-238 leads to a total intake from food and water of 5.7 Bq of U-238 per year, resulting 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 the 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 m^2 and distributed in a soil layer 10 cm deep (which seems to be a reasonable assumption from the measurements in Kosovo (no similar measurements were made in Serbia and Montenegro)) is assumed to be available to plant roots. This corresponds to a concentration of 70 mg DU/kg soil (870 Bq/kg) if the density of soil is 1,500 kg/m^3 and will result in an effective dose by ingestion of 7 µSv 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} to 10^{-3}. The low resulting dose caused by ingestion (about 10 µSv/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 Serbia and Montenegro, the DU ground contamination is as in the Reference Case (10 kg DU/1,000 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 a soil layer only 0.5 cm deep, 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 1g 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 µSv per day from such meat or milk consumed.

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 contamination is still close to the surface.

Conclusion: if the ground contamination is at the level of the Reference Case and distributed to a depth of at least 10 cm, there is no problem from either chemical or radiological viewpoints. In the case of contamination still close to the surface and of the same order of magnitude, some mitigation measures might be discussed. If the contamination level is less than 10 % of the Reference Case there is no problem whatsoever.

(g) External radiation
The same deposition is assumed, i.e. 70 mg DU/kg soil over 1,000 m^2. Natural uranium (3 mg/kg soil) in the level of equilibrium that it exists in soil, gives 17 nGy per hour or an effective dose of 0.02 mSv per year (corrected for indoor occupancy 0.8 and conversion factor Sv/Gy of 0.7). The gamma radiation from DU is only 0.8 % of that of natural uranium. Therefore, the resulting dose from 10 kg DU over an area of 1,000 m^2 would be 0.02/3x70x0.008 mSv per year = 4 µSv per year.

In Appendix L 'Theoretical assessments of external radiation from DU' there is an assessment of possible external radiation using a computer code RESRAD-6. The underlying assumptions are somewhat different from the assessment above and taking that into account the results are consistent.

Conclusion: if the ground contamination by DU is the same as in the Reference Case, or even 10 times or more higher, the 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 in terms of individual doses will decrease proportionally.

A.6 The Reference Case and corresponding measurement values

■ 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), i.e. 10 kg DU dispersed over an area of 1,000 m^2. By calibration, the following relations apply (measurements carried out using the 'Inspector' instrument; see Appendix C 'Methodology and quality control').

(a) Sensitivity of detection

No absorption
10 kg DU/1,000 m^2 = 10 g/m^2 = 100 mg/dm^2 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 ten and will probably not underestimate the surface contamination. This means that in the Reference Case 10 kg/1,000 m^2 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. 1 cps.

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

1 % of the Reference Case or 100 mg DU/m^2 = 1,240 Bq/m^2 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/m^2 = 12.4 kBq/m^2 corresponding to 1 cps (nett).

The activity distributed in a 10 cm deep soil layer.
The Reference Case means surface contamination of 10 kg DU/1,000 m^2 or 100 mg DU/dm^2. If the activity is evenly distributed to a depth of 10 cm 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 corresponds to about 150 mg/cm^2 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/dm^2 = 12.4 Bq/dm^2 = 1240 Bq/m^2 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 soil layer 10 cm deep, not less than a factor of two to five times the activity of the Reference Case can be detected, i.e. not less than 20 - 50 kg DU/1,000 m^2 or 20 - 50 g DU/m^2 or 200 - 500 mg DU/dm^2 can be detected.

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

■ Soil sample measurement sensitivities

The overall sensitivity for detection of DU in a soil sample is dependent on the uncertainties of the laboratory analyses and measurements, and on the uncertainties of the natural background 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 O 'Formulas and data') the samples containing DU can be identified. If the limit of detection 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 m^2. Assuming the activity is distributed to a depth of 10 cm 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/m^2.

Conclusion: In laboratory measurements the limit of detection is 0.01 of the Reference Case or 0.1 g DU/m^2.

A.7 Summary

The results of the risk assessments are summarised in table A.4
Explanations:

Rad = radiological aspects
Chem = chemical toxicity aspects
>30 = > 30 penetrators

→S = may approach a significant level of exposure when number of penetrators increases or the potential exposures increase by other reasons
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/1,000 m^2 = 10 g DU/m^2

Table A.4 The risks from different sources and means of exposure

Means of exposure ➔	**Inhalation**	**Soil in mouth**	**Contaminated hands**	**Contaminated water**	**Contaminated food**	**External radiation**
Source of exposure 🡻	**Rad Chem**	**Rad Chem**	**Rad Chem**	**Rad Chem**	**Rad Chem**	**Rad Chem**
Penetrators etc. (>30) Heavily corroded	Na Na Ins →S	Na Na Na Na	Ins S Ins→S S	Ins →S Ins →S	Na Na 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 cont. ≥RC On surface In 10cm layer	Ins Ins Ins Ins	Ins S Ins Ins	Ins S Ins Ins	Ins/S S Ins/S S	Na Na Ins Ins	Ins Na Ins Na
Ground surface cont.= 0.1 RC On surface In 10 cm layer	Ins Ins Ins Ins	Ins S Ins Ins	Ins Ins Ins Ins	Ins S Ins S	Na Na Ins Ins	Ins Na Ins 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 Na Ins Ins	Ins Na Ins Na

On surface = the contamination is superficial in the upper mm of the ground surface
In 10 cm layer = the contamination is distributed in the upper 10 cm of the 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 the case of ‘insignificant’ (Ins) levels there is no reason whatsoever to be concerned.

APPENDIX B

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PREREQUISITES AND LIMITATIONS

B.1 The objectives

The objectives of the mission (see Chapter 3.1) defined the minimum requirements of the work to be done. Some of the corresponding tasks were performed during the field visit to Serbia and Montenegro, 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, certain tasks were automatically excluded. The consequences of this can be summarised as follows:

Not all places were visited

NATO air attacks during which DU ammunition was used are known from ten locations in Serbia (all in the Presevo valley), and one in Montenegro. Five of the sites in Serbia and the one in Montenegro were investigated by the UNEP team. All of the sites had earlier been investigated by the authorities of the Federal Republic of Yugoslavia (FRY) and the site in Montenegro had also been studied by the Montenegrin authorities. During these investigations the sites had been surveyed for DU contamination and any penetrators, penetrator fragments and jackets found had been removed. At Cape Arza in Montenegro, contaminated soil had also been collected and removed. The sites had also been cleared of unexploded ordnance and mines. The sites investigated in Serbia represent more than 50 % of the attacked sites and are assumed to be representative. If the results of the mission had varied significantly it would have been very difficult to make any truly representative conclusions. On the other hand, where the results from each site were broadly similar, particularly those related to possible environmental contamination, general conclusions could be drawn. The criteria for site selection applied by the UNEP team are further described in Chapter 3.3.

No activity measurements of food

The only reliable and scientifically correct way to make general conclusions on this issue would be to collect and measure representative 'food baskets' from markets. However, with the exception of one of the sites, Bukurevac, the investigated sites are pastureland and not used for arable agriculture. From earlier assessments it is concluded that it is very unlikely that contamination of food would be a problem or concern. It would be easy, however, to undertake such collection and measurement in the future in order to confirm this conclusion.

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 about the health implications of DU exposure will persist, irrespective of statements to the contrary. However, such issues were 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 undertake any health studies on the basis of the limited knowledge concerning extent of exposure, and locations of individuals exposed during the military conflict. The question of health studies has been taken up by the WHO in the report *Depleted Uranium – Sources, exposure and health effects* (WHO, 2001).

B.2 Possible consequences of a two-year delay

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 the people involved.
- The collected DU should be stored in safe conditions under the responsibility of a designated authority.
- At contaminated sites signs should be posted to forbid public access.
- Access by grazing animals should be curtailed using fences.
- Local authorities and people concerned should be informed about the results.
- A programme of measurements, countermeasures and waste disposal should be developed.

The FRY and Montenegrin authorities had followed these recommendations. They had searched the areas, removed the DU encountered and fenced the most contaminated parts of the sites.

In conclusion, if there had been any risk of significant exposure to DU (such as through picking up penetrators, internal contamination via ingestion of loose DU or DU dust, or via contaminated animals) these risks occurred before the FRY and Montenegrin authorities took the countermeasures described above. Since the completion of countermeasures, these risks have been considerably reduced.

The consequence of changed conditions for the mission

During the period of two years between the military conflict and the UNEP mission, the conditions for finding DU had changed. 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 and/or dust. The consequence is that if covered by several cm (e.g. > 10 cm) of soil, the solid DU cannot be detected by field 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 objects.

The ground surface contaminated by DU dust is covered by soil, grass and/or dust. The consequence is that contaminated ground surface covered by some mm of soil will not be detectable by beta radiation field measurements.

DU dust originally dispersed over a given 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 the DU has been moved by rain or melting snow, it will have dispersed into the ground and, from experience, it is expected that two years after the original deposition of the DU, it will be in the upper 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 by adjacent soil. In this case the mission should find it.

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

B.3 Sources of information

Information was needed for all the various phases of the mission. Information concerning the choice of sites to be investigated, that were independently chosen by the UNEP team, was based on information provided by FRY military personnel based on their own observations during and after the attacks and on measurements they had subsequently carried out. NATO also provided positions of the attacks (see Appendix N ‘List of NATO Coordinates’).

During field investigations at the six sites visited, the exact locations of soil and water samples were determined using the experience of the UNEP team itself, in conjunction with the accompanying FRY personnel.

B.4 Safety limitations and their consequences

In ensuring the safety of the team, the main concern was the risk of unexploded ordnance that might not have been detected during the clearance of the sites investigated and adjacent areas. Therefore, military specialists examined the sites before the team members entered. Sometimes the risks of unexploded ordnance limited the extent of investigations.

APPENDIX C

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METHODOLOGY AND QUALITY CONTROL

C.1 Strategies

During the planning stage of the mission decisions were made on which sites to visit and on how to organise the work for optimal results. Selection of specific study areas and central matters of interest within each site were made by the UNEP team upon arrival in the field.

UNEP's strategy for **site selection** was based largely on information from NATO concerning the strike coordinates and target type for locations where DU ordnance was fired. One site, Pljackovica did not appear in the NATO list but was selected because the FRY authorities had found DU penetrators in the area. For further information concerning site selection, see Chapter 3.3.

When the team arrived at each site the **choice of specific study areas** was based on the following considerations:

(a) Advice from FRY army officers as to which areas had been made safe.
(b) Presence of marks on the ground made by penetrators and/or cluster bombs.
(c) Probable direction of the air strike.
(d) Locations of destroyed vehicles and gun emplacements.
(e) Locations of jackets and penetrators found previously by FRY and Montenegrin personnel.
(f) Drinking water sources and other nearby surface waters.
(g) Adjacent settlements and buildings.
(h) Information from local people about areas of probable interest (based on their own observations during the military conflict).
(i) Other points of particular interest from a scientific point of view.

The **central matters of interest** at each individual site were chosen on the principle that the mission would concentrate on those matters for which it was realistic to expect evidence to be available, and which it was realistically possible for the mission to investigate. In line with this approach, certain matters of interest had to be excluded; for example, deeply buried penetrators could not be investigated due to the impossibility of undertaking major excavations. The main issues examined were:

(a) Widespread contamination.
(b) Penetrators covered only by grass or by a thin layer of soil/sand/mud.
(c) Penetrators buried somewhat deeper in the ground.
(d) Jackets.
(e) Contamination points (contaminated penetrator holes, impact marks etc.).
(f) Penetrators on the surface.
(g) Dispersion of DU in the ground.
(h) DU contamination of water.
(i) DU contamination of air.
(j) DU contamination of buildings, vehicles etc.

The fieldwork in Serbia was mainly focused on investigations of the areas that the FRY authorities had previously searched and fenced off. Little time was allocated to studies outside these areas. The specific areas investigated at each site are marked on the site maps contained in Chapter 7 'Site-by-site Findings'.

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

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

C.2 Methods and survey techniques

C.2.1 General overview

In choosing methods and techniques a major requirement is that they are suited to meet the objectives and strategies decided upon. They also have to match the prerequisites and limitations of the mission. Furthermore, instruments set the boundaries of the techniques that can be used; i.e. it is not possible to do more than the capacities (quantitatively and qualitatively) that 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 irregular or broken ground in the same way as a flat field, village, or garden etc. Different techniques have to be applied.

(b) *Surface conditions* – in soft ground, uranium dust may have dispersed into the ground; a penetrator that has missed the target could easily have penetrated deep into the ground; there may be grass and other vegetation shielding the beta 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, methods and techniques have to be adjusted accordingly.

(c) *Probability of finding DU at a given location* – if it is known with relative certainty that DU has been used in a given area, then the field survey is conducted 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 locations examined were those declared as safe, meaning that the area had been searched for unexploded ordnance and mines and that there was only a low probability of any remaining. Nevertheless, in some cases, the risk of unexploded ordnance excluded deep digging for penetrators at points where increased gamma radiation indicated they might be present.

C.2.2 Fieldwork

During the fieldwork, the UNEP team was accompanied by personnel form the Vinca Institute of Nuclear Sciences, FRY Nuclear, Biological and Chemical (NBC) warfare officers and other FRY authorities, and in Montenegro, by personnel from the Montenegrin Ministry of Environmental Protection and Physical Planning and the PI Centre for Ecotoxicological Research of Montenegro. Once at the site to be investigated a short examination of the area was made. After a briefing by the team leader, security adviser, scientific leader, technical leader and FRY NBC officer, the choice of areas to be investigated and methods to be used was made. Generally, the Swiss team members then began soil sampling and the Italian team members started collection of botanical and water samples. With the assistance of Vinèa scientists, the three air filter pumps were positioned by the Greek team member. The other team members, with the participation of Yugoslavian colleagues, undertook survey measurements using the different techniques described in sections C.2.3 and C.2.4 of this Appendix. The technical leader had the responsibility of mapping the site area, based on positions obtained by a Global Positioning System receiver. The accuracy of these positions was usually better than ± 10 m.

C.2.3 Measurements in the field

■ Methods

For the radiometric measurements during surveys of DU the following methods are applicable:

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 the intensity of which increases with the radiation intensity; is insensitive to the direction of radiation; is insensitive to rain, humidity and temperature (down to –20º Celsius); and is robust but light.

Gamma spectrometric differential measurements using solid-state detectors are more sensitive but much more expensive, difficult and laborious, particularly if the instruments need cooling with liquid nitrogen. In the case of field measurements they can only be considered as complementary equipment for special measurements. However, if the background of natural radioactive elements (uranium, radium, thorium or potassium) is enhanced, gamma ray spectrometric measurements are needed to distinguish between gamma radiation emitted from DU and that from naturally occurring radioactive elements. The same applies when the area to be surveyed has been subject to fallout of radioactive nuclides, e.g. cesium-137 from the Chernobyl accident.

The unit of measurement is not critical but units of cps and µSv (or µGy) per hour are preferable. The instrument should meet the ordinary ISO standards, be 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 Bq/cm^2).

Beta and gamma measurements on soil sample from penetrator hole at Pljackovica

b) *Beta radiation*. The instruments for field measurements of beta radiation are normally of GM (Geiger-Müller) 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 (≤ the window of the beta instrument).

The purpose of using a beta instrument is to discover surface contamination, contamination points and penetrators, providing that none is covered by more 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.

When necessary, it must be possible to easily shield the window in order to measure gamma radiation only. For example, this might be needed for determining whether the measured activity is superficial or at some depth. It must be realised that without a shield the instrument measures both beta and gamma radiation.

The instrument should be light but robust, give a quick response to beta radiation, give a sound signal which increases in intensity in line with radiation intensity, and should be insensitive to rain, humidity and temperature.

The unit of measurement should be cps (µSv/h or µR/h 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 or point sources).

The instrument, particularly the thin window foil, has to be protected against dirt and DU 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 radiatio*n. Even though DU emits alpha radiation, it is not practical to measure this radiation using field techniques. The reason is that alpha radiation is very easily stopped by a thin layer of dust, grass (or similar), and the range in air is only a few cm. The resulting measurements will therefore be very uncertain and cannot be used. Consequently, alpha measurements were not conducted.

C.2.4 Instruments and Equipment

■ 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 through the decay of uranium-238, the beta radiation through the decay of protactinium-234m and the gamma radiation through the decay of protactinium-234m and thorium-234 (see Appendix O ‘Formulas and Data’, Table O.8).

Because the emitted *gamma radiation* is rather weak, a significant increase above the natural background gamma radiation only occurs in the case of 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 cm from a penetrator lying on the ground (depending on the type of instrument used and the gamma-ray background at the location in question).

The *beta radiation* from DU is rather strong (about 50 % of the beta radiation emitted during 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 of the ground decreases rapidly with distance. Thus, in order to measure the emitted beta radiation the detector must be close to the object emitting the radiation.

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

■ Instruments used

During the mission to Serbia and Montenegro several different instruments were used. The mission was supplied with gamma meters and beta counters brought from Sweden. The Greek team member also brought instruments. A description of the instruments used follows.

From Sweden, 17 scintillometers of type *Saphymo-SRAT S.P.P.2 NF* were brought for the measurements of gamma radiation. For beta measurements, 10 *Geiger-Müller Inspector* instruments manufactured by Radiation Alert, were used. Each team member was equipped with a *SRAT* and each group of two members used one or two *Inspector*s.

The Swedish team also brought a gamma ray spectrometer of the type *Exploranium GR256* manufactured by Exploranium Ltd, Canada. The spectrometer was used for *in situ* determination of the natural concentrations of uranium, thorium and potassium-40 in the bedrock and soils at each investigated site. These measurements gave rapid information on the concentration of natural nuclides, which was useful as it indicated whether any enhanced gamma radiation detected was caused by natural radiation or contamination by DU. Another benefit of bringing a gamma-ray spectrometer to Serbia and Montenegro was that it enabled checking for any fallout contamination of cesium-137 following the Chernobyl accident. It would not otherwise have been possible in the field to know if any enhanced gamma radiation was due to DU or cesium-137.

The *Saphymo-SRAT S.P.P.2 NF* scintillometer is manufactured by Saphymo-PHY, Massy, France (Saphymo-SRAT 1969). It is designed for uranium exploration in rugged conditions. The detector is a 1 x 1.5 inch (15.2 cm^3) NaI(Tl) (sodium iodide activated with thallium) scintillation crystal. The operation range for gamma radiation is 0.02 to 30 microsieverts per hour (µSv/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 seconds. The unit of measurement used by the *SRAT* is cps (counts per second). The size of the instrument is 32 x 13 x 12 cm and the weight 3.6 kg.

The SRATs employed during the field mission were originally used in Swedish uranium exploration work and are now stored as part of preparedness for responding to possible nuclear accidents. They were selected for the mission because of their high sensitivity, 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 window is covered by a mica foil, which is protected against damage by a metal net. 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, with beta and alpha rays being unable to penetrate the lid. With the lid removed the *Inspector* measures gamma, beta and alpha radiation. Units of measurement are cpm, cps, mR/h or µSv/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* measures 15 x 80 x 30 mm and weighs 272 g.

The *Inspector* instrument was chosen for the field mission because of its high sensitivity to beta radiation, 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. As a result, long-handled grippers designed for picking up litter (and manufactured by Scan-Motor AS, Denmark) were used for holding the instrument. As the *Inspector* 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 or twigs and stopped the alpha rays.

The *Exploranium GR256* gamma-ray spectrometer has a detector with a 3 x 3 inch sodium-iodide NaI(Tl) scintillator crystal (Exploranium; 1989). It measures the gamma ray spectrum within the interval 0.1 – 3 MeV. The spectrum is divided into 256 channels.

For each measurement the spectrometer was placed directly on exposed bedrock or on the soil layer. The measuring time used was 400 seconds. The results of the measurements were given as total gamma radiation in µR/h, ppm uranium (eU), ppm thorium and % potassium. As there is usually a disequilibrium between uranium-238 and radium-226 in weathered rock and in soils, and as the radium-226 concentration is determined by measurement of the gamma emission of bismut-214 at the 1.76 MeV peak, the results obtained do not represent the true uranium concentration (IAEA 1979). Therefore, the result is given as equivalent uranium concentration (eU), comparing the measurements obtained to a situation when there is equilibrium between uranium-228 and radium-226. The spectrometer, as set for the mission, is not affected by DU, as there is no radium-226 in DU.

The following instruments were brought from Greece: a scintillometer of type *Victoreen 190* and a beta survey meter of the type *Contamat FHT 111M* manufactured by ESM.

The *Victoreen* 190 survey meter was connected with an external sodium iodide NaI(Tl) gamma scintillation probe. The dimensions of the NaI crystal are 2 x 2 inches. The active area is 20cm^2. It is capable of measuring gamma rays with energies higher than 60 keV.

The *Contamat FHT 111M* is a permanently filled xenon counter tube for beta/gamma measurements. It has a titanium foil window with an area of 166 cm^2 and a thickness of 4.5 mg/cm^2. The response of the detector (net count rate/activity) for a Sr-90 source deposited over an area of 100 cm^2 is 0.34 cps/Bq.

The accompanying Yugoslavian and Montenegrin scientists and the FRY army personnel used GM instruments constructed at Vinèa (Vukotich et al., 2001). Occasional comparisons between these instruments and those brought by the UNEP team showed good agreement of results.

■ Calibration

Before the instruments were transported to Serbia 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 $(^{90}Sr + ^{90}Y)$ source with a source strength of 432.6 Bq. The response to DU in an area contaminated by 1 mg DU per cm^2 is approximately 120 cps ± 24 cps, when measured 1 cm above the surface. Thus, 1 cps corresponds roughly to ground surface contamination of 0.01 mg DU per cm^2 or 0.1 g per m^2. 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 1 cm above the surface. For beta radiation, the shielding effect of a plastic freezer bag around the *Inspector* instrument meant a reduction of 5 %.

Calibration of the *Exploranium GR256* gamma spectrometer was made on the calibration pads for calibration of airborne gamma-ray spectrometers at Borlänge airport, Sweden. Upon calibration, the instrument was adjusted to withdraw the background caused by cosmic radiation at sea level.

■ Techniques for surveying of the sites

The objectives of the field measurements were to indicate and identify surface contamination, penetrators, and jackets. For such a purpose, measurements can be more quantitative than qualitative and exact calibration is not necessary. Another objective was to compare the field measurements with the results of laboratory sample analyses. This was particularly the case when the sample was composed of superficial soil contamination. In this case the measurement is more qualitative.

Starting "Line-up survey" at Borovac

During the UNEP team's investigations in Serbia and Montenegro four different field survey techniques were used:

A. This method, referred to in the report as 'line-up survey, method A', means that the members of the team (most often 4-6 people) were lined up with 1-2 metres between each person. The group then walked slowly forwards, maintaining their alignment with one another, while sweeping the instruments at ground level left and right perpendicular to the walking direction in such a way that approximately all the area was measured. The walking speed was 7 ± 2 metres per minute depending on the terrain.

B. This method, referred to in the report as 'qualified at random survey, method B', involved sending out the team members to search for radioactivity in the environment after a briefing on what to expect, how to conduct the survey and where to search. This method is possible if the team members are highly qualified and experienced.

C. This method, referred to in the report as 'careful measurements, method C', was often used to complement the measurements derived from method A. It consisted of measurements made with the *Inspector* beta/gamma instrument, involving more careful removal of any covering of dust, grass etc., and measuring over a longer time period, to detect any possible shielded beta radiation from widespread contamination. These measurements were performed behind the line-up survey every ten metres.

D. This method, referred to in the report as 'individual survey, method D', meant that single individuals or groups of two individuals together conducted surveys by sweeping, as per method A, in predetermined directions and areas. This method was used in very special circumstances when very little was known about the precise areas of a given site within which DU had been used.

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

The team found the *SRAT* and *Inspector* instruments to be well suited for the work carried out. The robust construction of the instruments made them easy to handle in the field without any special precautions.

The *SRAT's* very low time constant and the loud audible signal made it possible to walk quite quickly over the study areas but to maintain good control over the slightest changes in radioactivity. In the search for radioactive objects high sensitivity is preferred over measurement accuracy. One disadvantage of the instrument is that it is rather heavy. Not a single instrument failed during the mission.

The *Inspector* instrument proved to be quite good. It is light, has a fairly good alarm signal and is easy to handle, even for an inexperienced user. The plastic freezer bag protected the window foil well. Only one GM-detector was punctured. There were no rainy days during the mission, so no comment can be made concerning reliability of the *Inspector* in wet conditions.

■ Concluding remarks on Instruments

The opinion of the team members is that in a search for DU penetrators and DU-dust contamination there is a need for 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 hash 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 3 x 3 inches, 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 μSv/h, at 10 cm distance from the penetrator 0.8 μSv/h, at 20 cm 0.3 μSv/h, and at 30 cm 0.15 μSv/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, when searching for DU penetrators and fragments it is necessary to carry out the measurements in a very detailed manner so that no DU objects are missed. Penetrators and pieces of DU that are covered by more than 10 cm of soil or water are almost impossible to detect through their gamma radiation. If covered by more than 20 cm of soil they are impossible to detect (see also Appendix L 'Theoretical Assessments of External Radiation from DU').

The background gamma and beta radiation at Cape Arza (limestone), Bukurevac (silt) and Borovac (silty-sandy soil on gneiss) was very low. The gamma radiation in these areas was 0.04–0.08 μSv/h, which includes the contribution from cosmic radiation. On the other hand, the background at Pljackovica (gneiss), Reljan (gneiss) and Bratoselce (gneiss) was somewhat enhanced compared to the other sites, due mainly to higher concentrations of thorium in the rock. The gamma radiation in these areas was 0.10–0.18 μSv/h. Low natural radioactivity gives increased possibilities of detecting and finding penetrators and contamination by DU, whereas, for instance, the relatively high natural background at Bratoselce at first gave the impression that the area was contaminated by DU.

■ Other Equipment

The team also took protective equipment, tools for sampling, plastic freezer bags and bottles for samples, as well as graph paper and 50 m measuring tapes for site mapping, and rolls of red plastic tape for marking contaminated areas.

For the personal use of each team member, UNEP supplied blue overalls designed to protect personal clothing. Each team member was also provided with a pair of disposable white, whole-body, non-woven overalls, rubber gloves, and a warm UN Jacket. In case the team needed to investigate a vehicle that had been hit by DU ordnance, one set of whole-body rubber overalls was included. The equipment also included disposable latex examination gloves, half masks with special filters suitable for preventing inhalation of DU dust, and simpler dust respirator masks.

The use of rubber boots made 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.

Straight away, on beginning investigations at the first site visited (Pljackovica) the measurements of gamma and beta radiation showed that there was no measurable DU contamination on the ground, except at restricted contamination 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. The situation was found to be the same at the other sites visited.

The team never had to use the half masks or the rubber overalls.

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

C.3 Sampling in the field

C.3.1 Sampling in the field (Spiez)

■ Methods

At the sites investigated samples of soil, water, lichen, bark, air – and in one case smear samples – were taken. The collection of the samples, followed by analysis in the laboratories was organised as follows:

- The Swiss team was responsible for the collection and analysis of the soil samples and samples of special interest, e.g. penetrators, fragments, smear samples.
- The Italian team was responsible for the botanical and water samples and analysis of the air samples.
- The Greek Team member, in cooperation with scientists from the Vinèa Institute, was responsible for the air sampling.

Soil samples (Burger, 2002)

Soil samples were taken at each site visited, whether or not there were indications of DU ammunition having been used. If possible, the location of the centre and dimensions of the attacked target site were defined first by measurements of the gamma and beta radiation.

Detailed pictures were taken of all sites.

The following rules were observed during sampling:

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

The following procedure was used during the soil sampling. Topsoil (layer 0-5 cm) core samples were taken using a bulb sticker. Usually, 10 or 12 samples were taken from a defined area (normally 5 x 5 m). The core samples from an area were pooled in a double plastic bag. The numbering on the bag was determined according to Spiez Laboratory procedures based on ISO/IEC 17025. In addition, a sample form (NATO AEP 49 Volume 2, Environmental Sample) for each pooled sample was completed immediately, at the time of sampling. The typical weight of such pooled soil samples was about 2 kg.

A) Sites with no indication of the use of DU ammunition (e.g. Bukurevac)

Areas of 5 x 5 m (i.e. 25 m^2) were defined. Some of these were within the expected zone of attack and most symmetrically around the expected target site, up to a distance of several hundred metres away, to make sure that it would be possible to detect the presence and areal extent of any DU contamination.

Within these sampling areas of 5 x 5 m, a total number of 10 cores, primarily of topsoil (layer 0 – 5 cm), were taken at random.

B1) Sites with indication of the use of DU ammunition

Having defined the centre of the attacked target, 12 cores of topsoil (layer 0 – 5 cm) were taken along the edges of concentric rings with radius 1, 5, 10, 20, 50, 100 and 200 metres from the central point.

B2) Situations where sampling from concentric rings was not possible

10 to 15 sampling areas of 5 x 5 m (i.e. 25 m^2) were defined. Some of them within the attacked target and most symmetrically around the expected target site, up to a distance of several hundred metres away, to make sure that it would be possible to detect the presence and areal extent of any DU contamination.

Within these sampling areas of 5 x 5 m, a total number of 10 cores, primarily of topsoil (layer 0 – 5 cm), were taken at random.

B3) Samples of special interest

Samples of special interest were, for e.g., shot holes (holes clearly indicating that a DU penetrator had hit the ground – in some cases with the penetrator still visible). The soil sample was taken directly from the hole by using a small shovel or the bulb sticker. The surface dimension and sampling depth were adapted to the specific conditions of each location. Samples were not pooled. They were described in detail.

By using procedure B2, single samples of special interest had already been taken within the main sampling procedure B1 (rings).

Penetrators and jackets were collected carefully and methodically, and at least triple packed to make sure that contamination from/of any other sample could be excluded. All relevant information was written down in detail.

Smear samples were taken dry from surface areas of 20 x 20 cm using smear sampling kits.

C.3.2 Sampling in the field (ANPA)

■ *Methods*

Botanical samples (Sansone et al., 2002)

Samples of tree bark and lichens growing on trees were collected at each of the investigated sites in order to search for the presence of DU dust particles. Considering that such particles can be dispersed in the environment according to wind direction, and can be deposited on trees/bushes and soil, the presence of DU in lichens, mosses and tree/bushes bark is mainly attributable to:

- direct deposition of DU dust particles during the attack;
- deposition of suspended materials in air (originating from resuspension of soil and deposited DU dust particles).

Lichen sampling was carried out according to the methodology followed in the University of Rome for trace metal monitoring (Brezzi, 1999-2000). This methodology identifies the following criteria in order to select the lichens to be sampled:

- age of the tree (preferably a mature tree/bush should be chosen);
- dimension of the tree (species with a large trunk should be selected),
- inclination of tree/bush (trunks with an inclination of less than 10° should be selected);
- absence of bark damage;
- exposure of lichens on bark, in relation to wind direction and insolation.

At each location, thalli of foliose lichens, together with their substrates, were collected from trees and/or bushes using a scalpel. Due to the lack of information concerning the prevailing wind direction, lichen samples were collected at different expositions and heights along the trunks in order to make a composite sample representative of the different exposures. Bark samples were also collected in some sites in order to investigate the relationship between the uranium content of bark samples and of lichen samples.

Where available, lichen growing on rocks or soil and moss samples were also collected, in order to identify other environmental matrices that can accumulate uranium. After sampling, the botanical samples were air-dried and then stored in paper bags.

Water samples (Sansone et al., 2002)

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 the structure of the surrounding soil, rainfall and hydrology. In order to verify the presence of DU in drinking water, water samples from private wells and taps were collected. A sample of sea water was also collected in the Cape Arza site.

One litre of water was sampled in each location using a polyethylene bottle. Immediately after sampling, without any filtering of the water, the pH of all water samples was adjusted by adding HNO_3, in order to ensure that trace elements were kept in solution and to inhibit biological growth.

Air samples

Uranium nuclides are present in air as resuspended soil particles. The typical uranium concentrations are very low. Normally the concentration of uranium radionuclides in air is in the range of 0.02 to 18 ìBq/m^3 (UNSCEAR 2000). 1 ìBq/m^3 is considered as a reference value. To measure such low concentrations of radionuclides in air, sampling systems equipped with high flow rate air pumps have to be used. During the UNEP mission to Serbia and Montenegro three air filter systems of the type GMWL-2000 were used. These were provided by the Vinèa Institute of Nuclear Sciences, which also provided a portable electricity supply unit. The air filters are placed in a metal box, which shelters the pump and filter from direct precipitation. The installation and operation of these pumps in the field was carried out in close cooperation between the UNEP members involved and scientists from Vinèa. Polystyrene filters of the type Microsorban were used in the air filter systems. The filter size was 8 x 10 inches (i.e. 516 cm^2). The polystyrene filters were provided by the Swedish Defence Research Agency. The Microsorban uranium-238 concentration was 1.47 ng/g (18.3 µBq/kg) according to analysis carried out prior to the mission. The Microsorban filter has been tested for its efficacy in collecting airborne radionuclides (Suschny, 1968). It has good collection efficiency for micron particles in the range 0.05-10 microns, high particle and mass loading capacity, low flow resistance and high mechanical strength.

Two identical manometers were used to measure the airflow. The flow rate did not change significantly during the measurements. The indications during the measurements fluctuate between 6.4 and 7.0. These values, according to the calibration curve given by the manometers manufacturer, correspond to an airflow of 47 to 49 cubic feet per minute. If the mean value is used as a representative one (the error in such a case is not more than 3 %) then the airflow is 48 cubic feet per minute. This value corresponds to 1.36 m^3/min (40 cm^3/sec). The expected uncertainty of this value of air volume sampled is less than 3 %. The air velocity through the filter was about 40 cm/sec.

C.4 Laboratory methods

C.4.1 Samples and analyses: an Introduction

The UNEP team members visited six different sites and additionally investigated an Armoured Personnel Carrier that had been hit by a penetrator. Altogether, the team collected 122 samples. Of these, 54 were soil samples, 11 water samples, 17 air samples, 30 botanical samples (lichen, bark, moss and mushrooms), 4 smear samples, 3 penetrators and 3 samples of penetrator fragments and/or jackets. Some of the botanical samples were divided into sub-samples as they contained more than one species, so altogether 69 samples of bio-indicators were analysed. All samples were allocated unique code numbers.

Altogether, including the sub-samples, 161 samples were analysed in the laboratory. Complete lists of the samples, including type of sample, location collected and results of analyses are given in Appendices: E ‘Military vehicle (APC) at Vranje Garrison ’ G ‘DU in Soil’, H ‘DU in water’, I ‘DU in air’, J ‘Bioindicators of DU’ and K ‘Analysis of DU penetrators and fragments’.

The samples collected by the Swiss and Italian team members were taken back to the laboratories of Spiez Laboratory, Switzerland and the Italian National Environmental Protection Agency (ANPA) in Rome to be analysed in detail. Two soil samples, two lichen samples and one water sample were analysed at both Spiez and ANPA Laboratories as part of the Quality Control (see Appendix C.4.3).

The laboratories have, respectively, provided a report on sample preparation, the analytical methods used and the results of the analyses (ANPA, 2002; Burger, 2002). The following is a synthesis of these reports.

The analyses included 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 main objectives of the sampling in the field were:

- to determine the possibility of widespread ground contamination around or within the areas visited by the mission;
- to determine whether localised, highly contaminated areas or 'contamination points' are present and the level of depleted uranium activity concentrations;
- to determine the activity concentrations of uranium isotopes in groundwater;
- to study vegetation (lichens, mosses, etc.) as bio-indicators of DU;
- to assess the amount of uranium isotope activity that can easily be removed from a DU penetrator, the effect of weathering on the penetrator, and the dissolution in groundwater;
- to assess the possible presence of DU contamination on the wrecks of targeted vehicles.

C.4.2 Preparation of samples and analysis

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

■ **Spiez Laboratory samples** (from Burger, 2002)

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/Inter-comparison soil samples

The samples were dried at 40 °C in air re-circulating 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 TURBULA® mixer for 10 minutes. 50 g of the dried and mixed soil fractions were milled in a 250 ml 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 520 °C in high temperature furnaces for 16 hours (weight constancy) and mixed again in soil sample bottles in a TURBULA® mixer for 10 minutes. 5 g of the mixed soil ash were mixed well with 7 g of fluxing agent (Lithium metaborate / Lithium tetraborate 80 % / 20 %) in an agate mortar. The mixture was transferred in a platinum-gold crucible (Pt/Au; 95/5) and 250 µl of ^{209}Bi-solution (1000 ppm) were added as internal standard. After drying in a drying oven for 30 minutes at 70 °C, the samples were fusioned in a high temperature furnace for 20 minutes at 1100 °C. The melt was poured into a 250 ml beaker containing 200 g c (HNO_3) = 4.5 mol/L. 1 ml of polyethylene glycol (c(PEG-2000) = 0.2 mol/L) was added as flocculating agent to precipitate silica gel and boric acid. This mixture was heated to 40 °C with constant stirring for 3 hours. After cooling down, 3 ml of the upper layer solution were filtered <0.45

µm (Spartan 30/0.45 RC; Schleicher & Schüll). 1.4 ml of the filtrate were diluted with w(HNO_3) = 2 % to 40ml → Master solution.

- Smear samples

The Smear samples were leached in 50 ml c(HNO_3) = 8 mol/L for 5 hours at a temperature of 50 °C. During this leaching process, the samples were in addition held in an ultrasonic bath 4 times for 1 minute. The solutions were transferred to a 100 ml measuring flask. The beakers were washed 3 times with 15 ml c(HNO_3) = 8mol/L and then the measuring flask was filled up with distilled water. Aliquots of these solutions were further diluted for the analysis by ICP-MS.

- Lichen

1 g of the lichen as delivered by ANPA were ashed in a platinum-gold crucible at 520 °C in a high temperature furnace for 18 hours. To avoid sample burning, the furnace was heated up very slowly (4 hours) starting from room temperature to 520 °C. The lichen ashes were mixed well with 700 mg of fluxing agent (see above under *soil and reference soil samples*) in an agate mortar. The mixture was transferred back to the platinum-gold crucible (Pt/Au; 95/5) and 250 µl of ^{209}Bi-solution (1000 ppm) were added as the internal standard. After drying in a drying oven for 30 minutes at 70 °C, the samples were fusioned in a high temperature furnace for 20 minutes at 1100 °C. The melt was poured into a 250 ml beaker containing 200 g c(HNO_3) = 4.5 mol/L. 1 ml of polyethylene glycol (c(PEG-2000) = 0.2 mol/L) was added as flocculating agent to precipitate silica gel and boric acid. This mixture was heated to 40 °C with constant stirring for 3 hours. After cooling down, 3 ml of the upper layer solution were filtered <0.45 µm (Spartan 30/0.45 RC; Schleicher&Schüll). 1.4 ml of the filtrate were diluted with w(HNO_3) = 2 % to 40 ml → Master solution.

- Well water

The filtration of aliquots was done with Spartan 30/0.45 RC; Schleicher&Schüll: filters <0.45 µm. The filtrated water was diluted 1:10 with w(HNO_3) = 2 %. Aliquots of unfiltered water were diluted 1:10 with w(HNO_3) = 2 %. 50 ppb of ^{209}Bi were added as the internal standard for the ICP-MS measurements.

- Penetrators and fragments

In the laboratories penetrators were handled properly to avoid any contamination. The penetrators were weighed directly after unpacking. Then the samples were cleaned mechanically with a sharp knife to remove corrosion products and dirt. The material thus removed was stored separately. From the material removed from penetrator NUC-01-104-09, black and yellow residues were isolated and prepared. These preparations were analysed with EDX (X-ray fluorescence spectrometry) and XRD (X-ray difraction) and fragments were washed in distilled water for a few minutes using an ultrasonic bath. Surface corrosion (yellow/black) was washed off stepwise with diluted HNO_3 to a maximum concentration c(HNO_3) = 5-7.2 mol/L HNO_3 in an ultrasonic bath, followed by washing with water and ethanol. The samples were dried under an infrared lamp and then weighed. The penetrators were held for 30-60 minutes in 100 ml hot concentrated HNO_3 (14 mol/L) for partial digestion. The fragments were totally digested in 100 ml hot concentrated HNO_3 (14 mol/L). All solutions from penetrators and fragments were diluted with water to a final concentration of c(HNO_3) = 5-7 mol/L. The samples were dried under an infrared lamp and re-weighed.

- Plutonium and neptunium separation

Tracer was added to 5 ml of each solution containing 0.2 g of the penetrator or fragment and diluted with 45 ml c(HNO_3) = 5 mol/L. This solution was introduced into a TEVA-Spec® -column. Uranium was eluted with 50 ml c($HNO_{3)}$ = 5 mol/L and 8 ml c(HNO3) = 2 mol/L. The column was then washed with 20 ml c(HCl) = 6 mol/L. Plutonium was eluted with 30 ml c(HCl) = 0.5 mol/L. 250 µl of concentrated sulphuric acid were added to the plutonium fraction. The fraction was put in a sandbath and brought near to dryness. Any residual organic material was destroyed by heating with sulphuric acid to fuming temperature on a hotplate. Some drops of nitric acid were then added. Plutonium was electro-deposited from a sulphuric acid ammonium-sulphate system on a steel plate and determined with alpha spectrometry.

Chemical and isotopic analyses

ICP-MS analysis

All analyses were performed on a FINNIGAN Element 2 high resolution inductively coupled plasma mass spectrometer HR-ICP-MS instrument in the low-resolution mode. In this configuration the response for 1 ppb ^{238}U was 1,200,000 cps. All samples were measured by at least one independent duplicate analysis.

Quantitative determination of Uranium-238. The dissolved soil samples were diluted with 2 % nitric acid to a concentration of 0.01 mg soil per ml. A five-point calibration with U was performed in the expected U concentration range. All calibration and soil samples contained the same amount of ^{209}Bi as internal standard. Only the isotopes ^{238}U and ^{209}Bi were measured. The U calibration was verified with two independent U standards. In order to check the sensitivity and the calibration during the measurement procedure, a U standard was measured after every six samples.

Determination of the isotopic composition of uranium. The dissolved soil samples were diluted with 2 % nitric acid to a concentration of 1 ng/ml ^{238}U. The isotopes ^{232}Th, ^{234}U, ^{235}U, ^{236}U and ^{238}U were measured. The performance of the ICP-MS was checked with natural and certified U solutions. The mass discrimination was small and negligible. As the ^{232}Th and ^{238}U peaks were six orders of magnitude higher than the ^{234}U and ^{236}U peaks, an interference correction for these isotopes was made.

Table C.1 Detection limits

^{234}U	^{235}U	^{236}U	^{238}U	Isotope ratio
10 ng/kg	10 ng/kg	10 ng/kg	50 ng/kg	1/100'000

Determination of the percentage of DU of the total uranium concentration. The difference of the average weight of a U atom in natural and depleted U can be ignored. Hence, the mole fraction of DU of the total U is equal to the mass fraction of DU of the total U and can easily be calculated from the measured ratio $R_m = {}^{235}U/{}^{238}U$. The ratio $^{235}U/^{238}U$ for natural

$$DU[\%] = 100 \cdot \frac{R_{U-nat} - R_m}{R_{U-nat} - R_{DU}} = 100 \cdot \frac{0.00725 - R_m}{0.00525}$$

and depleted U is assumed to be $R_{U\text{-nat}}$ = 0.00725 and R_{DU} = 0.00200, respectively.
The ratio R_m = U-235/U-238 was corrected linearly for the mass discrimination of the ICP-MS. The mass discrimination factor was determined with natural U.

Statistical and measurement uncertainties at the ICP-MS analysis

The combined relative standard deviations (k-values) were calculated by propagation of errors from the relative standard deviations (rsd). The relative standard deviations of the variables were either experimentally determined or estimated.

The detection limits depend on the composition of the samples. For example, high thorium contents can slightly increase the detection limits of ^{234}U. The estimated detection limits for the soil samples investigated in this report are given in Table C.1. In the tables that give the results from Spiez analyses '[-]' means that the concentration is below the detection limit.

Alphaspectrometry

Alphaspectrometry (plutonium and neptunium analyses) was made by high-vacuum alpha chambers with 1 inch PIPS detectors.

■ **ANPA – Laboratory work** (Sansone et al., 2002)

Lichen species identification

Once in the laboratory lichen samples were subdivided according to species in the laboratory of the Vegetal Biology Department of Rome University 'La Sapienza' (Italy). Clauzade and Roux (1985), Purvis et al. (1992), Wirth (1995) were consulted during the identification of the different species. The nomenclature used is based mainly on Nimis (2000) and abbreviations are according to Brummitt and Powell (1992). Specimens are preserved in the Herbarium of the University of Rome 'La Sapienza' (Italy) and are available for any future consultation. The substrates were removed from thalli using a stainless steel scalpel and then crushed, ground with a ceramic pestle and mortar and homogenised.

Radiochemical analysis

^{238}U, ^{234}U and ^{235}U in all samples have been determined by alpha-spectrometry following total dissolution (Jia et al., 2001).

Sample preparation

Soil samples

0.5 g of soil sample, as delivered by Spiez Laboratory (Switzerland), and 2 g of Na_2O_2 is added in a platinum crucible containing 2 g sodium carbonate. The crucible with cover is heated at 600 °C for 15-20 minutes in a muffle. The melted sample is cooled to room temperature and transferred to a 100 ml teflon beaker by distilled water and HNO_3. 0.03 Bq of ^{232}U, 5 ml of concentrated HNO_3, 5 ml of HCl, 5 ml of 40 % HF and 1 ml of 30 % H_2O_2 is added, evaporation is carried out at 250 °C. Before dry, the sample is further attacked with 5 ml of HNO_3, 5 ml of HCl and 5 ml of 40 % HF in order to eliminate the majority of silicates. The residue is changed into nitric form by two time evaporations with 4 ml of concentrated HNO_3. The residue obtained is dissolved again with 5 ml of concentrated HNO_3 and 10 ml of distilled water and filtered through a 0.45 µm Millipore filter paper in a 150 ml beaker. The teflon beaker is washed with 10 ml 2M HNO_3 and filtered into the 150 ml beaker. Some concentrated ammonia solution is added to the beaker to adjust the solution pH to 9.5-10 to co-precipitate uranium with hydroxide which is then centrifuged (3,500 rpm) in a 100 ml glass tube.

After discarding the supernatant, the precipitate is dissolved with 3 ml of concentrated HNO_3, 12 ml of distilled water and 0.5 ml of 40 % HF by heating at about 100 °C and transferred to a 150 ml beaker. The centrifuge tube is washed with 15 ml of 2 M HNO_3 and transferred into the 150 ml beaker.

Botanical samples

Before preparation, the samples, dried at 105 °C, milled and homogenised, were screened by gross beta measurements using a low-level planchet counter with proportional gas flow counter tubes. This procedure has been selected to decide the order for processing and analysing the samples.

A ceramic crucible containing 2 g of botanical sample was put in a muffle at 600 °C for 14 hours. To avoid sample burning, the muffle was heated up very slowly (10 hours) starting from room temperature to 600 °C. After cooling to room temperature, 0.4 g of Na_2CO_3, 0.03 Bq of ^{232}U and 10-20 ml of distilled water were added into the crucible. To remove uranium in water-soluble form, the crucible was heated at about 200 °C for 1-2 h. Then, the sample was transferred into a 100 ml teflon beaker with 10-20 ml of distilled water, 5 ml of concentrated HNO_3, 5 ml of 40 % HF and 1 ml of 30 % H_2O_2; mineralisation and evaporation were carried out at 250 °C. Before dry, the sample was further attacked with a mixture of 5 ml of concentrated HNO_3 and 5 ml of 40 % HF and evaporated to incipient dryness. 4 ml of concentrated HNO_3 and 10-20 ml distilled water were added to eliminate the remaining HF by heating at about 250 °C. Finally, the residue was dissolved with 2 ml of concentrated HNO_3 and 10 ml of distilled water by heating. The solution was filtered through a 0.1 µm Whatman paper filter into a 150 ml beaker. After filtering the teflon beaker and the filter were washed with 6 ml of 1 M HNO_3 into the 150 ml beaker.

Water samples

No particular preparation was needed for water samples. Forty mg of Fe^{3+} (40 mg Fe^{3+}/ml) as carrier, 0.03 Bq of ^{232}U as tracer and 20 ml of concentrated HNO_3 are added to one litre of water sample. After boiling for 30 min, the solution is removed to an electric-magnetic stirrer and adjusted to pH 9.5-10 with concentrated ammonia solution to co-precipitate uranium with iron (III) hydroxide. The solution is stirred for another 30 minute and the precipitate is allowed to settle down for at least 4-6 h and preferably overnight. The supernatant is carefully siphoned off and the hydroxide slurry is centrifuged at 3,500 rpm. The supernatant is discarded, the precipitate is dissolved with 5 ml of concentrated HNO_3 and 0.3 ml of 40 % HF and transferred to a 150 ml beaker. The solution obtained is evaporated to incipient dryness and the residue is dissolved with 4 ml of concentrated HNO_3, 26 ml of distilled water and 0.3 ml of 40 % HF by heating to 100 °C. Further separation is carried out following the uranium determination procedure given below.

Air filter samples

The same procedure used for botanical samples was applied to air filters.

Column preparation

A solution (50 ml) of 0.3 M TOPO (Trioctylphosphine oxide 99 %) in cyclohexane was added to 50 g of Microthene; the mixture was stirred for several minutes until homogeneity and was than evaporated to eliminate cyclohexane at 50 °C. The porous powder thus obtained contained about 10.4 % TOPO. A portion (1.6 g) of the Microthene-TOPO powder, slurred with 3 ml concentrated HCl and 10 ml of distilled water, was transferred to a chromatographic column; after conditioning with 30 ml of 2 M HNO_3, the column was ready for use.

Separation and determination of uranium

The solutions, obtained from the above-described procedures, were passed through a preconditioned Microthene-TOPO column at a flow rate of 0.6-0.8 ml/min. After washing with 20 ml 2M HNO_3, 50 ml 1M HCl and 5 ml of distilled water at the same flow rate, uranium is eluted with 30 ml of 0.025 M $(NH_4)_2C_2O_4$ at a flow rate of 0.1 ml/min. The first 3.5 ml of eluant are discarded and the remains were directly collected in an electro-deposition cell. 0.61 ml of 8M HNO_3 were added to the cell and the solution was adjusted to pH 1-1.5 with 1:4 ammonia solution. Uranium was electro-deposited on a stainless steel disk at a current density of 300 mA for 4 hours and counted by alpha spectrometry.

Lower limits of detection

The lower limits of detection have been assessed using Currie's method (1968). Taking into account the blank count rates, the counting efficiencies of the instruments, the radiochemical yields and the sample quantity, the lower limits of detection of the method are 0.37 Bq kg^{-1} (soil or lichen) and 0.22 mBq l^{-1} (water) for ^{238}U and ^{234}U, and 0.038 Bq kg^{-1} (soil or lichen) and 0.022 mBq l^{-1} (water) for ^{235}U if 0.5 g of soil and 1 litre of water are analysed. For the air filters the lower limit of detection are 0.17 µBq m^{-3} for ^{235}U.

Statistical and measurement uncertainties

The analytical uncertainty associated with the activity concentration has been estimated following some steps as reported on EURACHEM/CITAC Guide [Eurachem/Citac Guide,

$$C = \frac{\left(\frac{N}{T} - BK\right)}{\left(\frac{N_t}{T_t} - BK_t\right)} * \frac{V_t}{P}$$

2000]. Activity concentration can be expressed as:
where:

N = Number of sample counts;

T = Time of sample counting (seconds);

BK = Counts per second of background of reagent and counting system;

$\mathbf{N}_t$ = Number of tracer counts;

T_t = Time of tracer counting (seconds);

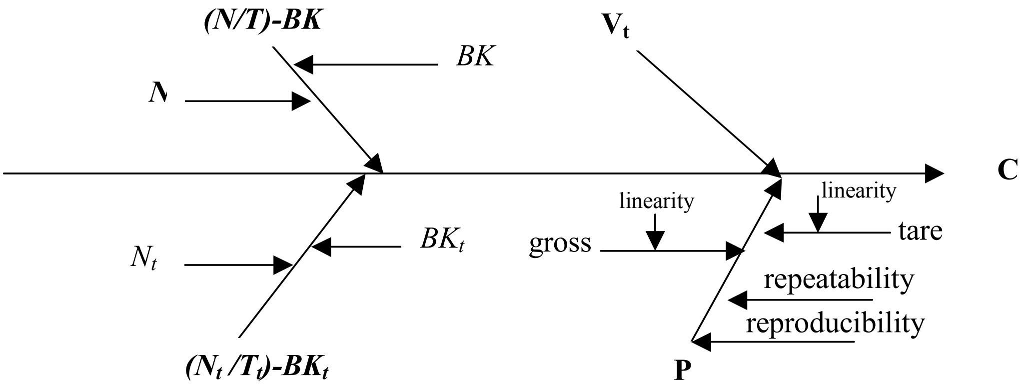
BK_t = Count per second of tracer background;

V_t = Tracer activity (Bq);

P = weight (kg) or volume (l, m^3).

The cause-effect diagram (sometimes called fish-bone) shown below highlights the significant uncertainty in avoiding over-counting. The uncertainty components have been expressed as standard deviations and combined, according to the appropriate rules, to give a combined standard uncertainty. The uncertainty associated with the time is neglected.

Concerning the uncertainty associated with the weight (P), the following contributions are considered: linearity of the balance, repeatability and reproducibility.



Concerning the water sample, the volume has been measured using a graduated cylinder, so the uncertainty associated with the volume has been evaluated on the basis of its characteristics. With regard to the air samples, the air volume collected by each air sampler has been estimated as the air pumping speed multiplied by the time duration of each measurement. The uncertainty in the measurement of the air speed has been calculated by the fluctuation of the indications of the measuring instrument during the measurement and it is estimated at 3 %. The uncertainty associated with the time duration has been neglected.

The uncertainty associated with the tracer activity (V_t) includes the uncertainty due to two dilutions of the tracer, the uncertainty reported on the tracer certificate and the uncertainty associated with the addition of the tracer to the sample.

The uncertainty associated with the ratios $^{234}U/^{238}U$, $^{235}U/^{238}U$ has been calculated according to the appropriate rules of the uncertainty propagation. In the tables the uncertainty is reported as 1 standard deviation.

$$\frac{\partial C}{C} = \sqrt{\left(\frac{\partial((N/T)-BK)}{(N/T)-BK}\right)^2 + \left(\frac{\partial((N_t/T_t)-BK_t)}{(N_t/T_t)-BK_t}\right)^2 + \left(\frac{\partial P}{P}\right)^2 + \left(\frac{\partial V_t}{V_T}\right)^2}$$

$$\partial C = \frac{\partial C}{C} * C$$

C.4.3 Quality Control

During the mission, the team members decided to organise a quality control exercise based on an inter-laboratory comparison between ANPA laboratory (Italy) and Spiez Laboratory (Switzerland) in order to verify the comparability of the results obtained in the two laboratories. Since most samples collected in Serbia and Montenegro were soils, lichens and water, the team decided to run the comparison on these sample types. Furthermore, the team decided to analyse a reference material (soil IAEA-326) in order to improve the comparison of the analytical data. In this framework, ANPA sent to Spiez laboratory two samples of lichens and one water sample, while Spiez laboratory sent to ANPA two soil samples and one reference material (IAEA-326). The laboratories applied their established methodology; ANPA analysed the samples by alpha-spectrometry system, while the ICP-MS system was used by Spiez Laboratory.

Table C.2 reports all data from the comparison. In the following, the comments refer only to ^{238}U determination, considered as an indicator of result comparability.

Table C.2 Data of the inter-laboratory comparison between ANPA Laboratory (Italy) and Spiez Laboratory (Switzerland).

Sample code	Sample Type	Lab.	^{238}U Bq kg^{-1}	^{234}U Bq kg^{-1}	^{235}U Bq kg^{-1}
ANPA-SA04/01	lichen	ANPA	1.14E+01±2.37E+00	1.20E+01±2.94E+00	7.16E-01±2.93E-01
		Spiez	2.36E+01±8.18E-01	2.26E+01±1.85E+00	1.08E+00±5.03E-02
ANPA-SA04/01 Total dissolution	lichen	ANPA	1.36E+01±5.47E-01	1.46E+01±5.79E-01	6.4E-01±9.54E-02
ANPA-SA31/01a	lichen	ANPA	2.22E+00±6.69E-01	1.76E+00±2.02E-01	1.02E-01±4.67E-02
		Spiez	3.73E+00±1.06E-01	1.15E+01±2.77E+00	1.36E-01±4.88E-03
ANPA-SA31/01a Total dissolution	lichen	ANPA	4.30E+0±4.1E-01	2.94E+0±3.59E-01	2.1E-01±9.82E-02
NUC2001-108-1	Soil (IAEA 326)	ANPA	3.05E+01±1.78E+00	2.81E+01±1.74E+00	1.37E+00±4.41E-01
		Spiez	2.84E+01±3.69E-01	2.61E+01±2.06E+00	1.29E+00±2.83E-02
NUC2001-101-11	soil	ANPA	2.41E+02±6.15E+01	6.45E+01±8.69E+00	5.14E+00±1.44E+00
		Spiez	2.18E+02±6.95E+00	6.28E+01±2.91E+00	4.14E+00±1.47E-01
NUC2001-101-7	soil	ANPA	1.32E+04±2.81E+03	1.50E+03±3.29E+02	1.89E+02±4.53E+01
		Spiez	1.44E+04±1.62E+02	1.70E+03±2.51E+02	1.84E+02±3.81E+00
Sample code	**Sample Type**	**Lab.**	**^{238}U Bq l^{-1}**	**^{234}U Bq l^{-1}**	**^{235}U Bq l^{-1}**
ANPA-SA23/01	water	ANPA	2.18E-02±1.46E-02	2.74E-02±1.96E-03	9.83E-04±3.54E-04

Figure C.2a reports the comparison between the IAEA recommended value and ANPA and Spiez data of ^{238}U activity concentrations in the IAEA-326 soil. These results confirm the good agreement between methods applied on totally dissolved samples. The importance of dissolution was already focused in the NAT-9 quality control exercise organised by the IAEA in the framework of the UNEP mission in Kosovo (NAHRES-60, 2001, UNEP, 2001). Figures C.2b and C.2c show the results found in the other two soil samples.

The measurement uncertainties for the Spiez Laboratory data were calculated by propagation of errors from the relative standard deviations. The relative standard deviation of the variables were either experimentally determined or estimated (Burger, 2002). In the case of ANPA data, the uncertainties reported are the combination of the contributions to the uncertainty assessed, as reported in the paragraph *Statistical and measurement uncertainties* and the repeatability, experimentally obtained analysing three different replicates. For this reason, the uncertainties associated with ANPA also take into consideration the contribution due to the homogeneity of the sample and are consequently higher than those reported for Spiez laboratory. Good agreement was also found for the water sample.

Figures C.3a and C.3b report the results obtained by Spiez and ANPA laboratories for lichen samples. The differences found can be attributable to:

- the different dissolution methods used in the two laboratories;
- the difficulties of homogenisation of the lichen samples collected on substrates (rocks) that can give a contribution to the uranium content in the lichens.

Spiez laboratory used for lichen samples the same procedures used for soil samples, while ANPA applied a different dissolution method for lichens in order to determine mainly the fraction of uranium transferred inside the biological samples. Figure C.3a shows that for one of the lichen samples, the difference is mainly due to the different dissolution methods. In fact, the results obtained by total dissolution methods (t.d.) are in agreement between the two laboratories. This explanation is not valid for the other lichen sample, for which the difficulties involved in realising an homogeneous sample was the most prevalent.

Conclusions

The results of the quality control exercise based on an interlaboratory comparison between ANPA laboratory (Italy) and Spiez Laboratory (Switzerland) showed good agreement for soil and water samples.

The results obtained for lichen samples were not in agreement due to:

- the different dissolution methods used in the two laboratories;
- the difficulties of homogenisation of the lichen samples collected on substrates (rocks) that can contribute to the uranium content in the lichens.

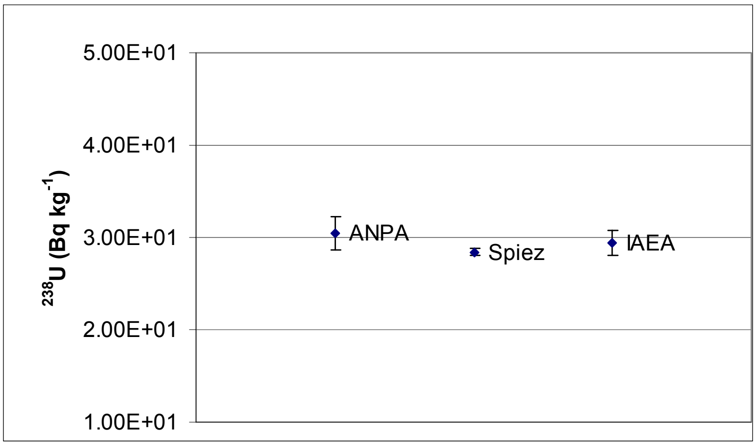


Figure C.1a ^{238}U activity concentrations data of the inter-laboratory comparison between ANPA Laboratory (Italy) and Spiez Laboratory (Switzerland) and the recommended value of IAEA-326 soil. The interval of IAEA value represents the 95 % interval of confidence.

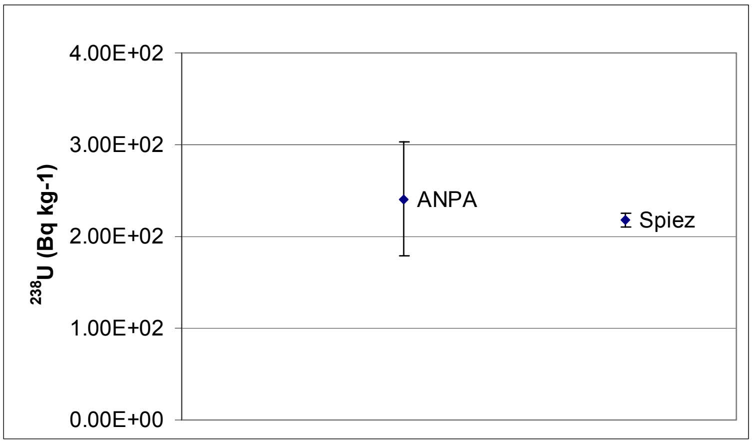


Figure C.1b ^{238}U activity concentrations data of the inter-laboratory comparison on soil (NUC2001-101-11) between ANPA Laboratory (Italy) and Spiez Laboratory (Switzerland).

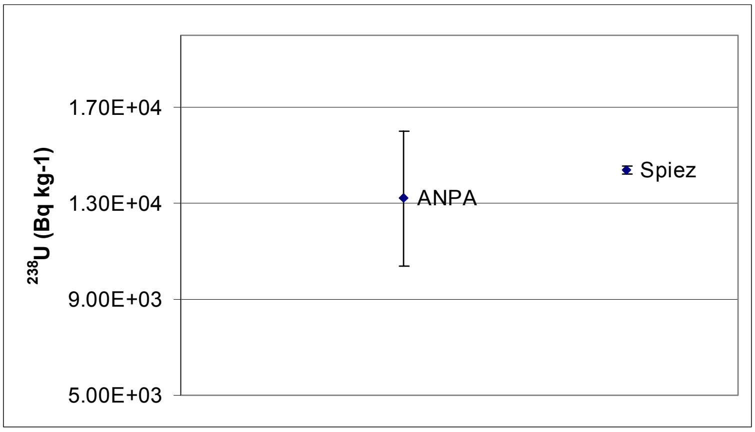


Figure C.1c ^{238}U activity concentrations data of the inter-laboratory comparison on soil (NUC2001-101-7) between ANPA Laboratory (Italy) and Spiez Laboratory (Switzerland).

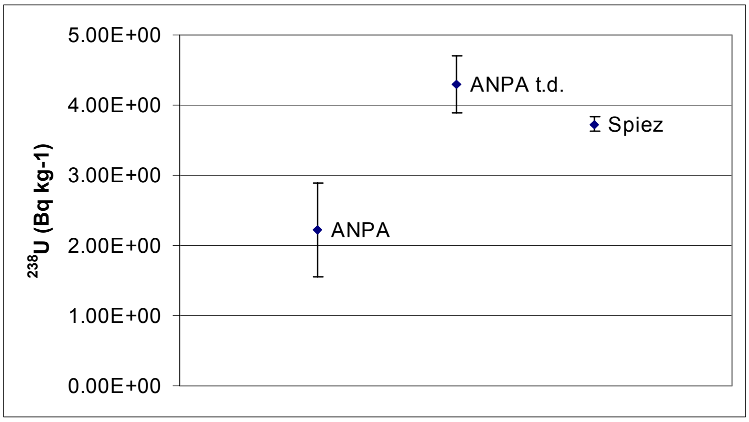


Figure C.2a ^{238}U activity concentrations data of the interlaboratory comparison on lichen (ANPA-SA31/01a) between ANPA Laboratory (Italy) and Spiez Laboratory (Switzerland). t.d. = total dissolution method.

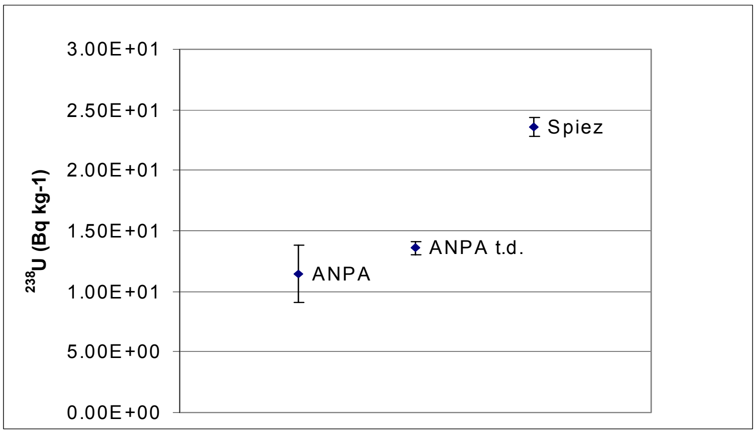


Figure C.2b ^{238}U activity concentrations data of the interlaboratory comparison on lichen (ANPA-SA04/01) between ANPA Laboratory (Italy) and Spiez Laboratory (Switzerland).). t.d. = total dissolution method.

APPENDIX D

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MILITARY USE OF DU

There are multiple military applications of depleted uranium. As in the civilian sector, DU may serve as counter-ballast, in both aircraft and missiles. It is important to note that not all counter-ballast is made of depleted uranium and that less DU is currently used for this purpose than was formerly the case. Because of its density (19.0 g/cm^3) and resistance to penetration by anti-armour munitions, depleted uranium can be used in the armour of tanks, though it is also the case 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 hit armour plating, the penetrators 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 an aerosol will depend upon the ammunition, the nature of the impact and the type of target, including whether or not it is an armoured vehicle. Both tanks and aircraft can fire depleted uranium munitions, with tanks firing larger calibre rounds (100 and 120 mm) and 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 and in Bosnia-Herzegovina in 1995. In the Kosovo conflict of 1999 NATO aircraft used DU weapons against targeted sites in Kosovo, southern Serbia and Montenegro. NATO confirmed to the United Nations that over 30,000 rounds of DU had been used in Kosovo, more than 2,500 rounds in Serbia and 300 rounds in Montenegro (UNEP, 2000). According to NATO/KFOR information provided to UNMIK the mix was 5 DU rounds per 8 rounds fired (KFOR, 2000). The numbers of DU rounds used against a single target in Serbia ranged from 30 to 1,340.

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 into the environment, contaminating the air and 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 pass intact 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 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.

It is important to note that hits by depleted uranium against 'soft' targets, e.g. non-armoured vehicles, do not generate significant contamination of dust. Most contamination from strikes on armoured vehicles should be limited to within about 100 metres of the target (CHPPM, 2000). Because 2.5 years had elapsed since the Kosovo conflict by the time of the UNEP mission to Serbia and Montenegro, the major interest of that mission was to examine the possible risks of remaining contamination of ground, water and biota near to the impact sites.

The type of DU ammunition fired by A-10 ‘Warthog’ aircraft has a conical DU penetrator. Its length is 95 mm and the diameter at the base is 16 mm. The weight of the penetrators is approximately 300 g. The penetrator is fixed in a ‘jacket’ (also referred to as a ‘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 Gatling 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.

The A-10 aircraft is equipped with one Gatling 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 approach, 1-3 m apart, occupying an area of about 500 m^2. 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).

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.

Penetrators that hit armoured vehicles either penetrate the armour or ricochet. When the penetrator passes through the armour it may catch fire and burn. Normally, 10-35 % (up to a maximum of 70 %) of the bullet becomes an aerosol on impact, or when the DU dust burnscatches fire (Rand, 1999). Most of the dust particles are smaller than 5 µm in size, and spread according to wind direction. DU dust is black and a target that has been hit by DU ammunition can be recognised by the black dust cover in and around the target (U.S. AEPI, 1994). Penetrators that impact on soft ground (e.g. sand or clay) will usually penetrate intact more than 50 cm into the ground.

After an attack where DU ammunition has been used, some DU will be deposited on the ground and other surfaces, either as pieces of DU metal, fine fragments and dust, and/or – 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.

Penetrators and large pieces of DU can be collected if they can be located. Otherwise, the only way DU is removed is through gradual leaching by rain and melting snow (see also Appendix G ‘DU in Soil’).

APPENDIX E

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Military vehicle (APC) at Vranje Garrison

Measuring beta and gamma radiation from penetrator hole in APC at Vranje Garrison

The smear samples collected show that contamination by DU dust occurred inside the APC. Expressed as total uranium, the deposition of uranium ranges from 0.053 to 0.261 µg/cm² and around the impact hole, 0.155 µg/cm² was measured. From these results an overall loose surface contamination inside the APC of 0.2 µg/cm² can be expected. Knowing that dry smear sampling on painted surfaces is not very effective (it is normally expected that 1–10 % can be smeared off) the surface contamination inside the APC can be expected to be in the range of 2–20 µg/cm².

Calculating on the basis of an interior surface area of 10 m² within the APC, 200-2000 mg uranium were deposited as dust on the inner surface. This would mean that at the moment when the penetrator hit the inside of the APC these 200–2000 mg of uranium were available in an air volume of about 4 m³ for some time which would result in an initial concentration of 50-500 mg uranium / m³. Of course, this theoretical initial concentration was present only for a short time (a question of minutes) before deposition on the inner surface took place. Based on a daily inhalation volume of 23 m³ for adult males (WHO), and assuming a stay of one minute after the attack, a rough estimate of the respiration intake for the crew members would result in a range of 1–10 mg DU. Such an intake could lead to a temporary weak impairment of renal function and to a committed effective radiation dose of the order of 1 mSv.

Table E.1 Samples collected at Vranje Garrison during the UNEP DU Mission.

Sample Code	Sampling Date	Sampling Site	Coordinates	Sample Type
NUC-01-102-01	30.10.01	Vranje Garrison	574649 711861	Penetrator fragment in tank, front / left
NUC-01-102-02	30.10.01	Vranje Garrison	574649 711861	Jacket fragment in tank, front / left
NUC-01-102-03	30.10.01	Vranje Garrison	574649 711861	Smear sample Blank
NUC-01-102-04	30.10.01	Vranje Garrison	574649 711861	Smear sample 20x20 cm inside tank, left side
NUC-01-102-05	30.10.01	Vranje Garrison	574649 711861	Smear sample 20x20 cm inside tank, front / middle
NUC-01-102-06	30.10.01	Vranje Garrison	574649 711861	Smear sample around shothole in tank
NUC-01-102-07	30.10.01	Vranje Garrison	574649 711861	Penetrator fragment inside of tank

Table E.2 Surface concentration of ^{238}U

NUC-2001-102-	^{238}U on smear test [µg]	^{238}U surface concentration [µg/cm^2]	k [%]
03	0.014	0.00003	2.00
04	21.139	0.053	0.93
05	104.277	0.261	1.37
06	61.958	0.155	1.15
Preparation Blank	0.003	0.00001	2.48

Table E.3 ^{238}U on jacket

NUC-2001-102-	^{238}U on jacket surface [mg]	K [%]
02	69.1	0.98

Table E.4 Isotopic composition

NUC-2001-102-	^{238}U		^{235}U		^{234}U		^{236}U	
	percentage [mass%]	rsd [%]	percentage [mass%]	rsd [%]	percentage [mass%]	rsd [%]	percentage [mass%]	rsd [%]
02	99.80	2.59	0.194	2.43	0.0007	7.16	0.0026	2.30
03	99.41	0.52	0.574	0.88	-	-	-	-
04	99.80	1.13	0.196	1.04	0.0006	3.58	0.0026	2.79
05	99.80	1.46	0.194	1.43	0.0006	3.86	0.0027	2.45
06	99.80	1.07	0.195	1.05	0.0006	9.04	0.0027	2.21

From the scientific point of view for this type of ammunition, a uranium dust explosion or fire is expected inside the APC due to the pyrophoric character of uranium. This could lead to the loss of the crew and the APC. However, there were no visible signs of such effects and the APC had clearly not been destroyed. The APC itself was slightly contaminated on its inner surfaces and small, heavily corroded fragments of the penetrator were found. When entering the vehicle it is still necessary to follow specific safety rules to avoid external and internal contamination.

Through clearing-up of remaining DU fragments and careful wet cleaning of the APC (taking precautions to avoid any further contamination of the environment and respecting safety regulations through proper waste disposal/storage) the vehicle could be restored to the extent that no precautionary measures related to DU should be necessary thereafter.

The U-235, U-234 and U-236 concentrations were not corrected for the mass discrimination of the ICP-MS. The combined relative standard deviations (k-values) were calculated by propagation of errors from the relative standard deviations (rsd). The relative standard deviations of the variables were either experimentally determined or estimated.

APPENDIX F

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STORAGE OF DU RESIDUES AT THE VINCA INSTITUTE OF NUCLEAR SCIENCES

F.1 Introduction

On 29 October 2001, during their visit to the Vinèa Institute of Nuclear Sciences near Belgrade, the UNEP team inspected the facility used to store residues of depleted uranium recovered from 5 locations in the Presevo Valley (Serbia) and from Cape Arza (Montenegro). The objective of this visit was to assess the radiological safety of the residues of depleted uranium and to make recommendations on the management and storage of these residues. The team was accompanied by Dr Ilija Pleæaš, Dr Aleksandar Periæ and Ms Sne•ana Pavloviæ, from the Radiation and Environmental Protection Laboratory.

Vinca storage. 5 barrels containing radioactive waste from sites targeted by depleted uranium in Serbia and Montenegro are being stored at Vinca

F.2 Background - Vinca Institute of Nuclear Sciences

The Vinèa Institute of Nuclear Sciences is a research centre located 15 km south of Belgrade on the right bank of the Danube river. It was created in 1948 as part of Yugoslavia's nuclear programme. Originally called the Institute of Physics, it was renamed the Institute for Investigations of the Structure of Matter in 1950 and in 1953 it became known as the Boris Kidric Institute of Nuclear Sciences. Between 1956 and 1959, two heavy water nuclear research facilities were built on the site of the Vinèa Institute. Reactor 'RB', a heavy water critical assembly, became critical in April 1958, while a heavy water research reactor 'RA', with a thermal power of 6.5 MW, became critical in December 1959 .In 1984, the reactor 'RA' was shut down to carry out major refurbishment and maintenance work. This work was never completed and the Yugoslavian authorities are now considering either decommissioning reactor 'RA', resuming operation of the reactor with a reduced thermal power of several hundreds kW. The Yugoslavian authorities are also planning an extensive refurbishment of the critical assembly 'RB', which is expected to improve its performance and safety.

During the 70s, as Yugoslavia's nuclear programme was progressively reduced, the research programme of the Institute gradually changed and was expanded to areas outside the nuclear field, with the aim of improving existing technologies and developing new ones for the peaceful application of nuclear energy. Nowadays, the Boris Kidric Institute of Nuclear Sciences at Vinèa is a multidisciplinary scientific institution with about 400 people involved in research work. The research programme of the Institute currently covers a wide range of scientific and engineering fields and is conducted by 15 laboratories including the Laboratory of Radiation Protection and Environmental Protection.

F.3 Storage of radioactive waste

All radioactive wastes generated from the operation and maintenance of the research reactors 'RA' and 'RB' are stored on site at Vinèa. In addition, radioactive waste resulting from the production and use of radioactive materials in the territory of the Socialist Federal Republic of Yugoslavia (the 'former Yugoslavia') is also stored at Vinèa. Although the visit of the UNEP team was limited to the interim storage facility for low-level radioactive solid waste, where the residues of depleted uranium are stored, it is important to note that serious concerns have been raised about the safety of the pool used to store spent fuel from the research reactor 'RA'. Although work has been carried out since 1996 in collaboration with the International Atomic Energy Agency, aimed at improving the safety of the spent fuel by minimising the risk of uncontrolled release of fission products, serious safety concerns remain in relation to the facility.

F.4 Storage of low-level radioactive waste

The repository used for the temporary storage of low-level solid radioactive waste at Vinèa consists of two hangars of similar size, both around 5 m in height and covering an area of about 300 m^2. The condition of one of the two hangars and the radioactive waste stored is a matter of some concern for the scientists from the Laboratory of Radiation Protection and Environmental Protection. The building has been full for five years but no information is available to characterise the waste. On advice from Dr Peric the UNEP team did not inspect this building in detail because, owing to some waste leakage, the area surrounding the building is contaminated. Dose rates measured in the proximity of the building were of the order of 40 μSv h^{-1}.

While the waste storage in this hangar does not present an immediate hazard to the public, being enclosed by the site security fence, action will be required in the near future to remediate the situation and to manage the radioactive waste. The second hangar was built more recently and appears to be in much better condition. The radioactive waste in this building has been characterised, treated and stored in accordance with the legislation regulating radiological protection matters in the former Yugoslavia. Dose rates just inside this building were of the order of 10 μSv h^{-1}, while the levels in the surrounding area were below 1 μSv h^{-1}. Residues of depleted uranium are stored in this building.

Scientists from the Radiation Protection Laboratory were of the opinion that the solid radioactive waste does not pose any risk to the environment or the population at the moment. However, the capacity of the temporary waste storage at Vinèa is sufficient for a maximum of only 4 to 5 years if radioactive waste in the country continues to be generated at the present rate. A plan to build a new permanent repository for low-level radioactive waste is being prepared. Such a facility would provide a long-term solution to the storage of radioactive waste of the former Yugoslavia including the residues of depleted uranium. A facility for the storage of liquid radioactive waste is also in operation at Vinèa, but the inspection of this facility was outside the scope of the UNEP mission.

F.5 Residues of depleted uranium stored at Vinca

Residues of depleted uranium from sites in Serbia and Montenegro targeted by NATO's air strikes during the Kosovo conflict are stored in the interim storage facility for low-level radioactive solid waste at Vinèa. The residues include full depleted uranium munitions, penetrators, jackets, fragments and soil recovered at Cape Arza in Montenegro and five other sites at four locations in the Presevo Valley in southern Serbia investigated by the Yugoslavian authorities: Pljackovica, Borovac, Bratoselce and Reljan. Parts of a military vehicle hit by depleted uranium munitions are also stored at Vinca. A detailed inventory of these residues is not available. Information provided by experts from Vinèa indicates that about twenty complete 30 mm depleted uranium munitions (i.e. both penetrator and jacket) are stored at the site, as well as between 250 and 300 penetrators and penetrator fragments, and a few hundreds jackets and jacket fragments are stored on site. Around 40 kg of soil taken from localised points of contamination in the area of Cape Arza are also kept at the storage facility. The total amount of depleted uranium residues stored at Vinèa, excluding the parts of the military vehicle, is probably of the order of a few hundred kilograms.

During its visit, the UNEP team had the opportunity to inspect the barrels containing depleted uranium residues from Cape Arza. The residues are believed to be in a fairly stable physical and chemical form. The depleted uranium is in metal form and will progressively oxidise to form a characteristic yellow powder. The residues are held in plastic bags kept in containers made of hard plastic in metallic boxes. All the containers are in very good condition and provide sufficient containment; dose rates measured on contact with the metallic boxes were of the order of 1 μSv h^{-1}.

F.6 Conclusions and recommendations

1. The residues of depleted uranium should remain, in the short term, at the interim repository for solid radioactive waste of the Vinèa Institute. The facility is adequate to cope with the storage of residues of depleted uranium for the next few years. The amount of depleted uranium residues stored appears to be quite limited, of the order of a few hundred kilograms. The residues are believed to be in a stable form and well contained and could be easily immobilised if necessary. Some care should

be taken when handling these residues, because of the pyrophoric properties of uranium. Currently, the radiological risk to the environment and the general population from the residues of depleted uranium stored at Vinèa is negligible.

2. There are some serious concerns with regard to the overall situation of the Institute's low-level waste interim storage facility. Of the two buildings currently used to store low-level radioactive solid waste, one needs to be refurbished quite urgently. While the waste storage in this hangar does not present an immediate hazard to the public, action is required to improve the shielding provided by this building and to decontaminate the surrounding area. The other hangar is in reasonably good condition but has only sufficient capacity for a maximum of four to five years. The construction of a national repository, which is being planned by the authorities of the Federal Republic of Yugoslavia, would provide the best medium- and long-term solution, but it is unlikely that such a repository will be operational before the interim storage facility has reached its full capacity.

3. The scientific staff at Vinèa have the necessary expertise to deal with the residues of depleted uranium in a competent manner. It is of some concern that, because of lack of resources available, this expertise might be lost in future years.

A programme of technical co-operation has been established by the International Atomic Energy Agency to provide the Vinèa Institute with the required support, as appropriate. The issues concerning the waste storage facility and the construction of a permanent repository could be addressed as part of this programme, but it is important to note that the condition of the fuel elements of reactor 'RA' and the pool used for the storage of these elements are of much more serious concern. The solution of these problems should be addressed as a matter of urgency and should take priority over any issues concerning the management of radioactive waste

APPENDIX G

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DU IN SOIL

G.1 Background

Due to its natural abundance, uranium can be found anywhere in the environment – in soil, water, food and air. Uranium is more abundant than silver or gold. Uranium occurs in the Earth's crust with an average abundance of about 3 mg/kg (normal range 0.1 to 20 mg/kg) (see Table O.10). Without the presence of uranium, Earth would be a rather different planet as heat produced by the radioactive decay of uranium is partly responsible (in addition to other naturally occurring radionuclides) for keeping the planet's core and mantle hot enough for convective flow to occur. It is important to realise that uranium may become depleted (or enriched) in some of its isotopes due to purely natural processes such as chemical weathering.

Plutonium, which is present in DU ammunition in very low concentrations, is also found worldwide in soil, air and water as a result of contamination from the nuclear weapons tests carried out in the atmosphere until the 1960s.

The published literature indicates that normally 10-35 % (up to a maximum of 70 %) of a DU penetrator hitting an armoured vehicle becomes an aerosol on impact, or when the dust catches fire (Rand, 1999). Most of the dust particles formed are smaller than 5 micrometres in size and spread according to the wind direction. The DU particles are deposited on the ground or surfaces in general. In addition, pieces or fragments of metallic DU can occur. It is reported from the Nellis Air Force Range, a training range for DU ordnance, that the DU dust is deposited within a distance of 100 metres of the target (Nellis, 1997). The dust consists mainly of uranium oxides.

Most of the penetrators that impact on soft ground ('no-hit' situation) will probably penetrate intact more than 50 centimetres into the ground and remain there for a long period of time, depending on the weathering/geochemical conditions. Penetrators or fragments on the ground surface will corrode due to the reactivity of uranium metal and will corrode even more in wet weather conditions. Fine fragments and dust will gradually be transported down into the upper soil layer, mainly by rain and wind. One can expect that a part of the fine dust particles will adsorb onto soil particles (mainly onto clay particles and organic components) and will thus be less mobile (Nach et al.,1981, Waite al., 1994).

Due to the different chemical properties of different soils and rocks, the effect of DU on the environment varies. Penetrators that hit clay may not affect the surrounding soil. Penetrators that hit quartz sand could be expected to be weathering relatively fast, while acid rain might accelerate the process (UNEP, 1999, 2001).

DU deposited as oxide in the soil is expected to be immobile. On the other hand, from the weathering process of DU in wet conditions (e.g. rain, snow), one would expect partially hydrated uranium oxides as the products of corrosion, which are mobile and soluble in water. So far, none of the analyses carried out on samples from Kosovo and Serbia confirm any contamination of ground water by DU, not even close to zones of attack. A complete picture of the geochemical behaviour of DU in the environment does not yet exist. However, French studies show that, under certain conditions, the mobility of DU in the ground might increase. (Crancon, 2001, UNEP 2001).

With regard to the ingestion pathway it is reported (EU, 2001, WHO, 2001) that, due to the very low transfer factors of DU into the biological material, the expected dose would be less than 1 µSv/year. Even in scenarios with very high consumption of vegetables that are grown in contaminated soils the doses will be insignificant.

Inhalation of resuspended DU in the zone adjacent to the target area, e.g. where a tank was hit by DU, could result in an intake of a maximum of 0.6–60 µg of DU (UNEP 1999, UNEP 2001, EU 2001, Keller et al. 2001). The effective dose of 0.07–7 µSv/year is negligible.

G.2 Experience from the UNEP DU mission to Serbia and Montenegro

Natural uranium levels at the investigated sites

The natural uranium levels of the soils that were sampled during the UNEP mission were in the range of 1.0 to 9.5 mg U/kg soil.

Contamination points

Most heavily contaminated was the soil at and around impacts of DU penetrators. As an example, at Pljackovica, a penetrator was found at a depth of 8 cm. The contamination of the soil in the penetrator hole was in one sample 5 g of DU per kilogram of soil. Another sample taken out of the same hole had a concentration of 1.1 g DU/kg soil. The spread of DU contamination in the hole was rather limited, affecting an area of about 10 x 10 cm and reaching a depth of about 20 cm.

The results from the investigations of the contamination points allow the following conclusions to be drawn:

- Major contamination is limited to a very small volume and surface area.
- Penetrators hitting a more or less soft surface (soil, asphalt), or striking at a bad angle, or striking a hard object below the surface (e.g. a large stone) can result in DU contamination of some grams per kilogram of soil for that hole. However, the volume of that contamination is nevertheless small.

These results confirm the findings of the UNEP Kosovo Mission, where it was additionally found that penetrators hitting a more or less hard surface (e.g. concrete) result in lower contamination of the ‘hot spot’.

Widespread DU contamination

The soil analyses shows that there is widespread ground contamination around the point of impact by a DU penetrator. However, the extent of the contaminated zone can be sufficiently well defined and consists of some tens of square metres depending on the type of surface where the attack had taken place. At a distance of between one and two metres away from an impact hole the maximum contamination level for DU in surface soil (0 – 5 cm depth) was found in Cape Arza, with a value of 23 mg/kg. At a distance of about five metres, 5.9 mg DU/kg was measured.

In general, the analyses of the soil samples from this mission show higher DU contamination around ground impacts than was the case in Kosovo. The range of values from the UNEP Kosovo Mission within the first 1–2 metres of impact holes was 0.5±0.25 mg DU/kg in surface soils (0–5cm), independent of the hardness of the surface. This picture was not confirmed in Serbia and Montenegro. There, soil samples taken at similar distances from penetrator impacts, often contained several mg DU/ kg .

On the other hand, the general results about the widespread contamination at greater distances also differ from the results of the UNEP Kosovo Mission.

To summarise the findings of the UNEP DU mission to Serbia and Montenegro:

- Penetrators hitting a more or less hard surface (e.g. concrete, rocks) result in DU contamination of the topsoil with amounts decreasing with distance from a site of impact. Excluding the contamination within the first 5 x 5 metres around the impact sites, the results from the mission indicate that DU contamination exceeding values of some mg DU/kg soil is restricted to about 100 x 100 metres from the assumed targets. However, in cases when penetrators burn after hitting hard targets like tanks, APCs or guns more wide spread contamination could be expected. That such cases had occurred at the sites investigated by the mission could not be confirmed.

- Penetrators hitting a more or less soft surface (soil, asphalt street) can result in DU contamination of topsoil of some mg DU/kg. Excluding the contamination in the first 5 x 5 metres of the penetrator impact, DU contamination above concentrations of some mg DU/kg is restricted to an area of about 20 x 20 metres.

- The DU contamination of the topsoil within the distances described can significantly exceed the natural levels of uranium in the first few metres. Except for the zone at the contamination points, it usually does not exceed a factor of five. However, due to the very limited zone of contamination above the natural uranium levels, a health risk is not to be expected either from living close to the sites attacked with DU ammunition or by visiting these areas.

Table G.1 Soil samples collected in Serbia and Montenegro during the UNEP DU Mission.

SOIL

Sample code	Sampling date	Sampling site	Coordinates	Sample type	Depth	% ignition residue
NUC-2001-101-01	30.10.01	Pljackovica	573614 714576 +1 m circle	Soil, 12 sticks	0 - 5 cm	93.0
NUC-2001-101-02	30.10.01	Pljackovica	573614 714576 +5 m circle	Soil, 12 sticks	0 - 5 cm	89.9
NUC-2001-101-03	30.10.01	Pljackovica	573614 714576 +10 m circle	Soil, 12 sticks	0 - 5 cm	88.0
NUC-2001-101-04	30.10.01	Pljackovica	573614 714576 +20 m circle	Soil, 12 sticks	0 - 5 cm	89.4
NUC-2001-101-05	30.10.01	Pljackovica	573614 714576 +50 m circle	Soil, 12 sticks	0 - 5 cm	87.9
NUC-2001-101-06	30.10.01	Pljackovica	573614 714576 +100 m circle	Soil, 12 sticks	0 - 5 cm	89.2
NUC-2001-101-07	30.10.01	Pljackovica	573599 714559	Soil over penetrator	0 - 5 cm	93.3
NUC-2001-101-08	30.10.01	Pljackovica	573599 714559	Soil around penetrator	5 - 15 cm	92.5
NUC-2001-101-10	30.10.01	Pljackovica	573599 714559 +0.5 m circle	Soil, 8 sticks	0 - 5 cm	88.4
NUC-2001-101-11	30.10.01	Pljackovica	573599 714559 +2 m circle	Soil, 10 sticks	0 - 5 cm	92.5
NUC-2001-101-12	30.10.01	Pljackovica	573829 714419	Soil / Field blank	0 - 5 cm	92.0
NUC-2001-103-01	31.10.01	Borovac	561935 694013 +1 m circle	Soil, 12 sticks	0 - 5 cm	98.0
NUC-2001-103-02	31.10.01	Borovac	561935 694013 +5 m circle	Soil, 12 sticks	0 - 5 cm	97.4
NUC-2001-103-03	31.10.01	Borovac	561935 694013 +10 m circle	Soil, 12 sticks	0 - 5 cm	96.8
NUC-2001-103-04	31.10.01	Borovac	561935 694013 +20 m circle	Soil, 12 sticks	0 - 5 cm	96.6
NUC-2001-103-05	31.10.01	Borovac	561935 694013 +50 m circle	Soil, 12 sticks	0 - 5 cm	96.4
NUC-2001-103-06	31.10.01	Borovac	561935 694013 +100 m circle	Soil, 12 sticks	0 - 5 cm	93.8
NUC-2001-103-07	31.10.01	Borovac	561935 694013 +200 m circle	Soil, 12 sticks	0 - 5 cm	95.2
NUC-2001-103-08	31.10.01	Borovac	563178 693024	Soil / Field blank	0 - 5 cm	95.3
NUC-2001-103-09	31.10.01	Borovac	561963 694025	Soil, point of higher radioactivity, 10 sticks, 2 sqm	0 - 5 cm	97.4
NUC-2001-104-01	31.10.01	Bratoselce	562279 688324 +1 m circle	Soil, 12 sticks	0 - 5 cm	92.1
NUC-2001-104-02	31.10.01	Bratoselce	562279 688324 +5 m circle	Soil, 12 sticks	0 - 5 cm	92.8
NUC-2001-104-03	31.10.01	Bratoselce	562279 688324 +10 m circle	Soil, 12 sticks	0 - 5 cm	92.8
NUC-2001-104-04	31.10.01	Bratoselce	562279 688324 +20 m circle	Soil, 12 sticks	0 - 5 cm	93.7
NUC-2001-104-05	31.10.01	Bratoselce	562279 688324 +50 m circle	Soil, 12 sticks	0 - 5 cm	93.6
NUC-2001-104-06	31.10.01	Bratoselce	562279 688324 +100 m circle	Soil, 12 sticks	0 - 5 cm	92.7
NUC-2001-104-07	31.10.01	Bratoselce	562279 688324 +200 m circle	Soil, 12 sticks	0 - 5 cm	94.5
NUC-2001-104-08	31.10.01	Bratoselce	561693 688083	Soil / Field blank	0 - 5 cm	92.0
NUC-2001-105-01	01.11.01	Bukurevac	558063 688746	Soil, 10 sticks, 5x5m	0 - 5 cm	92.0
NUC-2001-105-02	01.11.01	Bukurevac	557933 688628	Soil, 10 sticks, 5x5m	0 - 5 cm	88.6
NUC-2001-105-03	01.11.01	Bukurevac	558076 688248	Soil, 10 sticks, 5x5m	0 - 5 cm	93.7
NUC-2001-105-04	01.11.01	Bukurevac	558243 688325	Soil, 10 sticks, 5x5m	0 - 5 cm	90.3
NUC-2001-106-01	01.11.01	Reljan	563147 685117 Distance inside, 1 m to fence	Soil, 12 sticks	0 - 5 cm	93.6

Table G.2 Soil samples collected in Serbia and Montenegro during the UNEP DU Mission. ***Concentrations by mass***

Table G.3 Soil samples collected in Serbia and Montenegro during the UNEP DU Mission. *Concentrations by activity*

SOIL

Sample code	U-238 [Bq/kg]			U-234 [Bq/kg]			U-235 [Bq/kg]			U-236 [Bq/kg]			Utot [Bq/kg]			U-235/U-238 [mg/mg]	**%DU**
NUC-2001-101-01	7.50E+01	±	9.23E+00	3.67E+01	±	6.17E+00	1.96E+00	±	2.76E-01	2.42E-01	±	4.24E-02	1.14E+02	±	1.57E+01	4.147E-03	**59**
NUC-2001-101-02	6.61E+01	±	4.76E+00	3.60E+01	±	4.36E+00	1.88E+00	±	1.56E-01	1.85E-01	±	1.85E-02	1.04E+02	±	9.29E+00	4.505E-03	**52**
NUC-2001-101-03	1.51E+02	±	2.74E+01	4.90E+01	±	1.15E+01	3.04E+00	±	5.93E-01	5.78E-01	±	1.12E-01	2.03E+02	±	3.96E+01	3.211E-03	**77**
NUC-2001-101-04	3.69E+01	±	4.33E-01	3.51E+01	±	1.85E+00	1.62E+00	±	3.52E-02				7.37E+01	±	2.32E+00	6.946E-03	**6**
NUC-2001-101-05	4.59E+01	±	5.92E-01	3.65E+01	±	2.17E+00	1.69E+00	±	4.80E-02	5.68E-02	±	8.87E-03	8.41E+01	±	2.82E+00	5.855E-03	**27**
NUC-2001-101-06	4.40E+01	±	9.95E-01	4.46E+01	±	2.66E+01	2.01E+00	±	5.76E-02				9.06E+01	±	2.76E+01	7.255E-03	**<1**
NUC-2001-101-07	1.44E+04	±	1.62E+02	1.70E+03	±	2.51E+02	1.84E+02	±	3.81E+00	7.53E+01	±	3.71E+00	1.63E+04	±	4.20E+02	2.030E-03	**99**
NUC-2001-101-08	3.07E+05	±	7.65E+03	3.39E+04	±	2.99E+03	3.92E+03	±	1.12E+03	1.62E+03	±	9.60E+01	3.47E+05	±	1.19E+04	2.020E-03	**100**
NUC-2001-101-10	8.12E+01	±	3.54E+00	4.71E+01	±	4.53E+00	2.45E+00	±	1.31E-01	2.08E-01	±	2.56E-02	1.31E+02	±	8.22E+00	4.781E-03	**47**
NUC-2001-101-11	2.18E+02	±	6.95E+00	6.28E+01	±	2.91E+00	4.14E+00	±	1.47E-01	9.28E-01	±	7.79E-02	2.86E+02	±	1.01E+01	3.017E-03	**81**
NUC-2001-101-12	5.69E+01	±	1.30E+00	5.84E+01	±	3.53E+00	2.60E+00	±	7.44E-02				1.18E+02	±	4.91E+00	7.252E-03	**<1**
NUC-2001-103-01	2.31E+01	±	4.42E-01	2.33E+01	±	1.55E+00	1.01E+00	±	2.11E-02				4.75E+01	±	2.01E+00	6.991E-03	**5**
NUC-2001-103-02	2.08E+01	±	7.23E-01	1.99E+01	±	1.80E+00	8.48E-01	±	3.71E-02				4.15E+01	±	2.56E+00	6.584E-03	**13**
NUC-2001-103-03	1.95E+01	±	2.89E-01	1.80E+01	±	1.27E+00	8.00E-01	±	2.46E-02				3.83E+01	±	1.58E+00	6.569E-03	**13**
NUC-2001-103-04	1.89E+01	±	4.41E-01	1.89E+01	±	1.13E+00	8.16E-01	±	2.35E-02				3.86E+01	±	1.60E+00	6.950E-03	**6**
NUC-2001-103-05	2.16E+01	±	2.75E-01	1.92E+01	±	8.31E-01	8.96E-01	±	1.97E-02				4.17E+01	±	1.13E+00	6.634E-03	**12**
NUC-2001-103-06	1.95E+01	±	7.34E-01	1.94E+01	±	1.18E+00	8.56E-01	±	4.00E-02				3.98E+01	±	1.95E+00	7.057E-03	**4**
NUC-2001-103-07	1.73E+01	±	2.42E-01	1.73E+01	±	1.45E+00	7.74E-01	±	1.60E-02				3.54E+01	±	1.71E+00	7.188E-03	**1**
NUC-2001-103-08	1.26E+01	±	1.83E-01	1.24E+01	±	7.39E-01	5.63E-01	±	1.53E-02				2.55E+01	±	9.38E-01	7.201E-03	**<1**
NUC-2001-103-09	4.03E+01	±	6.65E-01	3.42E+01	±	2.38E+00	1.62E+00	±	3.87E-02				7.61E+01	±	3.08E+00	6.479E-03	**15**
NUC-2001-104-01	1.60E+02	±	1.72E+00	1.23E+02	±	5.66E+00	5.90E+00	±	1.19E-01	2.42E-01	±	3.33E-02	2.90E+02	±	7.53E+00	5.849E-03	**27**
NUC-2001-104-02	1.38E+02	±	1.51E+00	1.05E+02	±	4.50E+00	5.07E+00	±	8.12E-02	2.12E-01	±	3.69E-02	2.48E+02	±	6.13E+00	5.815E-03	**27**
NUC-2001-104-03	1.56E+02	±	1.85E+01	1.20E+02	±	2.02E+01	5.64E+00	±	8.07E-01	2.59E-01	±	8.65E-02	2.81E+02	±	3.96E+01	5.761E-03	**28**
NUC-2001-104-04	9.74E+01	±	1.20E+00	9.51E+01	±	2.26E+00	4.34E+00	±	6.89E-02				1.97E+02	±	3.53E+00	7.068E-03	**4**
NUC-2001-104-05	7.39E+01	±	8.72E-01	7.37E+01	±	2.79E+00	3.34E+00	±	5.62E-02				1.51E+02	±	3.72E+00	7.239E-03	**<1**
NUC-2001-104-06	4.60E+01	±	5.20E-01	4.62E+01	±	2.91E+00	2.10E+00	±	3.07E-02				9.43E+01	±	3.46E+00	7.270E-03	**<1**
NUC-2001-104-07	7.22E+01	±	7.94E-01	7.20E+01	±	2.70E+00	3.30E+00	±	3.76E-02				1.47E+02	±	3.53E+00	7.261E-03	**<1**
NUC-2001-104-08	3.26E+01	±	4.82E-01	3.39E+01	±	1.87E+00	1.49E+00	±	3.54E-02				6.80E+01	±	2.39E+00	7.260E-03	**<1**
NUC-2001-105-01	6.43E+01	±	7.20E-01	6.77E+01	±	4.34E+00	2.93E+00	±	6.79E-02				1.35E+02	±	5.13E+00	7.261E-03	**<1**
NUC-2001-105-02	6.26E+01	±	7.63E-01	6.44E+01	±	2.72E+00	2.85E+00	±	6.47E-02				1.30E+02	±	3.55E+00	7.272E-03	**<1**
NUC-2001-105-03	5.86E+01	±	6.56E-01	6.05E+01	±	3.81E+00	2.67E+00	±	5.00E-02				1.22E+02	±	4.52E+00	7.276E-03	**<1**
NUC-2001-105-04	4.62E+01	±	4.94E-01	4.73E+01	±	2.54E+00	2.10E+00	±	3.22E-02				9.56E+01	±	3.07E+00	7.278E-03	**<1**
NUC-2001-106-01	3.68E+01	±	6.59E-01	3.79E+01	±	2.61E+00	1.62E+00	±	3.44E-02				7.63E+01	±	3.30E+00	7.053E-03	**4**
NUC-2001-106-02	1.63E+02	±	3.85E+00	5.40E+01	±	2.86E+00	3.28E+00	±	9.61E-02	6.74E-01	±	8.34E-02	2.21E+02	±	6.89E+00	3.214E-03	**77**
NUC-2001-106-03	4.37E+01	±	7.16E-01	4.55E+01	±	2.61E+00	1.98E+00	±	4.78E-02				9.11E+01	±	3.37E+00	7.276E-03	**<1**
NUC-2001-106-04	7.59E+01	±	1.70E+00	4.62E+01	±	2.98E+00	2.28E+00	±	6.32E-02	2.10E-01	±	1.87E-02	1.25E+02	±	4.76E+00	4.804E-03	**47**
NUC-2001-106-05	4.50E+01	±	5.99E-01	5.06E+01	±	7.74E+00	2.04E+00	±	5.26E-02				9.76E+01	±	8.39E+00	7.261E-03	**<1**
NUC-2001-106-06	3.99E+01	±	7.11E-01	4.09E+01	±	2.08E+00	1.82E+00	±	4.09E-02				8.26E+01	±	2.83E+00	7.276E-03	**<1**
NUC-2001-106-07	3.40E+01	±	5.43E-01	3.56E+01	±	2.03E+00	1.54E+00	±	3.60E-02				7.11E+01	±	2.61E+00	7.280E-03	**<1**
NUC-2001-106-08	3.89E+01	±	5.80E-01	4.02E+01	±	3.12E+00	1.76E+00	±	3.70E-02				8.09E+01	±	3.73E+00	7.237E-03	**<1**
NUC-2001-106-09	4.93E+01	±	6.80E-01	4.92E+01	±	2.82E+00	2.23E+00	±	4.02E-02				1.01E+02	±	3.54E+00	7.273E-03	**<1**
NUC-2001-107-01	4.86E+01	±	7.20E-01	2.89E+01	±	9.93E-01	1.49E+00	±	2.41E-02	1.46E-01	±	1.20E-02	7.91E+01	±	1.75E+00	4.863E-03	**46**
NUC-2001-107-02	1.11E+02	±	1.90E+00	4.41E+01	±	1.55E+00	2.58E+00	±	4.77E-02	4.29E-01	±	3.60E-02	1.58E+02	±	3.53E+00	3.696E-03	**68**
NUC-2001-107-03	4.27E+01	±	5.50E-01	3.99E+01	±	2.77E+00	1.86E+00	±	2.72E-02				8.45E+01	±	3.35E+00	6.950E-03	**6**
NUC-2001-107-04	3.56E+01	±	3.91E-01	3.26E+01	±	1.73E+00	1.61E+00	±	2.20E-02				6.97E+01	±	2.15E+00	7.206E-03	**<1**
NUC-2001-107-05	3.36E+01	±	4.03E-01	3.35E+01	±	2.49E+00	1.51E+00	±	2.71E-02	7.84E-02	±	3.50E-02	6.87E+01	±	2.96E+00	7.163E-03	**2**
NUC-2001-107-06	2.76E+01	±	4.23E-01	2.86E+01	±	8.54E-01	1.26E+00	±	3.48E-02	8.92E-02	±	1.63E-02	5.76E+01	±	1.33E+00	7.217E-03	**<1**
NUC-2001-107-07	4.24E+01	±	8.19E-01	4.20E+01	±	1.85E+00	1.93E+00	±	4.22E-02	9.18E-02	±	1.92E-02	8.65E+01	±	2.73E+00	7.223E-03	**<1**

APPENDIX H

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DU IN WATER

Typically, uranium is present in natural waters at low concentrations ranging from less than 1 µg l^{-1} (5.0E-2 Bq l^{-1}) to more than 100 µg l^{-1} (150 Bq l^{-1}) (UNSCEAR, 20000). In river waters the mean uranium concentration is about 0.3 µg l^{-1}, while in groundwater systems the variability of uranium content depends on the type of rocks composing the aquifer, the water composition, the distance from uraniferous areas, where values up to 2000 µg l^{-1} have been measured (Cantaluppi & Degetto, 2000; Ragnarsdottir & Charlet, 2000). See also Appendix O 'Formulas and Data', Table O.11.

In natural waters, uranium in solution exists predominately as ions of U(IV) and U(VI), depending on pH, temperature, and redox conditions of the aquifer. Under reducing conditions and low pH (<4), mainly U(IV) compounds are found. These are generally less soluble than U(VI) compounds found under oxidising conditions. Uranium moves through oxidised surface layers in association with inorganic (clay minerals) or organic phases (colloid-sized particles and organic complexes as with humic and fulvic acids) or as complex ion in solution. Uranium leaches from oxidising environments to re-precipitate, possibly in a reducing environment, where there is high concentration of organic matter or iron-hydroxides, carbonaceous material, clay minerals or sulphides (Cantaluppi & Degetto, 2000; Ragnarsdottir & Charlet, 2000). Thus, concentrations of naturally occurring radionuclides in drinking water vary widely because of the differing background levels, climatic and agricultural conditions that prevail

Under reducing conditions, dissolved uranium concentrations are below µg l^{-1}, while, if the environment becomes more oxidising, the concentrations can reach mg l^{-1} of uranium dissolved in aqueous solutions with pH>5 and thousands of mg l^{-1} at pH=2.

The $^{234}U/^{238}U$ and $^{235}U/^{238}U$ activity ratios can be used to distinguish between natural and anthropogenic uranium. Goldstein et al. (1997) report that these ratios in natural waters range typically from 0.8 to 10 for $^{234}U/^{238}U$, while $^{235}U/^{238}U$ activity ratio is thought to have quite a uniform value of about 0.046. The high variability of $^{234}U/^{238}U$ activity ratio is due to the 'recoil effect' which occurs when the recoil energy, given to the ^{234}Th daughter during the ^{238}U decay, breaks the bond between ^{234}Th (and the subsequent daughters ^{234}Pa and ^{234}U) and the crystal matrix, so that the ^{234}U atom is freer and more easily leached and thus more ready to enter the solution than the remaining ^{238}U atoms (Mook and de Vries, 2001), considering fixed pH and redox conditions. Values of these ratios below natural limits can be indicative of anthropogenic sources of uranium in the sample considered (Sansone et al., 2001; 2001b).

Drinking water limits for uranium range from 320 µg l^{-1} in the USA (U.S. EPA, 2000) to 100 µg l^{-1} in Canada. The WHO standard guideline for public drinking waters is 2 µg l^{-1} (WHO, 1998). In any case, the low solubility and low uranium concentrations in rocks and soils are the cause of low uranium concentrations in natural waters (Ragnarsdottir & Charlet, 2000).

Depleted Uranium (DU) undergoes the same chemical and physical processes described for natural uranium. Its diffusion in the environment depends on the chemical type, particle dimensions, solubility, etc. Possible contamination of drinking water must be considered if large amounts of DU are buried in the soil: DU penetrators or fragments can be dissolved on the basis of the acidity and reducing properties of the environment and the hydrological characteristics of the region (UNEP, 2001; European Commission, 2001). Once dissolved, DU can be transported to underground aquifers, causing subsequent contamination of drinking water. A potential risk for human health could arise from the introduction of uranium into the environment from external sources, as is the case in the use of DU armour-piercing ordnance.

Table H.1 Water samples collection sites in Serbia and Montenegro

Sample Code	Sampling Date	Sampling Site	Coordinates	Sample Type
ANPA-SA06/01	30.10.01	Pržar	574041 713641	Tap water
ANPA-SA07/01	30.10.01	Pržar	573796 713729	Well water
ANPA-SA08/01	30.10.01	Pržar (Hotel)	573707 713478	Tap water
ANPA-SA13/01	31.10.01	Borovac	561577 695276	Tap water
ANPA-SA14/01	31.1001	Borovac	561162 694635	Well water
ANPA-SA15/01	31.10.01	Borovac	562061 694078	Well water
ANPA-SA16/01	31.10.01	Borovac	562087 694072	Well water
ANPA-SA17/01	31.10.01	Borovac	562028 694185	Well water
ANPA-SA23/01	31.10.01	Bratoselce		Well water
ANPA-SA27/01	01.11.01	Bukurevac	558184 688800	Well water
ANPA-M12/01	03.11.01	Cape Arza	300239 696157	Sea water

During the field mission to Serbia and Montenegro, water samples were collected in the locations reported shown in Table H.1. The samples were collected by means of polyethylene bottles and preserved in polyethylene containers by adjusting their pH to <2 at the time of collection. All the water samples were analysed by alpha spectrometry (Jia, 2001).

The main objectives of water sampling were to verify:

$$DU[\%] = 100 \cdot \frac{R_{U-nat} - R_m}{R_{U-nat} - R_{DU}} = 100 \cdot \frac{0.00725 - R_m}{0.00525}$$

- the possible contamination of underground aquifers due to the migration through the soil profile of uranium radioisotopes originating from depleted uranium ammunitions;
- the presence of any contamination of surface water bodies (including the sea) due to the erosion of contaminated areas;
- if the intake from drinking water of uranium isotopes originating from depleted uranium ordnance could represent a source of radiation exposure to the local population.

Table H.2 reports the activity concentrations of ^{238}U, ^{234}U, ^{235}U and the values of ^{234}U/^{238}U and ^{235}U/^{238}U activity ratios measured in the water samples. Table H.3 reports the concentrations of ^{238}U, ^{234}U, ^{235}U and the values of ^{234}U/^{238}U and ^{235}U/^{238}U concentration ratios calculated on the same samples. Tables H.2 and H.3 also report the percentage of DU contained in total uranium, calculated with the following formula, using the concentration data reported on Table H.3:

where:

R_m = ^{235}U/^{238}U (measured)

R_{U-nat} = ^{235}U/^{238}U (natural)

R_{DU} = ^{235}U/^{238}U (DU)

Table H.2 Activity concentrations (mBq l^{-1}) of ^{238}U, ^{234}U, ^{235}U on water samples

Sample Code	^{238}U mBq l^{-1}	^{234}U mBq l^{-1}	^{235}U mBq l^{-1}	$^{234}U/^{238}U$	$^{235}U/^{238}U$	%DU $^{235}U/^{238}U$ (mg/mg)
ANPA-SA13/01	5.20±0.36	5.79±0.38	0.28±0.09	1.11±0.11	0.054±0.018	nd
ANPA-SA17/01	0.61±0.13	0.86±0.14	0.03±0.04	1.41±0.39	0.045±0.064	4
ANPA-SA23/01	21.85±1.46	27.36±1.96	0.98±0.35	1.25±0.12	0.045±0.017	5
ANPA-SA27/01	0.56±0.12	0.83±0.13	0.02±0.02	1.47±0.40	0.044±0.032	9
ANPA-SA14/01	0.18±0.09	0.29±0.09	0.05±0.03	1.65±0.97	0.305±0.231	nd
ANPA-SA15/02	0.40±0.10	0.27±0.09	0.01±0.03	0.66±0.28	0.036±0.065	32
ANPA-SA16/02	0.52±0.11	0.43±0.11	0.02±0.03	0.82±0.28	0.036±0.065	33
ANPA-SA08/02	16.15±0.76	23.25±0.95	0.83±0.17	1.44±0.09	0.051±0.011	nd
ANPA-SA07/01	1.17±0.23	1.31±0.23	0.09±0.06	1.12±0.30	0.077±0.056	nd
ANPA-SA06/02	4.54±0.36	5.09±0.38	0.34±0.10	1.12±0.12	0.076±0.023	nd
ANPA-M12/01	44.45±1.58	49.75±1.72	2.20±0.29	1.12±0.06	0.050±0.007	nd

Table H.3 Concentrations (mg l^{-1}) of ^{238}U, ^{234}U, ^{235}U in water samples collected from

Sample Code	^{238}U mg l^{-1}	^{234}U mg l^{-1}	^{235}U mg l^{-1}	$^{234}U/^{238}U$	$^{235}U/^{238}U$	% DU $^{235}U/^{238}U$ (mg/mg)
ANPA-SA13/01	4.19E-04±2.93E-05	2.51E-08±1.66E-09	3.54E-06±1.14E-06	5.98E-05±5.72E-06	8.45E-03±2.78E-03	nd
ANPA-SA17/01	4.93E-05±1.09E-05	3.74E-09±6.27E-10	3.46E-07±4.83E-07	7.58E-05±1.36E-05	7.02E-03±9.92E-03	4
ANPA-SA23/01	1.76E-03±1.18E-04	1.18E-07±8.50E-09	1.23E-05±4.43E-06	6.72E-05±2.40E-06	6.97E-03±2.58E-03	5
ANPA-SA27/01	4.55E-05±1.00E-05	3.58E-09±5.81E-10	3.07E-07±2.17E-07	7.88E-05±1.83E-05	6.75E-03±5.00E-03	9
ANPA-SA14/01	1.43E-05±7.08E-06	1.27E-09±3.98E-10	6.78E-07±3.90E-07	8.88E-05±3.06E-05	4.73E-02±3.59E-02	nd
ANPA-SA15/02	3.25E-05±7.78E-06	1.15E-09±3.97E-10	1.81E-07±3.26E-07	3.54E-05±1.28E-05	5.57E-03±1.01E-02	32
ANPA-SA16/02	4.21E-05±9.21E-06	1.84E-09±4.79E-10	2.33E-07±4.18E-07	4.38E-05±1.20E-05	5.53E-03±1.00E-02	33
ANPA-SA08/02	1.30E-03±6.12E-05	1.01E-07±4.10E-09	1.04E-05±2.12E-06	7.73E-05±1.11E-05	7.97E-03±1.67E-03	nd
ANPA-SA07/01	9.42E-05±1.85E-05	5.66E-09±1.02E-09	1.12E-06±7.81E-07	6.01E-05±1.28E-05	1.19E-02±8.61E-03	nd
ANPA-SA06/02	3.66E-04±2.90E-05	2.20E-08±1.63E-09	4.30E-06±1.28E-06	6.02E-05±1.05E-05	1.17E-02±3.61E-03	nd
ANPA-M12/01	3.58E-03±1.27E-04	2.15E-07±7.44E-09	2.75E-05±3.64E-06	6.01E-05±6.84E-06	7.68E-03±1.05E-03	nd

The uncertainty estimation of each measurement reported in Tables H.2 and H.3 include:

- the uncertainty associated with the activity of the tracer (^{232}U) and the uncertainty associated with the addition of the tracer to the sample;
- the uncertainty associated with the counting statistics of the sample and the blank;
- the uncertainty associated with the weighing volume of the sample.

The $^{234}U/^{238}U$ activity ratios in the water samples collected in Serbia and Montenegro range from 0.66±0,28 to 1.65±0.97 (Bq/Bq) with a mean value of 1,20±0,29, while the concentration ratios range from 3.54E-05±1.28E-05 to 8.88E-05±3.06E-05 (mg/mg) with a mean value of 6.43E-05±1.56E-05 and a coefficient of variation of 24 %.

The data reported in Tables H.2 and H.3 indicate that ^{235}U data have very high uncertainties. This is attributable to the ^{235}U activity concentrations in the water, that were too low to be determined by alpha spectrometry. This isotope is best estimated using a mass-spectrometric technique (Bou-Rabee, 1995) rather than an alpha pulse-height analysis. On this basis, the positive % DU values reported in Tables H.2 and H.3 are to be considered as false positive as consequences of the high uncertainty associated with the ^{235}U analytical data.

On this basis, in the case of water samples collected in Serbia and Montenegro, the evaluation of the results has been made using only the ^{238}U and ^{234}U activity concentration data, obtained by alpha spectrometry, because of the better sensitivity of this method for these measurements (UNEP, 2001; Sansone et al., 2001).

Comparing the results obtained from the measurements of water samples collected in Serbia and Montenegro (Table H.2, Table H.3) with the reference values for natural waters (Goldstein et al., 1997), there is no evidence of DU contamination of drinking water. The results are also consistent with the results obtained from the water samples collected at the sites that were investigated by the UNEP DU Mission to Kosovo in 2000 (UNEP, 2001). Activity concentrations of naturally occurring radionuclides in drinking water vary widely because of the differing background levels, climatic and agricultural conditions that prevail. In the UNSCEAR report (UNSCEAR, 2000) the ^{238}U activity concentration in drinking water measured in Europe ranges from 5.0E-02 to 150 Bq l^{-1}. The values measured in the water samples collected during the field studies in Serbia and Montenegro are in all cases lower than the minimum value reported by UNSCEAR.

Based on the information currently available, uranium isotopes in water do not constitute a risk to health from a radiological point of view. In some cases, the aquifer depth is very close to the ground surface, so that the filtering action of the soil might be reduced (Sansone et al., 2001b) and DU leached from the penetrators might reach the groundwater system. Previous study (Sansone et al., 2001; 2001a) indicates that depleted uranium, when it occurs in small fragments or as dust particles, is more easily dissolved than uranium in mineral lattices. Thus, it has a higher mobility than natural uranium and the extent of the migration of dissolved DU through the soil profile could represent a potential risk of future contamination of the underground aquifers. Since only a limited number of samples have been collected in the areas where DU ordnance was used, ground water used for drinking should be checked in future to increase the confidence with regard to results observed during the field studies in Kosovo (UNEP, 2001) and in Serbia and Montenegro.

APPENDIX I

DU IN AIR

I.1 General aspects

■ Normal concentrations and radiation doses

The concentration of uranium in air varies widely. Reported values are 0.9-5 µBqm^{-3} in the United States and 0.02-18 µBqm^{-3} in Europe (UNSCEAR 2000 vol.1 page 123). The given reference value is 1 µBqm^{-3} of ^{238}U. That corresponds to 8 10^{-5} µg ^{238}U per m^3 air. Most of the natural levels of uranium will be in the range of 0.1-10 µBqm^{-3} ((1-100)10^{-5} µgm^{-3} or 0.01-1 ngm^{-3}).

The effective dose caused by inhalation of uranium and its radioactive daughter products as they are present in air is estimated to be 5.8 µSv per year. The major part is from Pb/Po-210. From ^{238}U alone it is 0.02 µSv per year, from ^{234}U 0.03 µSv per year. If all daughters of U-238 except radon and its daughter product are included, the dose is 0.3 µSv per year. The dose from ^{235}U and its daughter products can be neglected.

■ The relative concentrations of U-238 and U-234

The two uranium isotopes are in the same decay chain, the ^{238}U series, and if not disturbed by any selective chemical or physical effect they should be in radioactive equilibrium. In case of equilibrium, natural uranium contains by weight 99.2745 % of ^{238}U and 0.0054% of ^{234}U which in terms of activity corresponds to about 12.3 Bq each per mg of natural uranium. However, it has been observed that by chemical effects (different leaching rate) and physical effects (alpha recoil) as reported in WHO's study of *Depleted Uranium, Sources, Exposures and Health effects*, 2001 page 12, the ratio can vary 1-7 in favour of ^{234}U i.e. there is an excess of ^{234}U in dust in air. However, the real variation of the ratio of ^{234}U and ^{238}U in air at a given place or in a region reflects the variation of the ratio in soil at that location, as is discussed below.

In the case of depleted uranium, the concentration of ^{234}U decreases somewhat more than ^{235}U. If the concentration of ^{235}U decreases from 0.72 % to 0.20 % by weight i.e. a factor 3.6, while the concentration of ^{234}U decreases from 0.0054 % to 0.0010 % i.e. a factor 5.4. If DU is mixed with natural uranium in varying proportions the mass ratio as well as the activity ratio will vary accordingly.

Assuming that in a sample with some DU the mass proportion of DU is X and the part of natural uranium is 1-X the ratio ^{234}U/^{238}U is given from the formula:

$$\frac{(1-X)x0.0054 + Xx0.001}{(1-X)x99.2745 + Xx99.8}$$

This gives the mass ratio M. The activity ratio R is given by Mx2.31$0^5$/12.4.
For X=0 the R value is 1, for X=0.5 the R value is 0.6 and for X=1 the R value is 0.2 etc.

Corresponding formulas also apply for ^{235}U/^{238}U ratio, see Appendix O, 'Formulas and Data'.

Depleted uranium in air

By measurements on dust sampled with filters and subsequent chemical analysis, it is possible to estimate the concentrations of total uranium in air and also to find the concentration of ^{238}U - ^{235}U and ^{234}U. By using the formulas given, it is also possible to estimate the proportion of DU in the sample. However, from a health point of view, it is the concentration of uranium as such that is of interest. How much DU could possibly be expected in air in normal and extreme conditions if there is DU-dust contamination of the ground? What is the relation to the β/γ-measurement directly on the ground surface?

Relation 1. The normal situation

Assuming there is some correlation between the concentration of uranium in air pollution (dust) and that of the soil the following appliess:

- 1-3 mg U per kg soil
- Concentration of uranium in air 8 10^{-5}µgm^{-3} air
- Normal dust concentration 50 µgm^{-3}
- That gives 1.6 mg uranium/kg dust which is in agreement with the value above for uranium in soil.

Relation 2. DU contaminated ground surface

Assuming 10 kg of DU dust is distributed over the reference area of 1,000 m^2. This is the *Reference Case* in the report and the corresponding area contamination would be 10 gm^{-2}. The limit of detection with the β/γ-instrument used is 0.01 times the reference value (i.e. 0.1 gm^{-2}). If there is some absorption and the activity is distributed in the upper 1 mm of soil the limit of detection would be 10 times higher i.e. 1 gm^{-2}.

1 gm^{-2} in 1mm depth corresponds to 0.7 g DU per kg soil. Assuming that the first mm of soil is the part that mainly contributes to dust in the air, the concentration in normal dusty air would be 35 ng DU per m^3 of air (50 µgm^{-3} x 0.7ng DU per µg soil, dust) corresponding to 430 µBqm^{-3} in air, which is about 400 times higher than normal. This air concentration would result in an annual effective dose of less than 0.1 mSv (about 0.03 mSv) caused by continuous breathing of that air day and night during 365 days and is therefore insignificant.

Relation 3. DU contaminated ground and distributed in 10 cm depth.
Of course, the DU dust may have been distributed in a deeper layer than 1 mm, for instance 100 mm, with the consequence that the concentration of DU in soil would be 100 times less. Assuming the same amount of DU, 10 kg over 1,000 m^2, and the same pattern of suspension of dust from ground, the resulting DU concentration in air would be 100 times less and the surface contamination would similarly be 100 times lower than the detection limit.

Conclusions

1. Normal uranium concentration in air is 1µBqm^{-3} (8 10^{-5}µgm^{-3}) ± factor 10 upwards and downwards.
2. Resulting effective doses are 0.02-0.03 µSv per year from ^{238}U and ^{234}U respectively.
3. The ratio ^{234}U/^{238}U in air can normally vary as a result of natural causes, depending on the corresponding ratio in the soil at the location of investigation.
4. From measurements it is possible to estimate the proportion of possible DU in a sample by assessing the ratio ^{234}U/^{238}U if that is lower than 1. But there are many

uncertainties and a non-indicative value of ^{234}U/^{238}U does not necessarily mean that there is no DU in the air.

5. If there is no indication of DU contamination on the ground surface there can still be an easily detectable concentration of DU in air if the DU on the ground is superficial. On the other hand, if there is no detectable air contamination, there can still be a ground contamination above the reference level (10 g per m^2). That would be so if the nearby ground does not contribute significantly to the dust in air at the area under investigation.
6. From the radiation dose point of view it can be concluded that the effective doses from airborne uranium are very small, even if the concentration is several hundred times higher than normal. The heavy metal risks are also insignificant in these cases.

I.2 Results of air measurements in Serbia and Montenegro

■ Sampling sites

Air samples were collected at all sites investigated by the UNEP team. Table I.1 reports the sites where the air samples were collected in Serbia and Montenegro. At each of the sites (except Pljackovica) one filter system was placed in the centre of the fenced areas and the other two in symmetric positions near the borders of the fenced areas. The three systems were arranged in a line parallel to the wind direction. The distance between the systems were 30-50 m. At Pljackovica, only two systems were operated and the filter systems were standing within 3 m from each other. In Cape Arza the fenced area was not easily accessed so the systems were placed outside the fenced area, near the neighboring decontaminated area. During the time that UNEP teams' investigated the sites the weather was warm and dry. The wind speed was low to moderate, except at the Reljan site where it was a rather strong wind.

All air samples were analysed at the Italian National Environmental Protection Agency (ANPA) laboratories by alpha spectroscopy (see Appendix C 'Methodology and Quality Control').

Table I.1. Air-filter samples collection sites in Serbia and Montenegro

Results and Discussion

The $^{234}U/^{238}U$ and $^{235}U/^{238}U$ activity concentration ratios depend on the extent of the enrichment process, which causes depletion in the lighter uranium isotopes and can be used to distinguish natural from anthropogenic uranium. By measurements of dust collected by air filters and by analysing the uranium concentrations in the filters, the total uranium concentration in air, as well the concentrations of ^{234}U and ^{238}U, can be determined.

The analyses of the uranium isotopes in the samples collected during the UNEP mission were made at ANPA by alpha spectrometry. The minimum detection limits for the ^{235}U, using alpha spectrometry normally is of the same order of magnitude as the concentration of this nuclide in the air. Thus the uncertainties were significant because the activity of this nuclide per volume of air is much less than the activity of ^{238}U. Consequently, the judgment of the existence or not of DU contamination in the air must be based on the $^{234}U/^{238}U$ activity ratio if the analyses are made by alpha spectrometry and the ^{235}U concentrations are at normal levels for ^{235}U in air.

For natural uranium the $^{234}U/^{238}U$ activity ratio in soils with uranium of natural origin typically range from 0.5 to 1.2 (Sansone et. al., 2001b, references ANPA). In the case of Serbia and Montenegro the $^{234}U/^{238}U$ activity ratio was determined to be 1.01±0.09 in soil samples with uranium of natural origin (Burger M., 2002).

Disequilibrium between ^{234}U and ^{238}U in soil particles may exist due to alpha particle recoil from the decay of ^{238}U. In air uranium nuclides are present because of resuspension of soil particles, thus the $^{234}U/^{238}U$ activity ratio in air is within the same range as in the soil. If the above ratio is statistically lower than that expected for the natural range of activity ratios then the divergence could be attributed to the presence of depleted uranium in the air.

The results from the air filter analyses made on the samples from the UNEP DU mission are presented in Table I.2. The total uranium concentrations in the air are in the typical range of natural values. The highest value detected was from the samples collected at Bratoselce. At this site the highest values of natural uranium concentrations in soil were also measured. However, the $^{234}U/^{238}U$ activity ratio in the samples from Bratoselce is 0.9 and does not indicate any DU in the air.

The lowest uranium concentrations and also the lowest $^{234}U/^{238}U$ activity ratio values were measured in Cape Arza, which is located near the sea. It is well known that at coastal locations concentrations of uranium in air may be an order of magnitude lower than in continental or industrialised areas, which explains the low concentration of uranium-238.

The $^{234}U/^{238}U$ activity ratio in the two air samples from Pljackovica and the three from Cape Arza, are well below those expected from naturally occurring uranium in soil particles and they show that the air samples contain DU. The existence of the DU in air can only be explained by resuspension of DU contaminated particles in the air.

The resuspension may be caused by wind or the digging that took place near the pumps as the air filter pumps were working. The second explanation (resuspension due to digging) is possible but seems to be less probable especially in Cape Arza where the digging was not intensive and took place far away from the positions in which the pumps were operated. Nevertheless, from the current observations and results, it is difficult to determine the reason why DU contamination of air was found. More research and measurements are needed to clarify the mechanisms that cause this phenomenon.

Table I.2. Activity concentrations (μBq/m^3) of ^{238}U, ^{234}U in air-filter samples collected

Sample Code	Sampling Site	Duration (min)	Air volume (m^3)	U238 (μBq/m^3)	Error (μBq/m^3)	U234 (μBq/m^3)	Error (μBq/m^3)	Ratio U234/U238
Air:1-1	Pljackovica	115	156	22.86	1.46	6.20	0.73	0.27
Air:1-3	Pljackovica	115	156	19.14	1.08	6.77	0.61	0.35
Air:2-1	Borovac	110	150	2.96	0.44	3.26	0.46	1.10
Air:2-2	Borovac	110	150	2.33	0.34	2.22	0.34	0.95
Air:2-3	Borovac	110	150	3.01	0.39	2.01	0.34	0.67
Air:3-1	Bratoselce	85	116	7.99	0.78	7.87	0.77	0.98
A:3-2	Bratoselce	85	116	42.15	3.39	37.96	3.19	0.90
Air:3-3	Bratoselce	85	116	7.00	0.90	6.82	0.89	0.97
Air:4-1	Bukurevac	95	130	9.11	0.99	7.25	0.88	0.80
Air:4-2	Bukurevac	95	130	4.94	0.72	5.44	0.75	1.10
Air:4-3	Bukurevac	95	130	18.77	1.94	19.95	2.01	1.06
Air:5-1	Reljan	95	130	10.83	1.04	10.00	1.00	0.92
Air:5-2	Reljan	95	130	7.98	0.95	6.95	0.89	0.87
Air:5-3	Reljan	95	130	4.24	0.62	4.59	0.64	1.08
Air:6-1	Cape Arza	130	192	3.04	0.41	1.31	0.29	0.43
Air:6-2	Cape Arza	130	192	1.68	0.37	0.22	0.23	0.13
Air:6-3	Cape Arza	130	192	4.74	0.61	0.70	0.30	0.15

The doses due to the existence of DU in the air at the measured levels are negligible. This can be demonstrated by the following facts:

- The total uranium concentrations in places where DU contamination of air was detected were in the range of the values expected due to natural sources. Particularly in the case of Cape Arza, the total uranium concentration in air was much less than the other sites measured.
- The specific activity of depleted uranium is less than the specific activity of naturally occurring uranium.

Using the value 1.01±0.09 (Berger, 2002) for ^{238}U/^{238}U activity ratio as the reprentative value for samples with uranium of natural origin, the concentration of DU in air can be estimated. The committed effective dose due to the existence of DU in air as calculated on a worst-case scenario assuming that a person lives continuously for one year in the place where the maximum concentration of DU was detected (Pljackovica) is in the order of 1ì Sv. One has also to consider that the air samples were collected under dry warm weather conditions at moderate wind speed.

At higher wind speed the concentrations of DU in air might be higher, while in damp, rainy weather the DU particles are washed out from the air and deposited on the ground. However, the DU concentrations in air at the investigated sites will never be so high that the resulting doses will be significant.

Calculations based on the resuspension of soil particles from ground to air are very hard to perform because numerous unknown parameters are involved in such estimations. These include the exact physicochemical state of DU contamination compared with naturally occurring uranium and the vertical distribution of DU in the soil. These questions could be the subject of further research.

Conclusions

1. There is strong evidence for the existence of DU contamination in air at Pljackovica and Cape Arza.
2. The radiological significance of the contamination at the analysed levels was negligible (three orders of magnitude less than that expected due to other naturally occurring sources).
3. The dose estimations must be based on the air concentration measurements and not on models, which lead to great uncertainties because of the numerous unknown parameters involved in such estimations.
4. The clarification and verification of the mechanisms causing the DU contamination in air must be the subject of further research.

APPENDIX J

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BIO-INDICATORS OF DU

In studies of the abundance of toxic pollutants, a biological indicator can be generally defined as an organism which may be used to quantify relative levels of pollution through the measurement of the toxicant concentration in its tissues. Either the entire organism, or part of it, or a single tissue may be used. Biological monitoring based on measurement of the toxicant concentration in accumulator organisms which are able to concentrate pollutants, may supply a synthetic, direct and integrated response over time to environmental pollution levels. This technique, initially used to detect radionuclides from nuclear fall-out and effluents, has been successfully applied to non-nuclear pollution. In the case of atmospheric pollution, lichens, mosses, tree bark and pine needles are used as sufficiently sensitive and inexpensive techniques to monitor many contaminants at a large number of stations (Jeran et al., 1996).

Lichens, especially epiphytic ones, are widely used to monitor air contamination (Ferry et al., 1973; Richardson et al., 1980; Richardson and Nieboer, 1980; Nieboer and Richardson, 1981; Nash and Wirth, 1988; Sloof and Wolterbeek, 1991; Ribeiro Guevara et al., 1995; Haas et al.; 1998; McLean et al., 1998). They are efficient accumulators of many elements, particularly heavy metals and radionuclides that are released into the atmosphere because of natural and human activities (Jeran et al., 1995). Since the 1960s, they have been successfully employed to assess the global deposition of radionuclides derived from aerial nuclear weapons testing and the atmospheric re-entry of nuclear powered satellites (Holm and Persson, 1978; Taylor et al., 1979; Richardson and Nieboer, 1980). A large body of research has been carried out to monitor the radionuclides derived from the Chernobyl accident of 1986 (Adamo et al., 1989; Triulzi et al., 1996; Feige et al., 1990; Hoffmann et al., Loppi and De Dominicis, 1996). In addition, the distribution patterns of uranium and associated elements in lichens growing in the vicinity of uranium mining/milling operations have been extensively studied (Boileau et al., 1982; Jeran et al., 1995). The studies showed that lichens have a high capacity to accumulate uranium under moist and dry conditions from airborne particles and dust, and even tiny fragments of lichens may contain concentrations that can be readily detectable (Garty et al., 1979; Beckett et al., 1982; Trembley et al., 1997; Sansone et al., 2001).

Lichens consist of fungi and algae living together in a mutually beneficial way. Their remarkable capacity for accumulating pollutants is based on their intrinsic biology, as they lack roots and outer protective organs, such as stomata and cuticle, against the substances derived from the atmosphere, and excretory organs and deciduous parts (Jeran et al., 1995, 1996). Lichen morphology does not vary with the seasons and accumulation of pollutants can occur throughout the years. In addition, they are usually very long lived. Because they lack roots, lichens do not have access to soil nutrient pools and they depend on both wet and dry atmospheric deposition to obtain mineral nutrients.

The mechanisms of trace-element uptake and retention in lichens differ from species to species and from element to element. Study of the elemental composition has proved agreement between atmospheric element levels, element concentrations observed in the lichen tissues, and the exposure time of the lichens to airborne pollutants.

The accumulation and retention of trace elements is consistently higher than their physiological demand. Ecologically and structurally, mosses are closer to lichens than they are to other members of the plant kingdom. Mosses (Bryophyta) are quite interesting, simple green land plants with leaves and a stem and always without roots. Mosses depend upon external moisture to transport nutrients. Many mosses assimilate much of their nutrients and water through their tiny leaves. Unlike the leaves of higher (flowering) plants which have a waxy covering called a cuticle, mosses lack this protection. This allows mosses to take in water quickly through their leaves during periods of rain or high humidity, and to dry out fast when the air dries. This rapid and direct absorption is detrimental when the moisture is laden with pollutants.

Tree bark also accumulates atmospheric aereosols over long periods of time through wet and dry deposition, resulting in trace enrichment of environmental contaminants. Thus, tree bark has been widely employed as a passive monitor of airborne trace metal contamination. The UNEP depleted uranium environmental assessment in Kosovo (UNEP, 2001; Sansone et al., 2001) highlighted the possibility of using lichens and barks as indicators of past airborne contamination due to depleted uranium dust or aerosol particles, generated at the time of the conflict by the impact of DU penetrators.

On this basis, during the field mission in Serbia and Montenegro, lichen, moss and bark samples were collected at the sites visited by the UNEP team and the uranium isotopes were determined for the different species collected. Due to the large number of samples collected during the survey, uranium isotopes were measured only for a representative number of species.

A more detailed interpretation of the results in the lichen samples collected in Serbia and Montenegro will be published subsequently, since measurements continue on the samples collected.The main objective of the sampling performed in the field was to identify potential uranium accumulator organisms within the investigated sites and to confirm the results achieved during the UNEP survey in Kosovo.

Table J.1 reports the sites where the botanical samples were collected in Serbia and Montenegro.

Tables J.2, J.4, J.6, J.8 and J.10 report the activity concentrations of ^{238}U, ^{234}U, ^{235}U and the values of ^{234}U/^{238}U and ^{235}U/^{238}U activity ratios measured respectively in lichens collected from trees, rocks and soils and in bark and moss samples. Tables J.3, J.5, J.7, J.9 and J.11 report the concentrations of ^{238}U, ^{234}U, ^{235}U and the values of ^{234}U/^{238}U and ^{235}U/^{238}U concentration ratios calculated for the same samples. The Tables also report the percentage of DU of the total uranium calculated with the following formula, using the concentration data reported on Tables J.3, J.5, J.7, J.9 and J.11 where:

$$DU[\%] = 100 \cdot \frac{R_{U-nat} - R_m}{R_{U-nat} - R_{DU}} = 100 \cdot \frac{0.00725 - R_m}{0.00525}$$

R_m = ^{235}U/^{238}U (measured)

$R_{U\text{-nat}}$ = ^{235}U/^{238}U (natural)

R_{DU} = ^{235}U/^{238}U (DU)

Table J.1 Botanical samples collection sites in Serbia and Montenegro.

Sample Code	Sampling Date	Sampling Site	Coordinates	Sample type	Substrate
ANPA-SA01/03	30.10.01	Pljackovica	573657 714594	lichen	tree
ANPA-SA01/03CORT	30.10.01	Pljackovica	573657 714594	bark	
ANPA-SA01/04a	30.10.01	Pljackovica	573657 714594	lichen	tree
ANPA-SA01/04aCORT	30.10.01	Pljackovica	573657 714594	bark	
ANPA-SA02/03+04	30.10.01	Pljackovica	573664 714632	lichen	tree
ANPA-SA02/04a	30.10.01	Pljackovica	573664 714632	lichen	tree
ANPA-SA02/07	30.10.01	Pljackovica	573664 714632	lichen	tree
ANPA-SA02/08	30.10.01	Pljackovica	573664 714632	lichen	tree
ANPA-SA02/08CORT	30.10.01	Pljackovica	573664 714632	bark	
ANPA-SA03/01	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/02a	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/02b	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/02c	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/03a	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/03b	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/06a	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA03/06b	30.10.01	Pljackovica	573689 714660	lichen	tree
ANPA-SA04/01	30.10.01	Pljackovica	573637 714629	lichen	rock
ANPA-SA05/01	30.10.01	Pljackovica	573637 714562	lichen	tree
ANPA-SA09/01a	31.10.01	Borovac	561910 693899	lichen	tree
ANPA-SA09/01c	31.10.01	Borovac	561910 693899	lichen	tree
ANPA-SA10/01a	31.10.01	Borovac	561894 693852	lichen	tree
ANPA-SA10/04a	31.10.01	Borovac	561894 693852	lichen	tree
ANPA-SA12/01a	31.10.01	Borovac	561838 694023	lichen	tree
ANPA-SA12/01c	31.10.01	Borovac	561838 694023	lichen	tree
ANPA-SA12/02a	31.10.01	Borovac	561838 694023	lichen	tree
ANPA-SA12/02b	31.10.01	Borovac	561838 694023	lichen	tree
ANPA-SA12/02c	31.10.01	Borovac	561838 694023	lichen	tree
ANPA-SA18/01	31.10.01	Bratoselce	562274 688318	lichen	soil
ANPA-SA19/01a	31.10.01	Bratoselce	562305 688342	lichen	tree
ANPA-SA20/01a	31.10.01	Bratoselce	562305 688312	lichen	tree
ANPA-SA21/02a	31.10.01	Bratoselce	562258 688363	lichen	tree
ANPA-SA21/02aCORT	31.10.01	Bratoselce	562258 688363	bark	
ANPA-SA21/03a	31.10.01	Bratoselce	562258 688363	lichen	tree
ANPA-SA21/03aCORT	31.10.01	Bratoselce	562258 688363	bark	
ANPA-SA21/04	31.10.01	Bratoselce	562258 688363	lichen	tree
ANPA-SA21/04CORT	31.10.01	Bratoselce	562258 688363	bark	
ANPA-SA22/01a	31.10.01	Bratoselce	562282 688396	lichen	tree
ANPA-SA22/01b	31.10.01	Bratoselce	562282 688396	lichen	tree
ANPA-SA25/02a	01.11.01	Bukurevac	558156 688423	lichen	tree
ANPA-SA25/02b	01.11.01	Bukurevac	558156 688423	lichen	tree
ANPA-SA26/01a	01.11.01	Bukurevac	558084 688527	lichen	tree
ANPA-SA26/01aCORT	01.11.01	Bukurevac	558084 688527	bark	
ANPA-SA28/01a	01.11.01	Reljan	563208 685137	lichen	tree
ANPA-SA29/01a	01.11.01	Reljan	563173 685079	lichen	tree
ANPA-SA29/01a	01.11.01	Reljan	563173 685079	bark	
ANPA-SA30/01a	01.11.01	Reljan	563171 685063	lichen	soil
ANPA-SA30/01b	01.11.01	Reljan	563171 685063	lichen	soil
ANPA-SA31/01a	01.11.01	Reljan	563123 685073	lichen	rock
ANPA-SA31/02	01.11.01	Reljan	563123 685073	moss	rock
ANPA-M01/01a	03.11.01	Cape Arza	300180 696077	lichen	tree

ANPA-M02/01a	03.11.01	Cape Arza	300180 696077	lichen	tree
ANPA-M03/01a	03.11.01	Cape Arza	300187 696137	lichen	tree
ANPA-M03/01aCORT	03.11.01	Cape Arza	300187 696137	bark	
ANPA-M04/01	03.11.01	Cape Arza	300188 696136	moss	rock
ANPA-M05/02a	03.11.01	Cape Arza	300257 696122	lichen	tree
ANPA-M05/02b	03.11.01	Cape Arza	300257 696122	lichen	tree
ANPA-M06/01a	03.11.01	Cape Arza	300065 696128	lichen	tree
ANPA-M6/02a	03.11.01	Cape Arza	300065 696128	lichen	tree
ANPA-M6/02aCORT	03.11.01	Cape Arza	300065 696128	bark	
ANPA-M07/01a	03.11.01	Cape Arza	300222 696092	lichen	tree
ANPA-M07/01b	03.11.01	Cape Arza	300222 696092	lichen	tree
ANPA-M07/01c	03.11.01	Cape Arza	300222 696092	lichen	tree
ANPA--M08/01	03.11.01	Cape Arza	300222 696092	lichen	tree
ANPA--M08/01CORT	03.11.01	Cape Arza	300222 696092	bark	
ANPA--M09/01a	03.11.01	Cape Arza	300234 696084	lichen	tree
ANPA--M09/01aCORT	03.11.01	Cape Arza	300234 696084	bark	
ANPA--M10/01a	03.11.01	Cape Arza	300222 696092	lichen	soil
ANPA-M11/01	03.11.01	Cape Arza	300222 696092	lichen	tree

Table J.2. Activity concentrations of ^{238}U ^{234}U ^{235}U in lichen samples collected from trees located in Serbia and Montenegro.

Sample Code	Species	^{238}U Bq kg^{-1}	^{234}U Bq kg^{-1}	^{235}U Bq kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Pljačkovica							
ANPA-SA01/03	*Parmelia borreri*	4.04 ± 0.28	3.87 ± 0.27	0.25 ± 0.08	0.96 ± 0.09	0.061 ± 0.021	nd
ANPA-SA01/04a	*Parmelia borreri*	2.65 ±0.26	2.51 ± 0.25	0.17 ± 0.08	0.95 ± 0.13	0.063 ± 0.029	nd
ANPA-SA02/03+04	*Hypogymnia farinacea*	3.22 ± 0.17	2.77 ± 0.15	0.16 ± 0.04	0.86 ± 0.07	0.050 ± 0.014	nd
ANPA-SA02/04a	*Parmelia acetabulum*	3.57 ± 0.20	3.30 ± 0.19	0.16 ± 0.05	0.93 ± 0.08	0.043 ± 0.015	10
ANPA-SA02/07	*Parmelia borreri*	2.49 ±0.29	2.21 ± 0.27	0.08 ± 0.07	0.89 ± 0.15	0.032 ± 0.029	44
ANPA-SA02/08	*Parmelia borreri*	1.73 ± 0.11	1.81 ± 0.11	0.10 ± 0.03	1.04 ± 0.09	0.060 ± 0.020	nd
ANPA-SA03/01	*Parmelia tiliacea*	2.82 ± 0.28	3.46 ± 0.32	0.19 ± 0.09	1.23 ± 0.17	0.068 ± 0.032	nd
ANPA-SA03/02a	*Pseudevernia furfuracea*	0.70 ±0.08	0.69 ± 0.08	0.04 ± 0.03	0.99 ± 0.16	0.061 ± 0.047	nd
ANPA-SA03/02b	*Hypogymnia farinacea*	1.51 ±0.11	1.42 ± 0.11	0.08 ± 0.03	0.94 ± 0.10	0.050 ± 0.023	nd
ANPA-SA03/02c	*Parmelia sulcata*	4.76 ± 0.39	5.03 ± 0.40	0.30 ± 0.11	1.06 ± 0.12	0.063 ± 0.023	nd
ANPA-SA03/03a	*Pseudevernia furfuracea*	0.89 ± 0.13	0.89 ± 0.13	0.02 ± 0.04	1.00 ± 0.20	0.027 ± 0.046	59
ANPA-SA03/03b	*Hypogymnia farinacea*	1.50 ± 0.16	1.02 ± 0.14	0.04 ± 0.04	0.68 ± 0.12	0.027 ± 0.029	57
ANPA-SA03/06a	*Hypogymnia farinacea*	1.48 ± 0.12	1.48 ± 0.12	0.04 ± 0.03	1.00 ± 0.11	0.026 ± 0.021	61
ANPA-SA03/06b	*Hypogymnia farinacea*	0.85 ± 0.13	0.80 ± 0.12	0.12 ± 0.06	0.94 ± 0.20	0.141 ± 0.071	nd
ANPA-SA05/01	*Ramalina farinacea*	0.72 ± 0.12	0.49 ± 0.11	0.03 ± 0.05	0.69 ± 0.19	0.037 ± 0.066	30

Borovac							
ANPA-SA09/01a	*Parmelia sulcata*	2.71 ± 0.19	2.70 ± 0.19	0.05 ± 0.03	1.00 ± 0.10	0.020 ± 0.012	79
ANPA-SA09/01c	*Parmelia acetabulum*	2.77 ± 0.18	3.00 ± 0.19	0.16 ± 0.05	1.08 ± 0.10	0.057 ± 0.018	nd
ANPA-SA10/01a	*Xanthoria parietina*	1.40 ± 0.14	1.23 ± 0.13	0.07 ± 0.04	0.88 ± 0.13	0.049 ± 0.031	nd
ANPA-SA10/04a	*Xanthoria parietina*	1.79 ± 0.12	1.80 ± 0.12	0.09 ± 0.04	1.00 ± 0.09	0.052 ± 0.020	nd
ANPA-SA12/01a	*Pseudevernia furfuracea*	1.08 ± 0.12	0.91 ± 0.11	0.06 ± 0.04	0.84 ± 0.14	0.051 ± 0.037	nd
ANPA-SA12/01c	*Parmelia sulcata*	3.24 ± 0.24	3.47 ± 0.24	0.19 ± 0.07	1.07 ± 0.11	0.057 ± 0.022	nd
ANPA-SA12/02c	*Parmelia borreri*	4.14 ± 0.32	4.70 ± 0.35	0.33 ± 0.09	1.13 ± 0.12	0.079 ± 0.023	nd
ANPA-SA12/02a	*Physcia biziana*	4.14 ± 0.27	4.69 ± 0.29	0.22 ± 0.07	1.13 ± 0.10	0.052 ± 0.018	nd
ANPA-SA12/02b	*Parmelia acetabulum*	5.76 ± 0.29	5.32 ± 0.27	0.17 ± 0.06	0.92 ± 0.07	0.029 ± 0.010	52
Bratoselce							
ANPA-SA19/01a	*Physcia adscendens*	2.82 ± 0.24	2.82 ± 0.24	0.20 ± 0.07	1.00 ± 0.12	0.070 ± 0.026	nd
ANPA-SA20/01a	*Physcia adscendens*	2.80 ± 0.27	1.81 ± 0.22	0.13 ± 0.09	0.65 ± 0.10	0.046 ± 0.031	3
ANPA-SA21/02a	*Physcia biziana*	3.08 ± 0.16	2.69 ± 0.14	0.09 ± 0.03	0.87 ± 0.06	0.029 ± 0.011	53
ANPA-SA21/03a	*Parmelia acetabulum*	4.04 ± 0.21	4.25 ± 0.22	0.21 ± 0.06	1.05 ± 0.08	0.053 ± 0.014	nd
ANPA-SA21/04	*Parmelia borreri*	3.51 ± 0.19	3.11 ± 0.18	0.09 ± 0.04	0.88 ± 0.07	0.025 ± 0.011	64
ANPA-SA22/01a	*Parmelia quercina*	3.01 ± 0.15	2.96 ± 0.15	0.10 ± 0.03	0.98 ± 0.07	0.034 ± 0.011	36
ANPA-SA22/01b	*Physcia biziana*	4.36 ± 0.20	4.30 ± 0.20	0.31 ± 0.06	0.99 ± 0.07	0.071 ±0 .014	nd
Bukurevac							
ANPA-SA25/02a	*Physcia tenella*	4.89 ± 0.26	5.70 ± 0.28	0.19 ± 0.06	1.16 ± 0.08	0.039 ± 0.012	22
ANPA-SA25/02b	*Physconia grisea*	3.50 ± 0.27	3.25 ± 0.26	0.25 ± 0.09	0.93 ± 0.10	0.072 ± 0.025	nd
ANPA-SA26/01a	*Physconia grisea*	5.83 ± 0.27	5.88 ± 0.27	0.30 ± 0.07	1.01 ± 0.07	0.051 ± 0.011	nd
Reljan							
ANPA-SA28/01a	*Physcia adscendens*	2.79 ± 0.16	2.49± 0.15	0.11 ± 0.04	0.89 ± 0.08	0.040 ± 0.013	21
ANPA-SA29/01a	*Physcia adscendens*	2.65 ± 0.17	2.41± 0.16	0.12 ± 0.05	0.91 ± 0.08	0.047 ± 0.018	nd
Cape Arza							
ANPA-M01/01a	*Xanthoria parietina*	0.89 ± 0.12	0.97 ± 0.12	0.09 ± 0.04	1.08 ± 0.20	0.097 ± 0.050	nd
ANPA-M02/01a	*Parmelia subrudecta*	7.38 ± 0.38	3.59 ± 0.26	0.21 ± 0.07	0.49 ± 0.04	0.028 ± 0.010	56
ANPA-M03/01a	*Parmotrema chinense*	5.02 ± 0.33	3.53 ± 0.27	0.13 ± 0.06	0.70 ± 0.07	0.026 ± 0.012	63
ANPA-M05/02a	*Parmotrema chinense*	7.39 ± 0.53	6.68 ± 0.49	0.33 ± 0.11	0.90 ± 0.09	0.044 ± 0.015	7
ANPA-M05/02b	*Parmotrema hypoleucinum*	5.66 ± 0.46	4.58 ± 0.40	0.15 ± 0.08	0.81 ± 0.10	0.027 ± 0.014	58

ANPA-M06/01a	*Parmelia subrudecta*	14.33± 0.40	6.80 ± 0.24	0.32 ± 0.05	0.47 ± 0.02	0.022 ± 0.004	73
ANPA-M06/02a	*Xanthoria parietina*	12.90± 0.36	5.98 ± 0.22	0.43 ± 0.06	0.46 ± 0.02	0.033 ± 0.005	41
ANPA-M07/01a	*Parmelia borreri*	78.29± 3.78	13.20±0.94	0.58 ± 0.19	0.17 ± 0.01	0.007 ± 0.002	116
ANPA-M07/01b	*Hypogymnia tubulosa*	60.77 ± 1.72	9.85 ± 0.48	0.70 ± 0.13	0.16 ± 0.01	0.011 ± 0.002	104
ANPA-M07/01c	*Parmotrema chinense*	79.22± 4.24	13.09±1.05	1.53 ± 0.34	0.17 ± 0.02	0.019 ± 0.004	81
ANPA-M08/01	*Parmelia soredians*	61.24± 2.86	11.90± 0.76	0.72 ± 0.17	0.19 ± 0.02	0.012 ± 0.003	104
ANPA-M09/01a	*Parmotrema chinense*	52.12± 1.55	11.13± 0.54	0.91 ± 0.16	0.21 ± 0.01	0.017 ± 0.003	87
ANPA-M11/01	Parmotremahypoleucinum	22.70±0.77	4.72± 0.24	0.51±0.08	0.21±0.01	0.022±0.003	72

Table J.3 Concentrations of ^{238}U ^{234}U ^{235}U in lichen samples collected from trees located in Serbia and Montenegro.

Sample Code	Species	^{238}U mg kg^{-1}	^{234}U mg kg^{-1}	^{235}U mg kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Pljačkovica							
ANPA-SA01/03	*Parmelia borreri*	3.26E-01±2.26E-02	1.68E-05±1.19E-06	3.07E-03±1.04E-03	5.14E-05±5.09E-06	9.40E-03±3.24E-03	nd
ANPA-SA01/04a	*Parmelia borreri*	2.14E-01±2.07E-02	1.09E-05±1.08E-06	2.08E-03±9.40E-04	5.08E-05±7.05E-06	9.74E-03±4.50E-03	nd
ANPA-SA 02/03+04	*Hypogymnia farinacea*	2.60E-01±1.34E-02	1.20E-05±6.66E-07	2.01E-03±5.49E-04	4.63E-05±3.51E-06	7.76E-03±2.15E-03	nd
ANPA-SA02/04a	*Parmelia acetabulum*	2.88E-01±1.62E-02	1.43E-05±8.36E-07	1.94E-03±6.50E-04	4.97E-05±4.04E-06	6.73E-03±2.29E-03	10
ANPA-SA02/07	*Parmelia borreri*	2.01E-01±2.32E-02	9.58E-06±1.18E-06	9.94E-04±8.81E-04	4.77E-05±8.05E-06	4.95E-03±4.43E-03	44
ANPA-SA02/08	*Parmelia borreri*	1.40E-01±8.94E-03	7.83E-06±4.90E-07	1.30E-03±4.15E-04	5.60E-05±5.00E-06	9.28E-03±3.03E-03	nd
ANPA-SA03/01	*Parmelia tiliacea*	2.27E-01±2.30E-02	1.50E-05±1.37E-06	2.38E-03±1.10E-03	6.60E-05±9.01E-06	1.05E-02±4.94E-03	nd
ANPA-SA03/02a	*Pseudevernia furfuracea*	5.65E-02±6.62E-03	3.00E-06±3.54E-07	5.33E-04±4.07E-04	5.32E-05±8.84E-06	9.44E-03±7.29E-03	nd
ANPA-SA03/02b	*Hypogymnia farinacea*	1.22E-01±8.74E-03	6.13E-06±4.55E-07	9.41E-04±4.19E-04	5.03E-05±5.20E-06	7.73E-03±3.49E-03	nd
ANPA-SA03/02c	*Parmelia sulcata*	3.84E-01±3.14E-02	2.18E-05±1.74E-06	3.73E-03±1.36E-03	5.68E-05±6.49E-06	9.73E-03±3.63E-03	nd
ANPA-SA03/03a	*Pseudevernia furfuracea*	7.16E-02±1.03E-02	3.84E-06±5.54E-07	2.96E-04±5.06E-04	5.37E-05±1.09E-05	4.14E-03±7.09E-03	59
ANPA-SA03/03b	*Hypogymnia farinacea*	1.21E-01±1.30E-02	4.40E-06±5.88E-07	5.13E-04±5.37E-04	3.64E-05±6.24E-06	4.24E-03±4.47E-03	57
ANPA-SA03/06a	*Hypogymnia farinacea*	1.20E-01±9.38E-03	6.42E-06±5.03E-07	4.87E-04±3.79E-04	5.37E-05±5.96E-06	4.07E-03±3.18E-03	61
ANPA-SA03/06b	*Hypogymnia farinacea*	6.89E-02±1.01E-02	3.48E-06±5.32E-07	1.51E-03±7.22E-04	5.05E-05±1.07E-05	2.19E-02±1.10E-02	nd
ANPA-SA05/01	*Ramalina farinacea*	5.79E-02±9.87E-03	2.14E-06±4.68E-07	3.30E-04±5.86E-04	3.69E-05±1.02E-05	5.70E-03±1.02E-02	30
Borovac							
ANPA-SA09/01a	*Parmelia sulcata*	2.18E-01±1.50E-02	1.17E-05±8.04E-07	6.75E-04±3.95E-04	5.35E-05±5.21E-06	3.09E-03±1.82E-03	79
ANPA-SA09/01c	*Parmelia acetabulum*	2.23E-01±1.47E-02	1.3E-05±8.23E-07	1.96E-03±6.05E-04	5.81E-05±5.30E-06	8.79E-03±2.77E-03	nd
ANPA-SA10/01a	*Xanthoria parietina*	1.13E-01±1.11E-02	5.34E-06±5.63E-07	8.57E-04±5.34E-04	4.74E-05±6.85E-06	7.61E-03±4.80E-03	nd
ANPA-SA10/04a	*Xanthoria parietina*	1.45E-01±9.37E-03	7.78E-06±5.04E-07	1.16E-03±4.46E-04	5.39E-05±4.94E-06	8.04E-03±3.13E-03	nd
ANPA-SA12/01a	*Pseudevernia furfuracea*	8.74E-02±9.85E-03	3.95E-06±4.92E-07	6.95E-04±4.92E-04	4.52E-05±7.60E-06	7.95E-03±5.70E-03	nd

ANPA-SA12/01c	*Parmelia sulcata*	2.61E-01±1.91E-02	1.50E-05±1.06E-06	2.32E-03±8.57E-04	5.74E-05±5.83E-06	8.88E-03±3.34E-03	nd
ANPA-SA12/02c	*Parmelia borreri*	3.34E-01±2.59E-02	2.03E-05±1.5E-06	4.09E-03±1.16E-03	6.09E-05±6.51E-06	1.23E-02±3.60E-03	nd
ANPA-SA12/02a	*Physcia biziana*	3.34E-01±2.16E-02	2.03E-05±1.24E-06	2.71E-03±9.28E-04	6.08E-05±5.41E-06	8.13E-03±2.83E-03	nd
ANPA-SA12/02b	*Parmelia acetabulum*	4.65E-01±2.30E-02	2.3E-05±1.18E-06	2.11E-03±7.21E-04	4.96E-05±3.54E-06	4.53E-03±1.57E-03	52
Bratoselce							
ANPA-SA19/01a	*Physcia adscendens*	2.27E-01±1.94E-02	1.22E-05±1.04E-06	2.48E-03±9.04E-04	5.37E-05±6.48E-06	1.09E-02±4.09E-03	nd
ANPA-SA20/01a	*Physcia adscendens*	2.25E-01±2.19E-02	7.84E-06±9.65E-07	1.60E-03±1.07E-03	3.48E-05±5.45E-06	7.10E-03±4.81E-03	3
ANPA-SA21/02a	*Physcia biziana*	2.49E-01±1.25E-02	1.16E-05±6.25E-07	1.11E-03±4.18E-04	4.68E-05±3.44E-06	4.46E-03±1.70E-03	53
ANPA-SA21/03a	*Parmelia acetabulum*	3.26E-01±1.73E-02	1.84E-05±9.54E-07	2.68E-03±7.06E-04	5.65E-05±4.19E-06	8.21E-03±2.21E-03	nd
ANPA-SA21/04	*Parmelia borreri*	2.83E-01±1.51E-02	1.35E-05±7.60E-07	1.10E-03±4.78E-04	4.75E-05±3.69E-06	3.87E-03±1.70E-03	64
ANPA-SA22/01a	*Parmelia quercina*	2.43E-01±1.20E-02	1.28E-05±6.40E-07	1.30E-03±3.99E-04	5.29E-05±3.72E-06	5.34E-03±1.66E-03	36
ANPA-SA22/01b	*Physcia biziana*	3.52E-01±1.64E-02	1.86E-05±8.71E-07	3.87E-03±7.23E-04	5.29E-05±3.49E-06	1.10E-02±2.12E-03	nd
Bukurevac							
ANPA-SA25/02a	*Physcia tenella*	3.95E-01±2.08E-02	2.47E-05±1.22E-06	2.41E-03±7.11E-04	6.25E-05±4.52E-06	6.11E-03±1.83E-03	22
ANPA-SA25/02b	*Physconia grisea*	2.82E-01±2.17E-02	1.41E-05±1.12E-06	3.13E-03±1.06E-03	4.98E-05±5.51E-06	1.11E-02±3.87E-03	nd
ANPA-SA26/01a	*Physconia grisea*	4.70E-01±2.15E-02	2.54E-05±1.16E-06	3.75E-03±8.19E-04	5.41E-05±3.49E-06	7.98E-03±1.78E-03	nd
Reljan							
ANPA-SA28/01a	*Physcia adscendens*	2.25E-01±1.31E-02	1.08E-05±6.61E-07	1.38E-03±4.62E-04	4.80E-05±4.06E-06	6.13E-03±2.08E-03	21
ANPA-SA29/01a	*Physcia adscendens*	2.14E-01±1.36E-02	1.04E-05±6.94E-07	1.56E-03±5.86E-04	4.88E-05±4.48E-06	7.30E-03±2.77E-03	nd
Cape Arza							
ANPA-M01/01a	*Xanthoria parietina*	7.21E-02±9.54E-03	4.20E-06±5.32E-07	1.08E-03±5.36E-04	5.82E-05±1.07E-05	1.50E-02±7.69E-03	nd
ANPA-M02/01a	*Parmelia subrudecta*	5.95E-01±3.08E-02	1.55E-05±1.12E-06	2.57E-03±9.10E-04	2.61E-05±2.31E-06	4.32E-03±1.54E-03	56
ANPA-M03/01a	*Parmotrema chinense*	4.05E-01±2.64E-02	1.53E-05±1.16E-06	1.60E-03±7.35E-04	3.78E-05±3.77E-06	3.96E-03±1.83E-03	63
ANPA-M05/02a	*Parmotrema chinense*	5.96E-01±4.25E-02	2.89E-05±2.13E-06	4.09E-03±1.32E-03	4.85E-05±4.98E-06	6.86E-03±2.26E-03	7
ANPA-M05/02b	*Parmotrema hypoleucinum*	4.56E-01±3.72E-02	1.98E-05±1.75E-06	1.91E-03±9.74E-04	4.35E-05±5.23E-06	4.18E-03±2.16E-03	58
ANPA-M06/01a	*Parmelia subrudecta*	1.16E+00±3.24E-02	2.95E-05±1.05E-06	3.97E-03±6.58E-04	2.55E-05±1.15E-06	3.44E-03±5.78E-04	73
ANPA-M06/02a	*Xanthoria parietina*	1.04E+00±2.94E-02	2.59E-05±9.50E-07	5.32E-03±7.40E-04	2.49E-05±1.15E-06	5.11E-03±7.26E-04	41
ANPA-M07/01a	*Parmelia borreri*	6.31E+00±3.05E-01	5.72E-05±4.06E-06	7.28E-03±2.34E-03	9.05E-06±7.77E-07	1.15E-03±3.76E-04	116
ANPA-M07/01b	*Hypogymnia tubulosa*	4.90E+00±1.39E-01	4.27E-05±2.08E-06	8.72E-03±1.68E-03	8.70E-06±4.90E-07	1.78E-03±3.46E-04	104
ANPA-M07/01c	*Parmotrema chinense*	6.39E+00±3.42E-01	5.67E-05±4.53E-06	1.91E-02±4.28E-03	8.87E-06±8.54E-07	2.98E-03±6.89E-04	81
ANPA-M08/01	*Parmelia soredians*	4.94E+00±2.31E-01	5.15E-05±3.27E-06	8.97E-03±2.07E-03	1.04E-05±8.22E-07	1.82E-03±4.27E-04	104
ANPA-M09/01a	*Parmotrema chinense*	4.20E+00±1.25E-01	4.82E-05±2.33E-06	1.13E-02±2.01E-03	1.15E-05±6.52E-07	2.69E-03±4.84E-04	87
ANPA-M11/01	*Parmotrema hypoleucinum*	1.83E+00±6.18E-02	2.04E-05±1.04E-06	6.33E-03±9.62E-04	1.12E-05±6.80E-07	3.45E-03±5.38E-04	72

Table J.4 Activity concentrations of ^{238}U ^{234}U ^{235}U in lichen samples collected from rocks located in Serbia and Montenegro.

Sample Code	Species	^{238}U Bq kg^{-1}	^{234}U Bq kg^{-1}	^{235}U Bq kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Pljačkovica							
ANPA-SA04/01	*Lecanora muralis*	11.44 ± 2.37	11.96 ± 2.94	0.72 ± 0.29	1.04 ± 0.11	0.063 ± 0.022	nd
Rejlan							
ANPA-SA31/01a	*Ramalina capitata*	2.22 ± 0.67	1.76 ± 0.20	0.10 ± 0.05	0.84 ± 0.27	0.050 ± 0.034	nd

Table J.5 Concentrations of ^{238}U ^{234}U ^{235}U in lichen samples collected from rocks located in Serbia and Montenegro.

Sample Code	Species	^{238}U mg kg^{-1}	^{234}U mg kg^{-1}	^{235}U mg kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Pljačkovica							
ANPA-SA04/01	*Lecanora muralis*	9.23E-01±1.91E-01	5.18E-05±1.27E-05	8.95E-03±3.66E-03	5.58E-05±6.01E-06	9.73E-03±3.34E-03	nd
Rejlan							
ANPA-SA31/01a	*Ramalina capitata*	1.79E-01±5.39E-02	7.61E-06±8.73E-07	1.28E-03±5.84E-04	4.53E-05±1.47E-05	7.82E-03±5.34E-03	nd

Table J.6 Activity concentrations of ^{238}U ^{234}U ^{235}U in lichen samples collected from soil in Serbia and Montenegro.

Sample Code	Species	^{238}U Bq kg^{-1}	^{234}U Bq kg^{-1}	^{235}U Bq kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Bratoselce							
ANPA-SA18/01	*Cladonia convoluta*	82.00 ± 4.98	42.41 ± 2.71	2.23 ± 0.35	0.52 ± 0.05	0.027 ± 0.005	58
Rejlan							
ANPA-SA30/01a	*Parmelia somloensis*	14.07 ± 0.83	15.21 ± 0.88	0.65 ± 0.14	1.08 ± 0.09	0.04 ± 0.001	2
ANPA-SA30/01b	*Cladonia convoluta*	15.86 ± 1.08	15.81 ± 1.08	0.99 ± 0.25	1.00 ± 0.10	0.062 ± 0.017	nd
Cape arza							
ANPA-M10/01a	*Cladonia rangiformis*	69.36 ± 1.89	10.36 ± 0.38	0.95 ± 0.10	0.15 ± 0.01	0.014 ± 0.001	97

Table J.7 Concentrations of ^{238}U ^{234}U ^{235}U in lichen samples collected from soil in Serbia and Montenegro.

Sample Code	Species	^{238}U mg kg^{-1}	^{234}U mg kg^{-1}	^{235}U mg kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Bratoselce							
ANPA-SA18/01	*Cladonia convoluta*	6.61E+00±4.01E-01	1.84E-04±1.17E-05	2.79E-02±4.34E-03	2.78E-05±2.45E-06	4.22E-03±7.05E-04	58
Rejlan							
ANPA-SA30/01a	*Parmelia somloensis*	1.13E+00±6.67E-02	6.58E-05±3.80E-06	8.09E-03±1.73E-03	5.80E-05±4.78E-06	7.13E-03±1.58E-03	2
ANPA-SA30/01b	*Cladonia convoluta*	1.28E+00±8.70E-02	6.85E-05±4.66E-06	1.24E-02±3.17E-03	5.35E-05±5.15E-06	9.67E-03±2.56E-03	nd
Cape Arza							
ANPA-M10/01a	*Cladonia rangiformis*	5.59E+00±1.53E-01	4.49E-05±1.63E-06	1.19E-02±1.21E-03	8.02E-06±3.64E-07	2.13E-03±2.24E-04	97

Table J.8 Activity concentrations of ^{238}U ^{234}U ^{235}U from bark samples collected in Serbia and Montenegro.

Sample Code	^{238}U Bq kg^{-1}	^{234}U Bq kg^{-1}	^{235}U Bq kg^{-1}	$^{234}U/^{238}U$	$^{235}U/^{238}U$	% DU $^{235}U/^{238}U$ (mg/mg)
Pljačkovica						
ANPA-SA01/03 CORT	1.83 ± 0.14	2.04 ± 0.15	0.13 ± 0.05	1.11 ± 0.12	0.069 ± 0.029	nd
ANPA-SA01/04a CORT	1.88 ± 0.14	1.67 ± 0.13	0.05 ± 0.04	0.88 ± 0.10	0.028 ± 0.021	56
ANPA-SA02/08 CORT	0.81 ± 0.08	0.82 ± 0.08	0.03 ± 0.03	1.02 ± 0.14	0.037 ± 0.035	29
Bratoselce						
ANPA-SA21/02a CORT	2.43 ± 0.18	2.38 ± 0.18	0.10 ± 0.06	0.98 ± 0.11	0.041 ± 0.024	16
ANPA-SA21/03a CORT	3.11 ± 0.18	3.10 ± 0.18	0.12 ± 0.04	1.00 ± 0.08	0.040 ± 0.014	20
ANPA-SA21/04 CORT	3.41 ± 0.18	3.30 ± 0.18	0.20 ± 0.05	0.97 ± 0.07	0.060 ± 0.016	nd
Bukurevac						
ANPA-SA26/01a CORT	2.37 ± 0.13	2.55 ± 0.13	0.18 ± 0.04	1.08 ± 0.08	0.078 ± 0.018	nd
Rejlan						
ANPA-SA29/01a CORT	1.02 ± 0.11	1.15 ± 0.12	0.05 ± 0.02	1.13 ± 0.17	0.048 ± 0.024	nd
Cape Arza						
ANPA-M03/01a CORT	5.92 ± 0.59	5.77 ± 0.58	0.16 ± 0.11	0.98 ± 0.14	0.026 ± 0.020	61
ANPA-M06/02a CORT	3.65 ± 0.17	1.11 ± 0.10	0.06 ± 0.03	0.31 ± 0.03	0.015 ± 0.009	92
ANPA-M08/01 CORT	19.60 ± 0.75	3.34 ± 0.24	0.32 ± 0.08	0.17 ± 0.01	0.016 ± 0.004	89
ANPA-M09/01a CORT	11.02 ± 0.56	1.88 ± 0.18	0.14 ± 0.06	0.17 ± 0.02	0.013 ± 0.005	101

Table J.9 Concentrations of ^{238}U ^{234}U ^{235}U in bark samples collected from Serbia and Montenegro.

Sample Code	^{238}U mg kg^{-1}	^{234}U mg kg^{-1}	^{235}U mg kg^{-1}	$^{234}U/^{238}U$	$^{235}U/^{238}U$	% DU $^{235}U/^{238}U$ (mg/mg)
Pljačkovica						
ANPA-SA01/03 CORT	1.48E-01±1.15E-02	8.83E-06±6.51E-07	1.58E-03±6.43E-04	5.97E-05±6.40E-06	1.07E-02±4.42E-03	nd
ANPA-SA01/04a CORT	1.52E-01±1.13E-02	7.21E-06±5.70E-07	6.55E-04±5.00E-04	4.74E-05±5.14E-06	4.31E-03±3.31E-03	56
ANPA-SA02/08 CORT	6.53E-02±6.53E-03	3.56E-06±3.53E-07	3.74E-04±3.49E-04	5.45E-05±7.68E-06	5.73E-03±5.37E-03	29
Bratoselce						
ANPA-SA21/02a CORT	1.96E-01±1.48E-02	1.03E-05±7.87E-07	1.26E-03±7.25E-04	5.24E-05±5.64E-06	6.40E-03±3.73E-03	16
ANPA-SA21/03a CORT	2.51E-01±1.42E-02	1.34E-05±7.59E-07	1.55E-03±5.52E-04	5.35E-05±4.28E-06	6.20E-03±2.23E-03	20
ANPA-SA21/04 CORT	2.75E-01±1.47E-02	1.43E-05±7.78E-07	2.54E-03±6.51E-04	5.21E-05±3.98E-06	9.23E-03±2.42E-03	nd
Bukurevac						
ANPA-SA26/01a CORT	1.91E-01±1.03E-02	1.11E-05±5.73E-07	2.31E-03±5.26E-04	5.79E-05±4.33E-06	1.21E-02±2.83E-03	nd
Rejlan						
ANPA-SA29/01a CORT	8.21E-02±8.92E-03	4.97E-06±5.05E-07	6.06E-04±3.03E-04	6.05E-05±9.01E-06	7.38E-03±3.78E-03	nd
Cape Arza						
ANPA-M03/01a CORT	4.77E-01±4.74E-02	2.50E-05±2.51E-06	1.94E-03±1.43E-03	5.24E-05±7.41E-06	4.07E-03±3.03E-03	61
ANPA-M06/02a CORT	2.94E-01±1.40E-02	4.83E-06±4.15E-07	7.06E-04±4.09E-04	1.64E-05±1.61E-06	2.40E-03±1.39E-03	92
ANPA-M08/01 CORT	1.58E+00±6.09E-02	1.44E-05±1.03E-06	4.04E-03±1.00E-03	9.13E-06±7.42E-07	2.55E-03±6.41E-04	89
ANPA-M09/01a CORT	8.89E-01±4.48E-02	8.13E-06±8.00E-07	1.74E-03±7.28E-04	9.14E-06±1.01E-06	1.96E-03±8.25E-04	101

Table J.10 Activity concentrations of ^{238}U ^{234}U ^{235}U in moss samples collected in Serbia and Montenegro.

Sample Code	^{238}U Bq kg^{-1}	^{234}U Bq kg^{-1}	^{235}U Bq kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Rejlan						
ANPA-SA31/02	10.42 ± 0.27	10.56 ± 0.27	0.49 ± 0.05	1.01 ± 0.04	0.047 ± 0.005	nd
Cape Arza						
ANPA-M04/01	16.38 ± 0.60	10.30 ± 0.42	0.47 ± 0.08	0.63 ± 0.03	0.028 ± 0.005	54

Table J.11 Concentrations of ^{238}U ^{234}U ^{235}U in moss samples collected in Serbia and

Sample Code	^{238}U mg kg^{-1}	^{234}U mg kg^{-1}	^{235}U mg kg^{-1}	^{234}U/^{238}U	^{235}U/^{238}U	% DU ^{235}U/^{238}U (mg/mg)
Rejlan						
ANPA-SA31/02	8.40E-01±2.19E-02	4.57E-05±1.19E-06	6.10E-03±5.92E-04	5.44E-05±2.00E-06	7.26E-03±7.30E-04	nd
Cape Arza						
ANPA-M04/01	1.32E+00±4.84E-02	4.46E-05±1.82E-06	5.82E-03±9.53E-04	3.38E-05±1.85E-06	4.41E-03±7.40E-04	54

The uncertainties reported in the Tables include:

- the uncertainty associated with the weighing of the sample;
- the uncertainty associated with the activity of the tracer (^{232}U) and the uncertainty associated with the addition of the tracer to the sample;
- the uncertainty associated with the counting statistics of the sample and the blank.

The data reported in the Tables (J.2–J.11) indicate that ^{235}U data have very high uncertainties. This is attributable to the ^{235}U activity concentrations in the samples that were too low to be determined by alpha spectrometry. This isotope is best estimated using a mass-spectrometric technique (Bou-Rabee, 1995) rather than an alpha pulse-height analysis. On this basis, the evaluation of the results has been made only with the ^{238}U and ^{234}U activity concentration data, obtained by alpha spectrometry, because of the better sensitivity of this method for these measuraments (UNEP, 2001; Sansone et al., 2001).

The ^{234}U/^{238}U activity concentration ratios can be used as a fingerprint of natural vs. anthropogenic sources of uranium. Natural composition of uranium in soil is characterised by ^{234}U/^{238}U and ^{235}U/^{238}U activity ratios of about 1 and 0.046 respectively. Particularly ^{234}U/^{238}U activity ratios in soil typically range from 0.5 to 1.2 (Bou-Rabee, 1995; Goldstein et al., 1997; UNEP, 2001; Sansone et al., 2001, 2001a, 2001b). Depleted uranium has lower ^{234}U/^{238}U and ^{235}U/^{238}U activity ratios; considering an isotopic abundance of 0.2% for ^{235}U, these ratios become 0.18 and 0.013 respectively. Considering that in the soils of Serbia and Montenegro, not affected by DU contamination, the natural ^{234}U/^{238}U activity concentration ratios is 1.01±0.09 (Burger, 2002), it is possible to argue that ^{234}U/^{238}U activity concentration ratios values, measured on the botanical samples, that are below 0.92, can be indicative of anthropogenic contributions of uranium.

The ^{238}U activity concentrations in the epiphytic lichen samples collected in Serbia and

Montenegro (Table 2) range from 0.70±0.08 to 79.22±4.24 Bq kg^{-1}, with a mean value of 10.43±19.71 Bq kg^{-1} (coefficient of variation, CV=189%). The ^{238}U concentration (Table 3) range from 5.65E-02±6.62E-03 to 6.39E-00±3.42E-01 (mg/kg) with a mean value of 8.41E-01±1.59E-00. The high variability of ^{238}U data could be attributable to different factors:

- the different exposition of lichens to DU radioactive dusts or aerosol micro particles, generated at time of the conflict, by the impact of DU penetrators on NATO 'targets';
- the different exposition of lichens due to the trees position to the soil particles dispersed in the air, in relation to prevailing wind directions;
- the different mechanisms of uranium bioaccumulation in different species of lichens (McLean et al., 1998).

The ^{234}U/^{238}U activity ratios in the epiphytic lichen samples (Table J.2) range from 0.16±0,01 to 1.23±0.17 (Bq/Bq) while the concentration ratios (Table J.3) range from 8.70E-06±4.90E-07 to 6.60E-05±9.01E-06 (mg/mg). Comparing these ratios (Table 2) with those observed naturally in the soil of Serbia and Montenegro (1.01±0.09 Bq/Bq), it is possible to discriminate 13 samples in 3 locations where a contribution of DU is detectable.

The ^{238}U activity concentrations in lichen samples growing on rock substrate (Table J.4), collected in Serbia and Montenegro range from 2.22±0.67 to 11.44±2.35 Bq kg^{-1}, with a mean value of 6.83±6.52 Bq kg^{-1} (coefficient of variation, CV=95%). The ^{238}U concentration (Table 5) range from 1.79E-01±5.39E-02 to 9.23E-01±1.91E-01 (mg/kg) with a mean value of 5.51E-01±5.26E-01.

The ^{234}U/^{238}U activity ratios in lichen samples growing on rock substrate (Table J.4) range from 0.84±0.27 to 1.04±0.11 (Bq/Bq), while the concentration ratios (Table J.5) range from 4.53E-05±1.47E-05 to 5.58E-05±6.01E-06 (mg/mg).

The ^{238}U activity concentrations in lichen samples growing on soil (Table J.6) range from 14.07±0.83 to 82.00±4.98 Bq kg^{-1}, with a mean value of 45.32±35.44 Bq kg^{-1} (coefficient of variation, CV=78%). The ^{238}U concentration (Table J.7) range from 1.13E-00±6.67E-02 to 6.61E-00±4.01E-01 (mg/kg) with a mean value of 3.65E-00±2.86E-00.

The ^{234}U/^{238}U activity ratios in lichen samples growing on soil (Table J.6) range from 0.15±0,01 to 1.08±0.09 (Bq/Bq), while the concentration ratios (Table J.7) range from 8.02E-06±3.64E-07 to 5.80E-05±4.78E-06 (mg/mg). Two samples, collected in Bratoselce and Cape Arza exhibit ^{234}U/^{238}U activity ratios consistent with DU.

The ^{238}U activity concentrations in the bark samples (Table J.8) range from 0.81±0.08 to 19.60±0.75 Bq kg^{-1}, with a mean value of 4.75±5.43 Bq kg^{-1} (coefficient of variation, CV=114%). The ^{238}U concentration (Table J.9) range from 6.53E-02±6.53E-03 to 1.58E-00±6.09E-02 (mg/kg) with a mean value of 3.83E-01±4.38E-01.

The ^{234}U/^{238}U activity ratios in the bark samples (Table J.8) range from 0.17±0,02 to 1.13±0.17 (Bq/Bq), while the concentration ratios (Table J.9) range from 9.16E-06±7.42E-07 to 6.05E-05±9.01E-06 (mg/mg). Three samples collected in Cape Arza exhibit ^{234}U/^{238}U activity ratios consistent with DU.

The ^{238}U activity concentrations in the moss samples (Table J.10) range from 10.42±0.27 to 16.38±0.60 Bq kg^{-1}, with a mean value of 13.40±4.21 Bq kg^{-1} (coefficient of variation, CV=31%). The ^{238}U concentration (Table J.11) range from 8.40E-01±2.19E-02 to 1.32E-00±4.84E-02 (mg/kg) with a mean value of 1.08E-00±3.40E-01.

The ^{234}U/^{238}U activity ratios in the moss samples (Table J.10) range from 0.63±0,03 to 1.01±0.04 (Bq/Bq), while the concentration ratios (Table J.11) range from 3.38E-05±1.85E-

06 to 5.44E-05±2.00E-06 (mg/mg). One sample, collected in Cape Arza exhibits $^{234}U/^{238}U$ activity ratios consistent with DU.

On the basis of $^{234}U/^{238}U$ activity concentration ratios, the data reported in Table J.2 indicate for 14 samples of lichens growing on tree bark, the earlier presence of DU in the air, which means that at least some of the penetrators had hit hard targets, shattered into dust and dispersed in air. Only at Bratoselce did the epiphytic lichen samples show values within the natural limits of $^{234}U/^{238}U$ activity concentration ratios.

Two samples of lichens growing on soil (Bratoselce and Cape Arza) have $^{234}U/^{238}U$ activity concentration ratios consistent with anthropogenic contributions of uranium.

The ^{234}U and ^{238}U activity concentration measured for bark indicates activity ratios consistent with DU for three samples collected in Cape Arza.

The moss samples collected in Cape Arza also show $^{234}U/^{238}U$ activity concentration ratios indicative of DU presence in air.

In conclusion, the main outcome of the field investigation in Serbia and Montenegro is that lichens, barks and mosses are sensitive bio-indicators of past airborne contamination due to depleted uranium dust or aerosol particles generated at the time of the conflict by the impact of DU penetrators. At three sites, the presence of DU in lichen, bark and mosses samples indicates the earlier presence of DU in the air, which means that at least some of the penetrators hit hard surfaces, shattered into dust and dispersed in air.

The results achieved from the UNEP field surveys in the Balkans have clearly demonstrated the possibility of using lichens as indicators of past airborne contamination due to depleted uranium. The high variability found in the ^{238}U activity concentration, however, requires additional studies to define the distribution pattern of uranium radioisotopes and associated elements in lichens and the most appropriate lichen species to be used as bio-indicators of air pollution by depleted uranium.

APPENDIX K

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ANALYSIS OF DU PENETRATORS AND FRAGMENTS

During the UNEP mission to Serbia and Montenegro, nine whole penetrators, two fragments and one jacket fragment were collected. Three of the penetrators, two fragments and one jacket fragment have been subjected to different forms of analysis: analyses of the isotopic composition of the penetrators and fragments, and microscopic and spectrometric studies of the surface coating of uranium oxides on the penetrators and fragments. The other penetrators and fragments found were collected by FRY personnel. Similar studies as have been carried out on the penetrators and fragments were also carried out on penetrators and fragments collected during the UNEP DU Kosovo mission 2000 (UNEP, 2001).

K.1 Studies of DU penetrator material

Studies on material collected during the Kosovo Mission

Studies on the soil samples collected during the UNEP mission to Kosovo 2000 revealed that some of the soil samples contained traces of ^{236}U, which is a non-natural uranium isotope formed when uranium is used as fuel in nuclear reactors (UNEP, 2001). 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 Kosovo mission. The existence of ^{236}U in the penetrators triggered further studies of transuranic elements in the penetrators. As a result of these studies it was shown that some of the penetrators also contained trace amounts of plutonium as well as ^{236}U. The plutonium concentrations were very low and constitute impurities at the limits of detection. The Bristol University laboratory also analysed the penetrators for other elements formed in nuclear reactors, for example ^{99}Tc, ^{237}Np, ^{241}Am, ^{243}Am and ^{244}Cm. However, the concentrations of these elements were all below the detection limit.

■ Studies of the penetrators collected in Serbia and Montenegro

Similar studies as were carried out on the penetrators sampled in Kosovo were also conducted on penetrators and penetrator fragments collected during the UNEP mission to Serbia and Montenegro. These analyses and studies were made at Spiez Laboratory.

■ Isotopic analyses

Analyses of the isotopic composition of DU in the penetrators were made by ICP-MS. By radiochemical analyses, alphaspectrometry, the content of the transuranic elements plutonium-239 and neptunium-237 was analysed.

The ICP-MS analyses show a rather constant isotopic composition for the uranium isotopes ^{238}U, ^{235}U, ^{234}U and ^{236}U in the DU penetrators (Tables K.5 and K.6). All six samples analysed contained ^{236}U which shows that depleted uranium had been contaminated by reprocessed uranium. For the ^{235}U/^{238}U isotopic ratio of the penetrators and fragments the mean value was 0.00200 ± 0.00001, and in the penetrators and the fragments ^{236}U concentration is 0.0027 ± 0.0002 %. This also is exactly the isotopic uranium composition published in US military and open literature.

The radiochemical analyses show that the concentration of plutonium in the penetrators is very low (Tables K.7 and K.8). The range analysed is 0.0134 to 0.0318 [Bq/g] which corresponds to 5.8E-12 to 13.8E-12 [g/g]. These results confirm the findings on penetrators from Kosovo as well as the information given by the US DOE in the open literature.

The radiochemical analyses also show that the concentration of neptunium in the penetrators is below the detection limit of 0.002 [Bq/g].

■ Studies of corrosion

Studies of the corrosion of the penetrators started by weighing the penetrators and measuring them. The penetrators were heavily corroded and pitting had taken place. According to information in US military literature, penetrators originally weigh 292 g. The penetrators studied had lost 11 - 40 g of that weight due to corrosion. These findings differ from the results of studies of the penetrators found in Kosovo, which were only slightly affected by corrosion. Since then, one year has passed. The findings show that the level of corrosion increases dramatically with time. Once corrosion starts, the overall surface of course increases and increases even more with the pitting effect. Bearing in mind the actual state of the penetrators, one can conclude that within the next 10 to 20 years no more penetrators will be found in the Balkans. DU-contaminated points in the ground containing the decomposition products will be the result.

The corrosion of the penetrators and the forming of secondary uranium oxides was studied by X-ray fluorescence spectrometry (EDX) and X-ray diffraction (XRD). These analysis of the oxidized material mechanically extracted from the surface of the penetrators show mainly the amorphous character of these products. This means that in primarily different uranium oxides result as the products of corrosion. A very small amount of these oxides is converted to carbonates. In addition the presence of titanium in penetrators could be confirmed.

This finding could lead to the interpretation that by rain water mainly uranium oxides would be transported in direction of the ground water. Under which conditions in the soil the uranium oxides can convert to more mobile compounds and whether these conditions are present at the sites visited is a pure geochemical problem.

K.2 Origin of transuranic elements

The ^{236}U and plutonium in the penetrators come from the reprocessing of nuclear fuel. In uranium fuel, the concentration of ^{235}U is enriched by up to 4%. When the reactor fuel is spent, the removed fuel still contains ^{235}U. By reprocessing, the ^{236}U 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 shown that this kind of armour does contain some transuranics (U.S. Army Material Command, 2000). The concentrations were low - the average ^{239}Pu and ^{240}Pu 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. However, the plutonium activity concentration in none of the penetrators from Kosovo, Serbia or Montenegro analysed by the laboratories that took part in the UNEP DU missions exceeded 32 Bq/kg.

Table K.1 Sample identification

Sample code	Sampling Date	Sampling Site	Coordinates	Sample Type
NUC-01-101-09	30.10.01	Pljackovica	573599 714559	Penetrator in depth of 8 cm
NUC-01-102-01	30.10.01	Vranje Garrison	574649 711861	Penetrator fragment in tank front / left
NUC-01-102-07	30.10.01	Vranje Garrison	574649 711861	Penetrator fragment inside of tank
NUC-01-104-09	31.10.01	Bratoselce	562279 688324	Penetrator in depth of 40 cm
NUC-01-106-10	01.11.01	Reljan	563151 685160	Penetrator in depth of 80 cm

Table K.2 Masses of the penetrators and fragments as collected

Code	Sample	Weight [g]
NUC-01-101-09	Penetrator	264.83
NUC-01-102-01	Penetrator fragment	5.48
NUC-01-102-07	Penetrator fragment	8.95
NUC-01-104-09	Penetrator	275.85
NUC-01-106-10	Penetrator	292.15

Table K.3 Masses of the penetrators and fragments after mechanical surface cleaning (brushing)

Code	Sample	Weight after mechanical cleaning [g]	Loss of weight [g]
NUC-01-101-09	Penetrator	260.15	4.68
NUC-01-102-01	Penetrator fragment	only chemical cleaning	-
NUC-01-102-07	Penetrator fragment	only chemical cleaning	-
NUC-01-104-09	Penetrator	260.20	15.65
NUC-01-106-10	Penetrator	283.83	8.32

Statistics for the radiochemical plutonium and neptunium analysis

Results calculated for 1g of penetrator ; 1g of fragment.

Standard deviation: +/- 1 sigma

Confidence level of the detection limit: 95 %
The rsd values stand for the relative standard deviation of the alpha spectroscopic measurements i.e. the statistical uncertainty of the count rate.

Table K.4 Masses of the penetrators and fragments after weak chemical cleaning

Code	Sample	Weight after chemical cleaning [g]	Loss of weight [g]	Diameter smallest / largest [mm]
NUC-01-101-09	Penetrator	253.45	6.70	15.4 / 15.7
NUC-01-102-01	Penetrator fragment	5.19	0.29	-
NUC-01-102-07	Penetrator fragment	8.05	0.90	-
NUC-01-104-09	Penetrator	257.83	2.37	15.3 / 15.6
NUC-01-106-10	Penetrator	280.70	3.13	15.9 / 16.0

Table K.5. Isotopic compositions of uranium

NUC-2001-	^{238}U		^{235}U		^{234}U		^{236}U	
	percentage [mass%]	rsd [%]	percentage [mass%]	rsd [%]	percentage [mass%]	rsd [%]	percentage [mass%]	rsd [%]
101-09	99.797	1.85	0.197	1.99	0.0006	5.88	0.0027	3.30
102-01	99.799	1.75	0.195	1.76	0.0006	5.69	0.0027	3.18
102-02	99.800	2.59	0.194	2.43	0.0007	7.16	0.0026	2.30
102-07	99.800	0.35	0.194	0.38	0.0006	2.92	0.0027	0.98
104-09	99.799	2.53	0.194	2.40	0.0007	5.92	0.0028	2.76
106-10	99.799	1.79	0.195	2.08	0.0007	5.52	0.0027	1.78

The isotopic compositions were not corrected for the mass discrimination of the ICP-MS.

Table K.6 Isotopic ratio ^{235}U / ^{238}U

NUC-2001-	Isotopic ratio ^{235}U / ^{238}U	DU of total U [%]	rsd [%]
101-09	0.002016	99.70	0.11
102-01	0.001995	100.09	0.08
102-02	0.001988	100.24	0.10
102-07	0.001989	100.21	0.09
104-09	0.001989	100.21	0.10
106-10	0.001995	100.09	0.17

Table K.7 Plutonium in [Bq/g]

Code	Sample	Σ Pu-239/Pu-240 [Bq/g]	rsd [%]
NUC-01-101-09	Penetrator	0.0210	6
NUC-01-102-01	Penetrator fragment	0.0175	8
NUC-01-102-07	Penetrator fragment	0.0167	8
NUC-01-104-09	Penetrator	0.0134	9
NUC-01-106-10	Penetrator	0.0318	11

Table K.8 Plutonium in [g/g] calculated as Pu-239

Code	Sample	Pu-239 [g/g]	rsd [%]
NUC-01-101-09	Penetrator	9.1E-12	6
NUC-01-102-01	Penetrator fragment	7.6E-12	8
NUC-01-102-07	Penetrator fragment	7.3E-12	8
NUC-01-104-09	Penetrator	5.8E-12	9
NUC-01-106-10	Penetrator	13.8E-12	11

Table K.9 Neptunium in [Bq/g]

Code	Sample	Np-237 [Bq/g]	rsd [%]
NUC-01-101-09	Penetrator	< 0.002	6
NUC-01-102-01	Penetrator fragment	< 0.002	8
NUC-01-102-07	Penetrator fragment	< 0.002	8
NUC-01-104-09	Penetrator	< 0.002	9
NUC-01-106-10	Penetrator	< 0.002	11

APPENDIX L

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THEORETICAL ASSESSMENTS OF EXTERNAL RADIATION FROM DU

L.1 Objectives

Assessing the radiological consequences for human populations arising from the military use of DU has attracted considerable attention in many countries of the world and among international organisations (see, for example, DoF, 2000; UNEP, 1999; UNEP, 2001; WHO, 2000; UK, 2001; Agapov, 2001). This paper refers to the field inspection of regions contaminated by DU and to the creation and practical application of various mathematical models.

In Appendix A 'Risk Assessment' (and other sections of this report) the various factors concerned with possible exposure to radiation of people living in areas contaminated by DU are considered. The relationships between doses of external gamma radiation from polluted ground and internal exposure by inhalation and ingestion of uranium isotopes and their derived products can vary widely. This depends on the ease of dispersion of DU particles that have fallen out onto the ground surface, their chemical composition, the thickness of the contaminated soil, the speed of vertical migration of nuclides, and the conversion factors of radioactive substances in biological chains to human beings. However, in all cases, the observable levels of DU ground contamination mean that the radiation doses to the local population are only a few percent of the natural levels of background radiation.

A similar estimation was examined in detail in the report Pavlovski, 2002. In that report, for the purpose of estimating the significance of various possible pathways for exposure of the human population to radiation due to DU contamination of soil, it was decided to carry out special calculations by using the computer code RESRAD-6, developed in the Environmental Assessment Division of Argonne National Laboratory. RESRAD is a computer model designed to estimate radiation doses and risks from *RES*idual *RAD*ioactive materials. RESRAD-6 represents the sixth major version of the RESRAD code since it was first issued in 1989 (RESRAD, 2001).

Parsing the information presented by Pavlovski, 2002 it is possible to determine that, under given conditions and assumptions, the external exposure from contaminated ground during the first year is the defining radiation factor (almost 90 % of the total radiation exposure dose of the population). From the estimated uranium nuclides, U-238 and its daughters play the main role (92 % of the total dose). These calculations are based on the conservative assumptions that the population lives permanently and continuously in the area contaminated with depleted uranium. It was also assumed that neither decontamination of the area, nor any restriction of people's essential activities had been implemented. Furthermore, the potential risks like exposure from picking up solid pieces of DU and from being contaminated by touching soil heavily contaminated by DU are not considered.

The calculations using the RESRAD code that are presented in the above-mentioned report have also shown that, after 1,000 years, when most of the activity has dispersed into the soil, the main role in generating exposure of the population can be played by the arrival of uranium and radioactive daughter nuclides in groundwater. However, it is important once again to note that these doses are not great and account for only a few percent of the natural background radiation.

At the same time, it is necessary to note that these estimations were obtained with the assumption of uniform surface area contamination of 10 g DU/m^2. In reality, wide spread contamination of that size has not been found. On the other hand some sites attacked with DU weapons have contained localised areas (although often small) of considerably greater contamination. This shows that more detailed assessments of the role of external exposure as a source of risk to the population might be justified. Another important problem may be the incorrect operation of normal radiation monitoring instruments when checking external dose rates from areas contaminated with DU. The outcomes of similar calculations are presented below.

L.2 Photon external dose rate from DU penetrators in the open air

When beginning calculations for estimating photon external dose rates (PEDR), it was decided to use the 'FIELD' code, developed by the Nuclear Safety Institute of the Russian Academy of Science (IBRAE RAS). This computer code allows calculations of flow of particles, energy flux density, air kerma rate and effective dose rate for sources of various nuclide composition and geometry. In the calculations, it is possible to include information about the self-absorption of photons in the source body. When carrying out calculations using the 'FIELD' code, it is necessary to have information about the geometry of the source and its specific activity on various gamma emitters. The appropriate estimations were therefore carried out. It was assumed that the penetrator can be presented as a self-absorption cylinder of radius 0.73 cm and length 8.5 cm (see Figure L.1), with a weight of 271 g and volume of 14.2 cm^3.

Figure L.1 The screen form of the code 'FIELD' for PEDR calculations from the self-absorption cylinder.

As input data for the calculation, it was decided to take the initial DU contamination of the area concerned as being 10 g/m^2. This corresponds to the *Reference Case* from the UNEP DU Desk Assessment Report (UNEP, 1999). The uranium composition in the DU penetrators or in the contaminated soils was adjusted to the values actually measured, as presented in

Table L.1 Uranium contamination of the DU penetrators (UNEP, 2001)

Nuclide	Activity, kBq/g
U-234	1.50
U-235	0.161
U-236	0.0615
U-238	12.4
Total	**14.1**

the report of the UNEP mission to Kosovo in 2000 (UNEP, 2001). The average values from Table VII.1 of that report are shown below in Table L.1. To account for the accumulation of uranium daughter nuclides in DU penetrators, the calculations were realised by using the ‘Universal Decay Calculator’ program, available through the ‘WISE Uranium Project’ web site on the internet (WISE, 2002). These estimations indicate that in one year the total activity of nuclides in a DU penetrator increases up to 10.6 MBq. For subsequent estimations it was decided to assume a mixture of nuclides, characteristic for a period of 10 years. With these assumptions, the specific activity of the penetrator material will be 0.744 MBq/cm^3 or 39 kBq/g.

The total number of nuclides included in the calculation was 36. Three of these nuclides (Bi-210, Po-210 and Po-218) do not radiate photons during radioactive decay. The remaining 33 nuclides radiate photons with 371 various energies, the majority of which are less than 50 keV. For simplification of calculation, the energy distribution of photons was grouped together around main gamma-lines and eight groups were selected. Information about these groups is presented below in Table L.2.

Table L.2 Photon energy groups in the estimation of PEDR from DU penetrator.

Photon energy group	Photon energy, MeV	Probability, photons/decay
1	0.01327	0.06897
2	0.08091	0.03176
3	0.1200	0.00171
4	0.1823	0.00251
5	0.2051	0.00024
6	0.7663	0.00066
7	0.9262	0.00119
8	1.001	0.00187
Total		**0.10890**

It is important to note that scattered photon radiation from particles passing through the material is not taken into account in the ‘FIELD’ code. It is not so important for the analysis of radiation fields in air close to a source of radiation, but it can result in considerable errors in allocating a source of radiation in the ground. To avoid similar errors, it was decided to carry out some calculations using the computer code MCNP (Monte Carlo N-Particle code) developed in Los Alamos National Laboratory (USA).

MCNP is a general-purpose, continuous-energy, generalised-geometry, time-dependent, coupled neutron/photon/electron Monte Carlo transport code. It can be used in several transport modes: neutron only, photon only, electron only, combined neutron/photon transport where the photons are produced by neutron interactions, neutron/photon/electron, photon/electron, or electron/photon. The neutron energy regime is from 10-11 MeV to 20 MeV, and the photon and electron energy regimes are from 1 keV to 1000 MeV (MCNP, 2000). In the IBRAE RAN there are 2 licenced versions of this code – MCNP v.4a and MCNP v.4c. All subsequent calculations were produced using the code MCNP v.4a.

The comparison of the results computed by the 'FIELD' and MCNP codes, for PEDR depending on distance from a DU penetrator, is shown in Figure L.2. The actual measurement of PEDR according to the UNEP (2001) and DOF (2000) reports are also shown. Our calculations show that for a distance of 0.1-10 m from a DU penetrator, the scattered radiation in the total PEDR is insignificant and does not exceed 25 %. It also explains the good convergence of results of dose rate calculations for distances greater than 10 cm produced by the 'FIELD' and MCNP codes. At the same time, it is important to note that the measured values of PEDR for distances 5 -20 cm from the DU penetrator exceed the calculated values by approximately three times. Apparently, the reason for this is that the main contribution of photon flux is results from gamma-quantums with energy less than 100 keV (see Figure

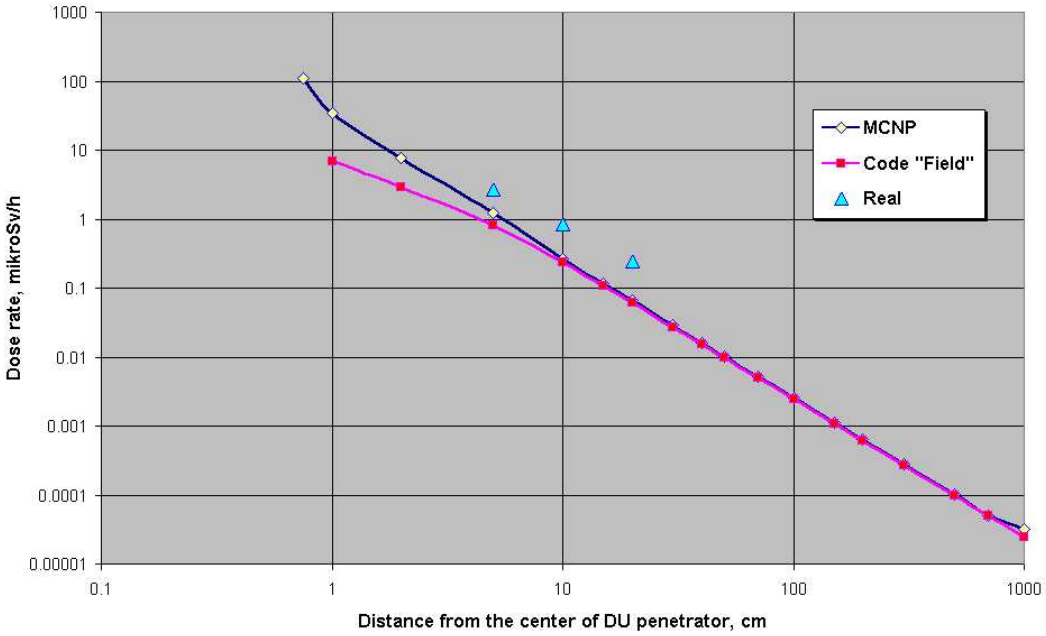

Figure L.2 PEDR in the open air as a function of distance from DU penetrator

Figure L.3 Contribution of direct and scattered photons in the photon flux at a distance of 10 cm from a DU penetrator.

L.3). The high registration performance is characteristic for these photons. Therefore, observations using instruments calibrated on high-energy photons appear to be considerably overstated. This effect was observed by IBRAE RAN experts during work in contaminated areas of Chernobyl (e.g. see Bogatov, 1995).

L.3 PEDR from DU penetrators placed in the soil

The PEDR calculations using the MCNP code were carried out for the following variables:

- Depth of DU penetrator in ground: 0.75, 1.0, 2, 5, 10, 15, 20, 25, 30, 40 and 50 cm;
- Height of a point of detection above the ground surface: 1, 2, 3, 5, 7, 10, 15, 20, 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 700, 1000 cm;
- Distances from a hypocenter of a DU penetrator position on axes Õ and Y: 0, 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 cm.

The calculations were carried out by running the number of histories sufficient for obtaining a relative results error at a level of 2-3 %. This corresponded to 10^6-10^9 histories. The time of calculations, depending on geometry of the task, varied from several minutes to 10 hours, using PCs with processors 600 - 1330 MHz. The main results of these calculations are presented in Figures L.4 – L.7. The first of these, Figure L.4, shows that the PEDR above the location of a DU penetrator varies depending upon the depth of its position in the ground

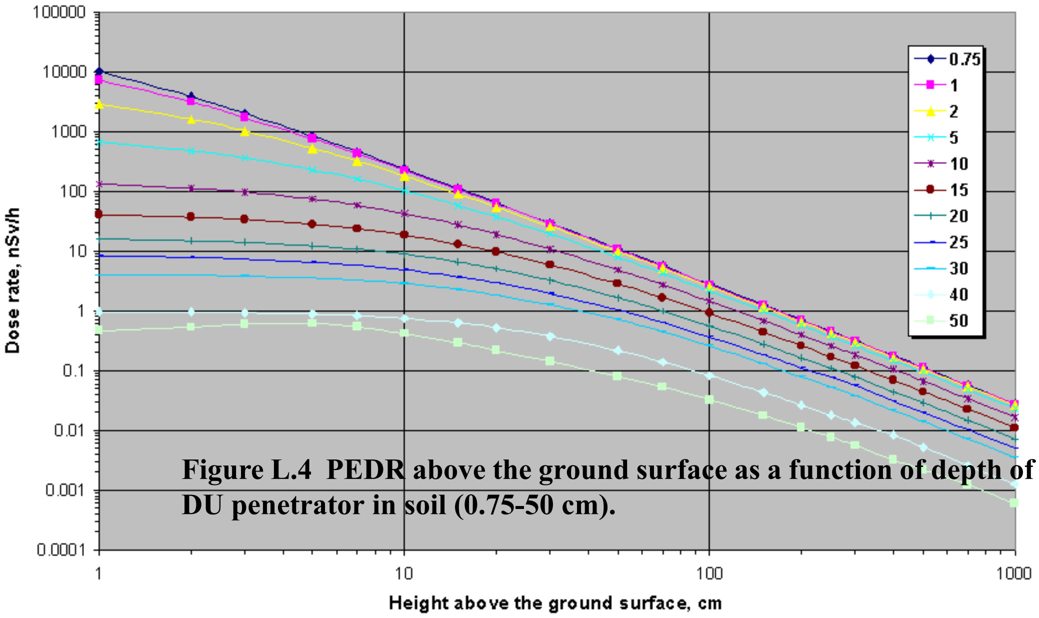

Figure L.4 PEDR above the ground surface as a function of depth of the position of a DU penetrator in soil (0.75-50 cm).

The spatial distribution of PEDR above the DU penetrator location is shown in Figure L.5. The asymmetry of figures on axes X and Y is bound to the supposition, accepted in calculations, that the penetrator is aligned to the ground surface along an axis X. If it is accepted that the observations of usual radiometric instruments overestimate actual values of dose rate by approximately three times (for soft gamma-radiation of isotopes of uranium and their derived nuclides) then the lower limit for sufficient detection of radiation from the DU penetrator could be 30 nSv/h. In these suppositions it is possible to detect the penetrator at a depth of 10-15 cm when the centre of the detector is at a height of 10 cm above the ground surface.

Figure L.5 Dose rate at a height of 10cm (left) and 100 cm (right) from the ground for a DU penetrator located at a depth of 5 cm

The relation between direct and scattered radiation in the photon flux and dose rate of gamma radiation is presented in Figures L.6 and L.7. From these figures it can be seen that the significance of scattered radiation essentially increases with increasing depth of the penetrator in the ground.

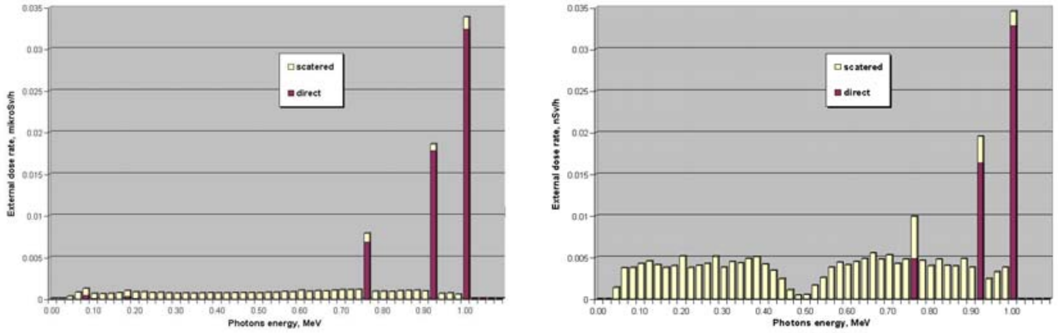

Figure L.6 Distribution of photon flux against energy at a height of 10 cm above the ground surface for penetrators located at depths of 5 cm (left) and 30 cm (right).

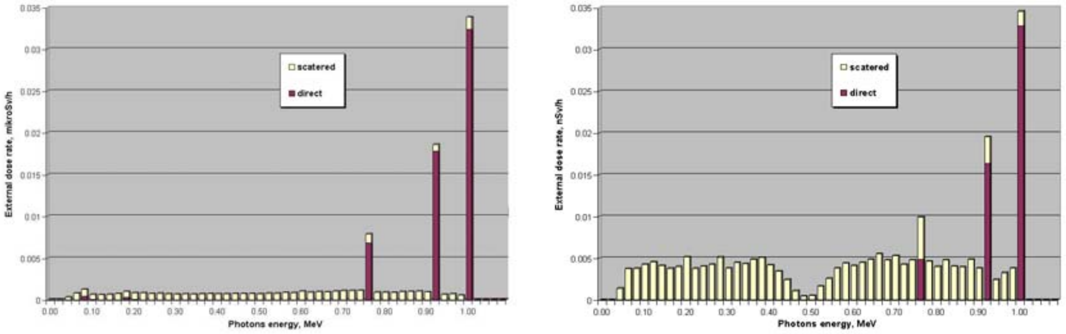

Figure L.7 Distribution of PEDR against energy at a height of 10 cm above the ground surface for penetrators located at depths of 5 cm (left) and 30 cm (right).

All the calculations shown above are based on assumptions about maintaining integrity of the uranium core. As soon as the penetrator enters the ground the uranium starts to corrode as a result of natural processes in the soil. Corrosion of a DU penetrator reduces its volume and lowers its density. This reduces the potential of the DU penetrator as a source of radiation. Thus, self-absorption of radiation by a source essentially decreases and the dose rate above the location of the penetrator can increase. This is demonstrated in Figure L.8, which shows that upon deterioration of material from a penetrator, the gamma dose rate increases. Thus it was assumed that the disintegration of penetrator material reduces the rate of increase of corrosion products by 10 times in comparison with the initial volume of a DU penetrator.

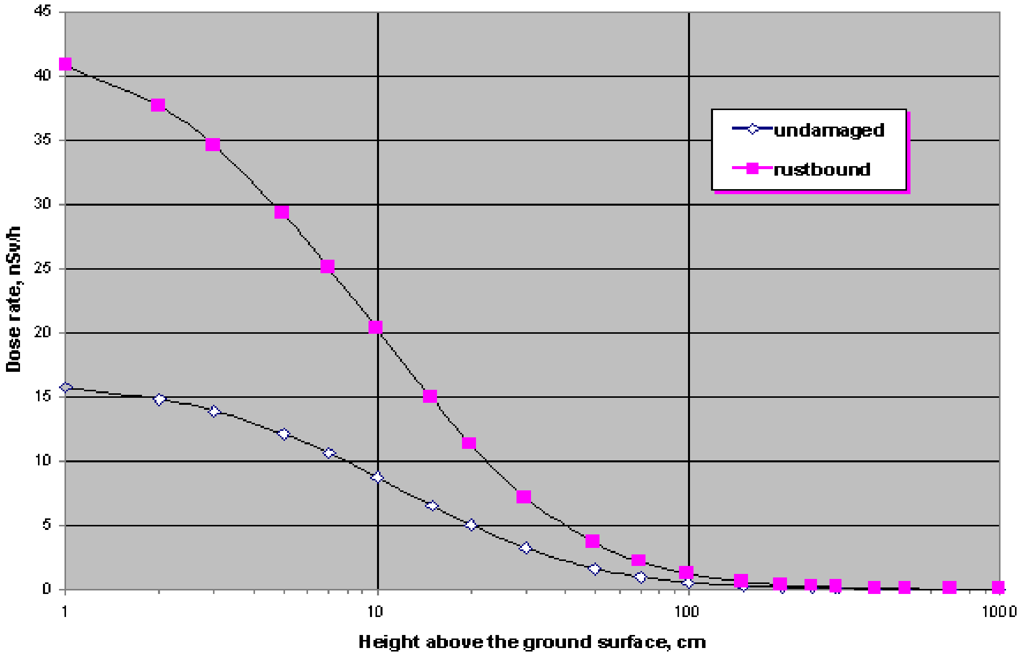

Figure L.8 PEDR above the ground surface at the site of an undamaged and corroded penetrator located in the ground at a depth of 20 cm.

It reduces the density of the source of radiation from 19 g/cm^3 to 1.9 g/cm^3. The estimates represented in Figure L.8 show that corrosion of a DU penetrator can at least double the PEDR. In this case, it is possible to detect a penetrator even at a depth of 20 cm.

L.4 PEDR from the DU contaminated soil

The calculations of radiation characteristics above a DU-contaminated ground surface were made using the computer code MCNP with the following suppositions:

- The DU contamination is concentrated in a surface layer 1 cm thick;
- Contamination of the ground by DU is evenly distributed at a rate of 10 g/m^2;
- The size of the contaminated area is 200 x 200 m;
- A point of detection is at the centre of this quadrat;
- The photon flux and PEDR are determined for two points - at heights of 10 cm and 100 cm above the ground surface.

The results of these calculations are presented in Figures L.9 and L.10. From these figures it can be seen that the PEDR increases with distance above the ground surface. This is explained by an increase in the surface area (square meters) of DU contaminated soil as a source of radiation. It is also possible to see that the scattered radiation accounts not only for most of the photon flux, but also generation of PEDR. Integrated for the whole spectrum of gamma energies, the values of dose rate from direct and scattered radiation are shown in Table L.3.

Such a significant contribution of scattered radiation to external radiation dose rates above ground contaminated with DU causes a problem when using standard instruments for the analysis of radiation conditions in this situation. Our calculations have shown that the results of measurements by radiometric instrument calibrated on gamma-energy Cs-137 +

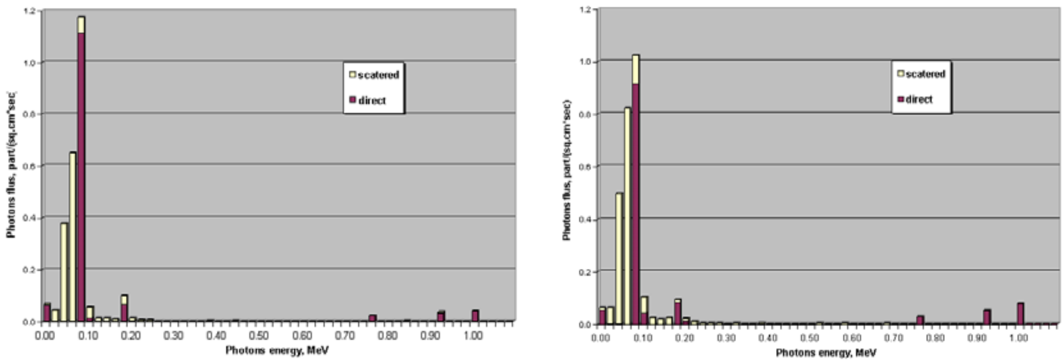

Figure L.9 Distribution of photon flux against energy at height 10 cm (left) and 100 cm (right) above the ground surface contaminated by DU at a level of 10 g/m².

Figure L.10 Distribution of PEDR against energy at height 10 cm (left) and 100 cm (right) above a ground surface evenly contaminated with DU at a rate of 10 g/m².

Ba-137m (0.661 keV), can overestimate true values for *'the ideal theoretical tissue-equivalent detector*' many times. In Figure L.11 it is shown that the coefficient of overestimation varies depending on a clipped part gamma radiation spectrum in the field of small energies. For example, if the gamma-quantums of all energies are included in calculations of dose rates, the overestimation can be as high as 13-17 times. Measurements substantially above ground contaminated by DU involve problems of accuracy when using standard instruments because the lower limit of sensitivity is about 50 keV. The overestimation can be up to 5 times. On the contrary, when all photons with energies less than 200 keV are excluded, the value of PEDR will be underestimated by approximately 1.5 times.

The other problem concerning correctness of measurement of radiation fields above soil contaminated by DU, is the effect on a detector of beta particles and electrons. It will also be desirable to make a comparison of the computer's calculations, represented in the given application, with an experiment under field conditions. It is probable that in the future, during execution of similar UNEP missions to other areas contaminated by DU, these tasks

Table L.3 Dose rate above the contamination soil.

Height, cm	External dose rate, nSv/h		
	Direct	Scattered	total
10	3.9	2.0	5.9
100	4.7	2.8	7.5

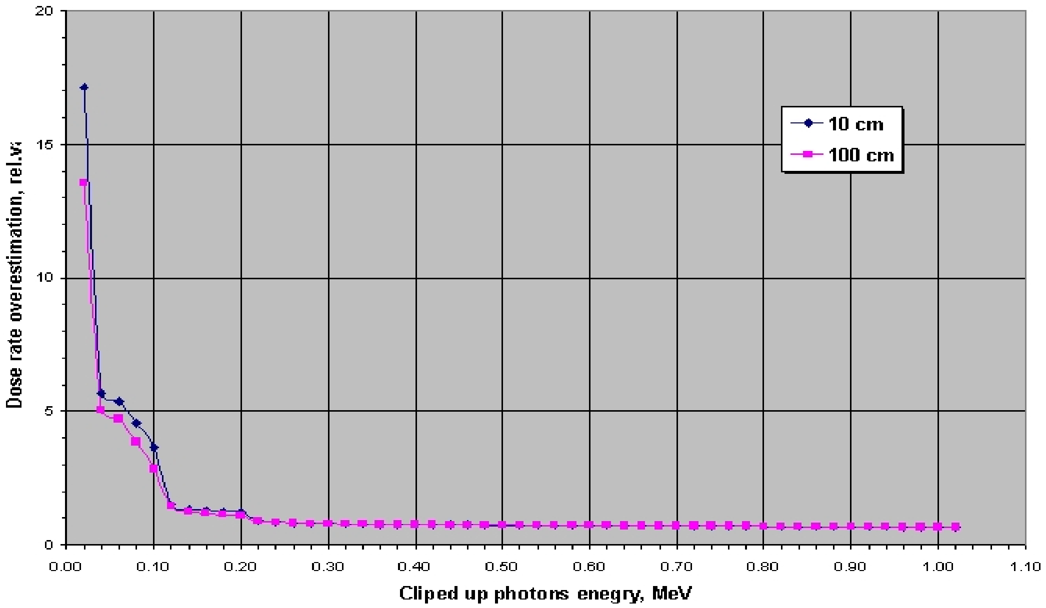

Figure L.11 Over-estimation of dose rate as a function of excluding the low energy part of a gamma radiation spectrum.

will be realised.

L.5 Conclusions

From this study with given conditions and assumptions the following conclusions are drawn:

1. In the initial period after contamination of a given area by DU, the main radiation factor can be external gamma radiation. Over considerable periods of time the significance of DU contamination of groundwater can be shown. However, observable levels of DU contamination in the field show that the resulting radiation exposure will be negligible in comparison with doses derived from natural background radiation.

2. The contribution of scattered radiation from DU penetrators in the open, on the value of gamma radiation dose rate is not significant. The role of scattered radiation in creation of photon flux and external dose rate is essentially increased when uranium penetrators are deeper in the ground.

3. Standard radiation monitoring instruments can sometimes overestimate the real values of the external dose rate from gamma radiation above ground that is contaminated with DU.

4. Deterioration in the integrity of DU penetrators in the ground, due to natural processes, can lead to an increase in the external dose rate above the ground surface.

APPENDIX M

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PROJECT PROPOSAL

The pyrophoric nature of Depleted Uranium is of special relevance to the environmental impacts resulting from its use in ordnance and armouring. When a DU projectile hits a hard target, it burns and oxidises, bursting into radioactive dust or aerosolised micro-particles. Once in the environment, DU dust is dispersed depending on its chemical and physical form (chemical species, particle dimensions, solubility, etc.) and it is subject to transport by wind and leaching, depending on soil characteristics and on meteorological and climatic conditions at the site.

The results achieved during the field surveys performed by UNEP in Kosovo (UNEP, 2001), and in Serbia and Montenegro, where DU ammunitions were used during the Kosovo conflict, highlighted a general lack of information regarding the basic mechanisms of dispersion of DU particles in the environment. The field activities showed that, in some cases, the mere monitoring of deposition levels is insufficient for calculating long-term dose or for deciding on the types of countermeasures to be taken. It has also been realised that better knowledge of the basic mechanisms of dispersion of DU particles in the environment could allow better appreciation of the environmental consequences of DU and the resulting potential radiation dose to the population.

During the field surveys in Kosovo, Serbia and Montenegro, soil, water, lichen and other bio-indicator samples were collected to assess the spread of DU ground contamination within targeted sites and the migration of DU through the soil profile.

The results from soil samples collected above and underneath penetrators (UNEP, 2001; Sansone et al., 2001; 2001a; 2001b), showed that ground-surface contamination by DU can be detected within a few metres of the penetrators or localised points of concentrated contamination (‘hot spots’) caused by penetrator impacts. Penetrators lying on the soil surface oxidise and the outermost layer of the penetrator surface can then be removed easily and thereby contaminate its surroundings. The DU dispersed into the ground beneath penetrators and jackets lying on the surface can be detected to a depth of 10 – 20 cm. It appears clear from these data that wet conditions can favour uranium dissolution and that the DU can migrate through the soil profile. Several months after the end of the Kosovo conflict, the extent of DU migration through the soil profile had not been expected on the basis of the existing literature. A potential effect of the presence of DU penetrators on the ground may be the possible contamination of underground aquifers in the future.

The results from analyses of lichen samples taken at DU-targeted sites located in Kosovo, Serbia and Montenegro, showed that lichens are sensitive bio-indicators of past airborne contamination due to DU dust or aerosol particles generated at the time of the Kosovo conflict. In fact, in some DU-targeted sites listed by NATO, where any measurable widespread ground contamination was detectable, the presence of DU in lichen samples indicates the earlier presence of DU in the air, which means that at least some of the penetrators hit hard targets, shattered into dust and dispersed in air. This underlines that lichens are very sensitive to air quality and can be used to indicate past air pollution exposure, in particular in areas in which DU ammunition has been used.

Unfortunately, the results achieved in Kosovo, Serbia and Montenegro also showed that there is a lack of knowledge concerning the accumulation of DU in trunk epiphytic lichens. The high variability found in ^{238}U activity concentration data can be attributable to different factors. The mechanisms of uranium bio-accumulation in lichens are poorly understood and it is possible to assume that different parts of lichen tissues or different species of lichens have different bio-accumulative properties. Consequently, the different analysed samples could be affected by uncertainties arising from variations in mass and exposed surface area of the samples. It is also possible to argue that the high variability found in uranium isotopes measured could indicate that the radiological impact of DU ordnance was site-specific and that the contamination scenario was different in the various parts of the investigated area. In addition, the variability in the uranium isotope activity ratios could also be due to different types of DU having been used in the penetrators.

■ Proposed future research activities

In view of the lack of knowledge about the mechanisms of uranium radioisotope mobilisation from DU ordnance through leaching and uptake by plants, it is important that future researchs activities are addressed to critically review existing data and to monitor selected sites/environments affected by DU contamination in order to understand the reasons for the extent of the migration of depleted uranium along the soil profile. In addition, the leaching, migration and bio-availability of DU radioisotopes through the soil profile could be studied using several lysimeters with DU penetrators lying on the surface of the ground. This could enable a reliable evaluation of the impact of DU on underground aquifers and will provide suitable rehabilitation methodology to reduce radiation doses so that it is possible to restore the ecological and economic value of contaminated land.

The results achieved from the UNEP field surveys in the Balkans have clearly demonstrated the possibility of using lichens as indicators of past airborne contamination due to DU dust or aerosol particles generated at the time of the conflict. At present, however, very little information is available concerning DU accumulation mechanisms in trunk epiphytic lichens and it is possible to assume that different parts of lichen tissues or different species of lichens have different bio-accumulative properties.

Future research activities could be addressed to study the distribution patterns of uranium radioisotopes and associated elements in lichens growing in sites/environments affected by DU contamination, or in areas with different levels of natural radioactivity, or in the vicinity of uranium mining/milling operations. Considering that lichens are supplied with nutrients and trace elements from precipitation, through-fall, and dust from both anthropogenic and natural sources, the expected outcomes of these studies are the definition of the most appropriate lichen species to be used as bio-indicators for monitoring of DU isotope contamination of air. In addition, because of the slow, uniform growth rates of lichens, the proposed research activities could also give indications for establishing the duration of the impact of DU penetrators on targeted sites. This will permit easier interpretation and comparison of past air quality exposure from the different areas in which depleted uranium ordnance has been used.

APPENDIX N

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LIST OF NATO COORDINATES

NATO UNCLASSIFIED

Data concerning the possible locations of depleted uranium ordnance expanded in Serbia (excluding Kosovo) and Montenegro during operation *Allied Force* (grid coordinates).

FRY Serbia (excluding Kosovo)

Site Number	Date	Location (UTM)	Number of Rounds*
5	15-Apr-99	34TEM580880	250/156
6	15-Apr-99	34TEM680995	UNKWN
7	16-Apr-99	34TEM643964	UNKWN
33	15-May-99	34TEM6496	130/81
38	17-May-99	34TEM540821	120/75
41	25-May-99	34TEM620945	300/188
42	25-May-99	34TEM632934	150/94
46	28-May-99	34TEM625882	200/125
65	1-Jun-99		970/606
106	11-Jun-99		970/606
108	UNKWN	34TEM630851	UNKWN
112	28-May-99	34TEM631852	180/113

FRY Montenegro

Site Number	Date	Location (UTM)	Total Number of Rounds*
55	29-May-99	34TCM01479634	230/144
58	30-May-99		250/156

*** Based on 5/8 mix of depleted uranium**

- 112 strikes
- 96 different targets attacked:
  – 85 Targets in Kosovo (excluding Serbia);
  – 10 Targets in FRY/Serbia (excluding Kosovo);
  – 1 Target in FRY/Montenegro.

APPENDIX O

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FORMULAS AND DATA

O.1 The isotope ratio

O.1.1 Natural uranium

Table O.1 Composition of natural uranium by weight

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

O.1.2 Depleted uranium

Table O.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. Some definitions use U-235 less than 0.7 %, some less than 0.35 %, and some less than 0.3 %. The table below shows the composition by weight if 0.35 % is taken as the maximum value in the definition of DU.

In a mixture of natural uranium and DU, the ratio U-235/U-238 will vary as follows.

Table O.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

Assume an amount M (mg) of uranium of which X is the DU component and 1-X the natural uranium component. The ratio R = U-235/U-238 in the amount M with DU defined as U-235 = 0.2 % is estimated by using the formula:

$$R = \frac{0.72 - 0.52X}{99.2745 + 0.5255X}$$

Table O.4 The relation between the fraction X of DU of the 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

$$R = \frac{0.72 - 0.37X}{99.2745 + 0.3755X}$$

Table O.5 The relation between the fraction X of DU of the 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 O.4 and O.5 show that if the measured value of R is compared with Table O.3, assuming U-235 is 0.2 %, there may be an underestimation of up to 30 % of the sample's DU content if, in fact, the U-235 content is 0.35 % instead of 0.2 %.

O.2 Half-lives, specific activities and decay schemes

Table O.6 The specific activity of some radio-nuclides of interest

Radio-nuclide	Occurrence Natural = N Artificial = A	Half-life (years)	Specific activity Bq/mg of respective radio-nuclide
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 O.7 Specific activity of some common radio-nuclides in depleted uranium, DU (^{235}U 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	12.38
^{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.

* Branched decay

O.3 Health standards, limits and levels

■ Chemical: health standards

The WHO has derived a guideline for drinking-water quality of 2 µg of uranium per litre. This value is considered to be protective for sub-clinical renal effects reported in epidemiological studies (WHO, 1998). For oral exposure, a Tolerable Daily Intake (TDI) for uranium of 0.6 µg/kg body weight per day has been established by the WHO (WHO, 1998). U.S. EPA 1991 as a limit for uranium in drinking water of 30 µg/litre (EPA, 2000). This is a new standard, the reference being 65 Federal Register (FR) 76708, 7 DEC 2000, National Primary Drinking Water Regulation, Radionuclides, FR USEPA, 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 for 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

Table O.8 Uranium-238 series (ICRP, 1983)

Nuclide	Type of decay	Half-life	Average emitted energy per transformation		
			Alpha energy MeV	Beta energy MeV	Gamma energy MeV
^{238}U	α	4.468 10^{9}y	4.26	0.010	0.001
↓					
^{234}Th	β	24.1 d	-	0.059	0.009
↓					
*^{234m}Pa (99.84%) + * ^{234}Pa (0.16%)	β β	1.17 min 6.7 h	-	0.820	0.013
↓					
^{234}U	α	2.45 10^{5}y	4.84	0.013	0.002
↓					
^{230}Th	α	7.54 10^{4}y	4.74	-	0.002
↓					
^{226}Ra	α	1600 y	4.86	-	0.007
↓					
^{222}Rn	α	3.824 d	5.59	-	-
↓					
^{218}Po	α (99%) + β (0.02%)	3.05 min	6.11	-	-
↓					
* ^{218}At (0.02%) +	α	1.6 s	6.82	0.04	-
* ^{214}Pb (99.98%)	β	26.8 min	-	0.291	0.284
↓					
^{214}Bi	β (99%) + α (0.04%)	19.9 min	-	0.648	1.46
↓					
* ^{214}Po (99.98%) +	α	1.64 10^{-4}	7.83	-	-
* ^{210}Tl (0.02%)	β	1.3 min	-	-	-
↓					
^{210}Pb	β	22.3 y	-	-	0.047
↓					
^{210}Bi	β	5.01 d	-	0.389	-
↓					
^{210}Po	α	138.4 d	5.40	-	-
↓					
^{206}Pb		Stable			

Risk Level (MRL) for chronic inhalation exposure of 8 µg/m^3. For oral exposure, an intermediate MRL of 2 µg/kg body weight per day was established (ATSDR, 1999).

■ Radiation: Recommendations, limits and action levels

ICRP recommendations (From ICRP 60, 1991 and ICRP 65,1993):

- 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 dwellings 3-10 mSv per year. The same levels apply for work-

Table O.9 Uranium-235 series (ICRP 1983)

Nuclide	Type of decay	Half-life	Average emitted energy per transformation		
			Alpha energy MeV	**Beta energy MeV**	**Gamma energy MeV**
^{235}U	α	7.04 10^8 y	4.47	0.048	0.154
↓					
^{231}Th	β	25.52 h	-	0.163	0.026
↓					
^{231}Pa	β	3.28 10^4 y	5.04	0.063	0.048
↓					
^{227}Ac	α (1.38%) + β (98.6%)	21.77 y	0.069	0.016	-
↓					
* ^{227}Th (98.6%)	α	18.72 d	5.95	0.046	0.106
+					
* ^{223}Fr (1.38%)	β	21.8 min	-	0.391	0.059
↓					
^{223}Ra	α	11.43 d	5.75	0.075	0.133
↓					
^{219}Rn	α	3.96 s	6.88	-	0.058
↓					
^{215}Po	α	1.78 10^{-3} s	7.52	-	-
↓					
^{211}Pb	β	36.1 min	-	0.454	0.053
↓					
^{211}Bi	α (99.7%) + β (0.28%)	2.14 min	6.68	-	0.047
↓					
* ^{211}Po (0.28%)	α	0.516 s	0.021	-	-
+					
* ^{207}Tl (99.7%)	β	4.77 min	-	0.492	-
↓					
^{217}Pb		Stable			

places.

- 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.

EU limits

According to Article 9 of the Council Directive 96/29 EURATOM of 13 May 1996, which lays down basic safety standards for the protection of health of workers and the general public against the dangers arising from ionising radiation (the BSS), “the limit on effective dose for exposed workers shall be 100 mSv in a consecutive five-year period, subject to a maximum effective dose of 50 mSv in a single year" (EU, 1996). According to Article 10, the dose to a pregnant woman shall be as low as reasonably achievable and not exceeding 1 mSv. These dose limits refer to exposure at work. Article 13 referring to dose limits for members of the public sets the maximum effective dose at 1 mSv/year. This limit refers to exposure to artificial sources. Article 2.4 excludes from this limit exposure to natural levels of radiation.

Table O.10 Natural uranium-238 concentrations in common soils and rocks*. Higher and lower concentrations occur occasionally. (Åkerblom and Mellander 1997).

Soils	Range (mg/kg)	Range (Bq/kg)	Reference
World average	3	35	UNSCEAR 2000
World range	0.01-75	1-900	UNSCEAR 2000
Sand	0.5-3	5-35	
Clay	1-8	10-100	
Serbia and Montenegro at the sites visited by the UNEP Mission	1-10	12-120	This report
Rocks			
World average		35	Kogan *et al.* 1971
Basic igneous rocks	0.1-3	1-30	
Granite, normal	2-6	20-500	
Granite, uranium-rich		100-500	
Limestone	0.2-3	2-30	
Sandstones	0.5-5	1-60	
Chattanooga shale (USA)	20-80	250-1,000	Swanson 1960
Alum shale (Sweden)	50-300	600-3,700	Andersson *et al.* 1985
Uranium ores of good quality (0.5-30 % uranium)	10,000-300,000	$6.2\ 10^5$-$370\ 10^5$	

Table O.11 Natural uranium-238 concentrations in water.

Water type	Range (µg/l)	Range (mBq/l)	Reference
Fresh waters	0.1 - 8	1 - 90	
Groundwaters	<1 - 12	<1 - 140	(UNSCEAR 1993)
Finnish values up to	12,100	150,000	(UNSCEAR 2000)
Yugoslavian values	0.04 - 41	0.5 - 510	(UNSCEAR 1993)
Yugoslavian values at the sites visited by the UNEP Mission	0.02 - 1.8	0.2 - 22	This report
Sea water	1 - 3.3	12 - 40.5	
Reference value for drinking water	0.08	1	(UNSCEAR 2000)

EU Council Directive 98/83/EC on the quality of water intended for human consumption requires the Member States to monitor the concentrations of radionuclides in public drinking water (EU, 1998). If the indicative dose exceeds 0.1 mSv per year, the competent authorities shall investigate to identify the cause and to take justified precautions. For uranium, the reference concentration is 100 µg/l (EU, 2001).

O.4 Natural levels of uranium

* Uranium in rocks that are unaffected by weathering or dissolution by groundwater is normally in radioactive equilibrium with all its daughter products down to Pb-206 (see Table O.8 above). However, this is usually not the case in weathered rocks and in soils where either uranium or radium may have been partly dissolved and leached from the minerals. In air, the total activity concentration of uranium is about 1 µBq/m^3 and the reported range for the U.S.A. is 0.9 - 5 µBq/m^3 (UNSCEAR, 2000).

Data on uranium (UNSCEAR reports)

- Activity of U-238 is 12.4 Bq/mg.
- Body burden 30 µg uranium (99.8 % is U-238 by weight. 360 mBq for both U-238 and U-234 assumed to be in equilibrium).
- Effective dose 7µSv per year caused by only U-238 and U-234 (in equilibrium, both contributing about 50 %) in the body.
- Total effective dose 110 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.
- Activity concentration in air 1 µBq/m^3 for both U-238 and 234 (8 10^{-5} µgm^{-3}, 99.8 % U-238 by weight).
- Inhaled 7 mBq per year for both U-238 and 234 (~0.6 µg uranium, 99.8 % U-238 by weight).
- Effective dose caused by inhaled uranium:
  - 0.3 µSv per year if all uranium daughters (except radon and its daughters) are in equilibrium;
  - 5.8µSv 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 alone and 0.03 µSv per year from U-234 alone.
- Normal dust load 50 µg/m^3.
- Natural uranium concentration in soil in average 3 mg per kg, activity concentration 33 Bq/kg for both U-238 and U-234 (3 mg/kg).
- Uranium in dust as in soil, i.e. 1.7 µBq/m^3 air for both U-238 and U-234.
- Ingested by food 5.7 Bq/year (0.46 mg uranium per year, the major part U-238 by weight) for both U-238 and U-234.
- Normal drinking water concentration 0.08 mg uranium per m^3, activity concentration 1 Bq/m^3 (0.08 mg uranium/m^3) for both U-238 and U-234.
- Intake by water 0.5 Bq per year (0.04 mg uranium per year, 500 l water per year) for both U-238 and U-234.
- Effective dose caused by ingested (by food and water) uranium 0.3 µSv per year from both U-238 and U-234. Therefore: 33 Bq/kg soil (for both U-238 and 234) leads to a total annual intake by food and water of 6.2 Bq for both U-238 and U-234, which leads to an effective dose of 0.3 µSv per year from both 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 the 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).

O.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 European Union 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 ionising 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) for ingested or inhaled uranium by an individual in the given age group.

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

Table O.12 Committed effective dose per unit intake via ingestion (Sv/Bq) for members of the public

Uranium-238								
Half-life	**Age < 1 y**		**Age**	**1-2 y**	**2-7 y**	**7-12 y**	**12-17 y**	**> 17 y**
	f_1 for g < 1 y	h(g)	f_1	h(g)	h(g)	h(g)	h(g)	h(g)
4.47 10^{9}y	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 < 1 y**		**Age**	**1-2 y**	**2-7 y**	**7-12 y**	**12-17 y**	**> 17 y**
	f_1 for g < 1 y	h(g)	f_1	h(g)	h(g)	h(g)	h(g)	h(g)
2.44 10^{5}y	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 < 1 y**		**Age**	**1-2 y**	**2-7 y**	**7-12 y**	**12-17 y**	**> 17 y**
	f_1 for g < 1 y	h(g)	f_1	h(g)	h(g)	h(g)	h(g)	h(g)
7.04 10^{8}y	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 O.13 Committed effective dose per unit intake via inhalation (Sv/Bq) for members of the public

Uranium-238 Half-life 4.47 10^{9} years								
Type	**Age < 1 y**		**Age**	**1-2 y**	**2-7 y**	**7-12 y**	**12-17 y**	**> 17 y**
	f_1	h(g)	f_1	h(g)	h(g)	h(g)	h(g)	h(g)
F	0.040	1.9 10^{-6}	0.020	1.3 10^{-6}	8.2 10^{-7}	7.3 10^{-7}	7.4 10^{-7}	5.0 10^{-7}
M	0.040	1.2 10^{-5}	0.020	9.4 10^{-6}	5.9 10^{-6}	4.0 10^{-6}	3.4 10^{-6}	2.9 10^{-6}
S	0.020	2.9 10^{-5}	0.002	2.5 10^{-5}	1,6 10^{-5}	1.0 10^{-5}	8.7 10^{-6}	8.0 10^{-6}

Uranium-234 Half-life 2.44 10^{5} years								
Type	**Age < 1 y**		**Age**	**1-2 y**	**2-7 y**	**7-12 y**	**12-17 y**	**> 17 y**
	f_1	h(g)	f_1	h(g)	h(g)	h(g)	h(g)	h(g)
F	0.040	2.1 10^{-6}	0.020	1.4 10^{-6}	9.0 10^{-7}	8.0 10^{-7}	8.2 10^{-7}	5.6 10^{-7}
M	0.040	1.5 10^{-5}	0.020	1.1 10^{-5}	7.0 10^{-6}	4.8 10^{-6}	4.2 10^{-6}	3.5 10^{-6}
S	0.020	3.3 10^{-5}	0.002	2.9 10^{-5}	1,9 10^{-5}	1.2 10^{-5}	1.0 10^{-5}	9.4 10^{-6}

Uranium-235 Half-life 7.04 10^{8} years								
Type	**Age < 1 y**		**Age**	**1-2 y**	**2-7 y**	**7-12 y**	**12-17 y**	**> 17 y**
	F_1	h(g)	f_1	h(g)	h(g)	h(g)	h(g)	h(g)
F	0.040	2.0 10^{-6}	0.020	1.3 10^{-6}	8.5 10^{-7}	7.5 10^{-7}	7.7 10^{-7}	5.2 10^{-7}
M	0.040	1.3 10^{-5}	0.020	1.0 10^{-5}	6.3 10^{-6}	4.3 10^{-6}	3.7 10^{-6}	3.1 10^{-6}
S	0.020	3.0 10^{-5}	0.002	2.6 10^{-5}	1.7 10^{-5}	1.1 10^{-5}	9.2 10^{-6}	8.5 10^{-6}

Table O.14 Effective dose coefficients (Sv/Bq) for workers

Uranium-238

	Inhalation			Ingestion	
Type	F_1	$h(g)_{1\mu m}$	$h(g)_{5\mu m}$	f_1	$h(g)$
F	0.020	$4.9\ 10^{-7}$	$5.8\ 10^{-7}$	0.020	$4.4\ 10^{-8}$
M	0.020	$2.6\ 10^{-6}$	$1.6\ 10^{-6}$	0.002	$7.6\ 10^{-9}$
S	0.002	$7.3\ 10^{-6}$	$5.7\ 10^{-6}$		

Uranium-234

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

Uranium-235

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

Table O.15 Compounds and f_1 values used for the calculation of ingestion dose

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

Table O.16 Compounds, lung absorption types and f_1 values for the calculation of inhalation dose coefficients

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

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

Table O.17 Lung clearance and integrated effective dose as a function of time

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

Table O.18 Committed effective dose per unit of intake (Sv/Bq)

Isotope	Ingestion Sv/Bq	Inhalation Sv/Bq
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 O.19 Committed effective dose per unit of intake of depleted uranium (Sv/mg)

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

Comments

As seen from the tables, the dose factors for infants and new-born babies (< 1 year old) are about a factor of four times higher than for adults (> 17 years old) in the case of inhalation, and even greater in the case of ingestion. However, the volume of air breathed and mass of food and water consumed per unit of time are much smaller for infants and new-born 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) the radiation dosese from intakes by adults and infants are not so different. Furthermore, in the 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 O.17 is an example of lung clearance after an intake of 100 Bq U-234 as 5 µ S-particles by an adult. 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, when considering long-term exposure, childhood accounts for a relatively short period in relation to a full lifetime.

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. Tables O.18 and Table O.19 show selected committed effective doses per unit intake (Sv/Bq) of various uranium isotopes and of depleted uranium (Sv/mg), respectively.

(x) This value is about 3 times larger than that used in UNSCEAR 2000 and referred to in this Appendix because a more conservative clearance factor is used in this report.

APPENDIX P

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DISCUSSION OF HEALTH ISSUES

P.1 RESULTS OF TARGETED EXAMINATIONS OF PARTICIPANTS IN THE DECONTAMINATION OF URANIUM-CONTAMINATED TERRAIN

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■ CONTENT

The results of targeted and repeated examinations of 11 individuals, who had for four months worked on the decontamination of the terrain contaminated by uranium ammunition, have been presented below. Thermoluminescent dosimeters did not register increased doses, nor did the urine gamma activity increase. Capillary smears evidenced the presence of toxic granulation and deformations of leukocyte nuclei in two cases, as well as stimulated lymphocytes and virocytes (monocytes) in others. Chromosomal changes were discovered in 50 % of the tested individuals. No significant changes in the numerical values of the blood cells have been detected.

■ INTRODUCTION

An expert team was set up in January 2001 with the task of decontaminating the terrain on the peninsula of Lustica bombed during the NATO Pact's aggression in 1999. The chosen experts worked on the decontamination of Cape Arza from early February to late May 2001. They collected 39 kilograms of Uranium 238, originating from radioactive ammunition.

All participants in the decontamination were subjected to medical check-ups in accordance with the programme envisaged in targeted examinations of individuals in areas of ionizing radiation under the Law on the Ionizing Radiation Protection. (1) The targeted examination encompassed the preliminary check-ups and repeated health check-ups immediately after the participants, who had been actively involved in the decontamination, had completed their task. During their work, the team members wore adequate protection equipment and personal thermoluminescent dosimeters (TLD). During their work, the team suffered a mild epidemic the viral etiology of which has remained unclear.

■ METHODOLOGY

The eleven team members were subjected to the following examinations before and after the decontamination task: general clinical check-ups, general blood tests and karyotypes. The blood cells were microscoped in coloured capillary smears for morphological analysis and detection of immature forms. The karyotype of the lymphocytes, that were isolated from the blood and prepared by the usual method for analysing chromosome aberrations, was monitored.

The gammaspectrometric method was used to measure the radioactivity of 24-hour urine (2). The TL dosimeters on the TLD reader were monitored.

■ RESULTS AND DISCUSSION

The preliminary medical examinations showed that the general state of health of all individuals was normal. The results were within the limits of physiological values so that all of them were capable of fulfilling the planned tasks. All results of the repeated examinations were compared with the preliminary results and are shown in Table P.1

Table P.1 Pre-Decontamination and Post-Decontamination Check-up Results

No of individual	Capillary Smear			Le-formula (%)					CA	MN	TLD (mSv)
	Normal	Morph. Changes		NG	Ly	Mo	Eo	Bz			
		g.s.	i.s.								
1.I			*	59	35	5	1	0	0		
1.II			**	66	27	7	0	0	*	11	0.48
2.I	Yes			60	38	2	0	0	0		
2.II		**		54	41	5	0	0	**	11	0.28
3.I	Yes			70	25	5	0	0	0		
3.II		*	*	61	34	5	0	0	*	9	0.25
4.I	Yes			57	38	2	3	0	0		
4.II		**		53	37	4	6	0	0	9	0.55
5.I	Yes			64	35	1	0	0	0		
5.II	Yes			52	40	6	2	0	0	4	0.37
6.I	Yes			61	36	2	1	0	0		
6.II		*	*	57	42	1	0	0	0	8	0.40
7.I			*	58	37	2	3	0	0		
7.II			*	47	46	4	3	0	0	8	0.48
8.I	Yes			59	35	6	0	0	*		
8.II		*	*	43	40	11	6	0	0	9	0.26
9.I	Yes			64	35	1	0	0	0		
9.II		*		55	36	4	5	0	0	11	0.31
10.I	Yes			52	40	7	1	0	0		
10.II		*		50	43	4	3	0	*	8	0.38
11.I			*	63	30	7	0	0	*		
11.II		*	*	50	43	7	0	0	*	13	0.40

g.s. – granulocytic strain i.s. – immunocytic strain CA - chromosomal aberrations * - changes in cytoplasm * - appearance of 'large' Ly * - uncharacteristic changes ** - changes in nucleus and cytoplasm ** - appearance of 'large' Ly and virocytes ** - specific changes MN - micronuclei

There were no variations nor significant changes in the number of elements in the haemogram before and after the decontamination. The percentage of lymphocytes had increased in the Leukocyte formula in eight out of eleven cases, while the percentage of monocytes increased in seven cases. Lymphomonocytosis with the appearance of virocytes is probably a consequence of the verified viral infection. The percentage of eosinophils was more than double after decontamination compared to the pre-decontamination percentage (2.27± 2.49 compared to 0.82±1.17); however, this difference is statistically not significant (t=2.02, p=0.07).It cannot be claimed with certainty whether it, too, is linked to the infection or a consequence of radioactivity. It is a common fact that exposure to small doses or the effects of milder contamination may result in moderate, even long-term eosinophilia. Basophils were not detected, nor were immature forms or blast cells. Exposure to uranium during the decontamination task did not affect maturation in the bone marrow. Toxic granulation in the cytoplasm of neutrophilic granulocytes was evidenced in six team members; in two, karyoschisms – irregularities in the form of the nucleus - were manifested as well. This corresponds to non-specific toxic changes and cannot be considered solely the consequence of uranium effects.

Amongst six of the team members, who account for 50 % of the team, the changes in genetic material which had not been detected during the preliminary check-up, were evidenced in the repeated examination. The structure and morphology of the anomalies is specific not only to exposure to sources of ionizing radiation; identical changes are caused also by numerous chemical matters with radiomimetic characteristics and they very often spontaneously occur in an organism although no known external xenobiotic was detected. Only in one case is there a characteristic finding, which is not significant in terms of statistics. Chromatid breakages are mostly in question, while, in 2 cases, acentric fragments are at issue. The results of chromosomal aberrations have deteriorated compared with the preliminary check-ups in 4 cases. The overall number of chromosomal aberrations after decontamination has increased, but not significantly in terms of statistics (McNemar's pair test = 0.64, p=042, 95% confidence interval 0.55-6.16). Also, there are no statistically significant differences when the specific and non-specific changes in chromosomes are separately analysed. The detected chromatid lesions, which had not been detected on 200 lymphocytes before contamination, do not indicate that they were inevitably caused by the decontamination task, i.e. alpha radioactive emission from the ammunition; however, this possibility cannot be fully ruled out. The number of micronuclei is not* (unclear in Serbian whether the number is or is not within the usual value limits, translator) within the usual value limits.

Termoluminescent dosimeters did not register doses of ionizing radiation which are greater than those in the natural environment, which can be explained by the type of radioactive emission to which they were exposed during decontamination, as well as by the distance and site of dosimeter application.

The urine gamma activity has not increased. The measured activity is the result of radiocesium and other radionuclides, not of uranium, which this method is not expected to register unless large quantities and major direct internal contamination are in question.

■ CONCLUSION

The detected changes in the blood cells and chromosomes are specific not only to ionizing radiation; they may also be the result of different toxic matter, and can therefore be found amongst the rest of the population as well. However, since they were non-existent before, they represent positive findings. Subsequent consequences cannot be ruled out. Further monitoring needs to include examination of uranium in the urine by fluorometrical and alphaspectrometrical methods in the upcoming period, as well the calculation of effective equivalent dose.

■ LITERATURE

1. Law on Ionizing Radiation Protection, Official Gazette of the Federal Republic of Yugoslavia, No 46/96.
2. Decision on Systematic Research of Radionuclide Content in Environment, Official Gazette of the Federal Republic of Yugoslavia, No 45/97.

P.2 WHO REVIEW OF MONTENEGRIN REPORT ON RESULTS OF TARGETED EXAMINATION OF PARTICIPANTS IN THE DECONTAMINATION OF URANIUM-CONTAMINATED TERRAIN

Reviewed by Drs. MH Repacholi, L Kheifets and L Goldstein
WHO Radiation and Environmental Health Unit

At the request of UNEP, WHO was asked to review this paper to determine what results can be drawn from it. This is part of an ongoing collaboration between these two UN agencies on the health and environmental effects of depleted uranium.

This paper describes the results of medical and laboratory examinations of 11 individuals taken before and after four months work to decontaminate land contaminated by uranium-containing munitions during the 1999 conflict in Serbia. During the decontamination process, 39 kilograms of uranium-238 was collected. Of relevance to the study was that during their work, the team suffered a mild epidemic, the viral etiology of which was unclear.

■ RADIATION EXPOSURE

The workers wore radiation dosimeters (thermoluminescent) during the clean-up operation, but no increase in radiation dose was registered. In addition, measurements taken from urine samples did not register any increase in gamma radiation activity. These results are as expected from handling depleted uranium, which has an activity of about 40 % less than natural uranium. This has been described in a recent WHO review (see: http://www.who.int/environmental_information/radiation/depleted_uranium.htm)

■ MEDICAL EXAMINATIONS

Medical examinations included general clinical checks, blood tests and chromosomal analyses (karyotyping of lymphocytes) before and after the 4-month work period.

The general medical examinations suggested that the workers were in good health before and after the decontamination period. While there was no significant change in a number of elements of the haemogram, the percentage of lymphocytes had increased in eight of the eleven cases and the percentage of monocytes increased in seven cases. There was also a non-significant increase in the number of eosinophils.

The authors report that chromosomal changes were detected in 50 % of the workers completing the clean-up operation compared to the results of the initial examination.

■ CONCLUSIONS

Detailed methods for karyotyping were not provided. Analysis of chromosomal effects may be complicated by the presence of what presumably is a viral infection in most if not all the team members.

The incidence of chromatid breaks was not significant. Note that with very small numbers of subjects in the study only very large effects would reach statistical significance. Micronuclei (acentric fragments) were found in six of the team members (although Table 1 shows it in all team members) for samples taken after the decontamination. It is not clear if this assay was performed before the task or if the “before and after” data for the six workers are somehow transposed in the Table. In any event the text states “the results of chromosomal aberrations have deteriorated compared with preliminary check-ups in four cases”. I take this to mean that re-testing did not confirm these results.

It is often difficult to identify micronuclei with certainty. Different cytologists may apply different standards. It is not clear whether the same cytologist viewed all samples nor what the criteria were. Micronuclei are often regarded as unreliable measures of radiation induced damage.

The authors state in their conclusions that “changes in blood cells and chromosomes ... were non-existent before [and so] they represent positive findings.” Whether they do or not is arguable. It is certainly not clear, given that the chromosomal changes are real, whether they are due to any environmental exposures (including radiation) the workers may have encountered at the clean-up sites. The data simply aren’t strong enough to draw any conclusions.

One could imply from the lack of radiation exposure of the workers recorded by two different methods, that the reported effects are unlikely to be due to radiation emitted by the depleted uranium. Further, if the workers were using protective clothing, it is unlikely that there was any significant inhalation, ingestion or contact from depleted uranium to produce any chemical toxicity.

APPENDIX Q

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UNITS

Bq	unit for radioactivity, 1 Bq is the disintegration of 1 atom per second.
Bq/kg	becquerel per kg.
mBq/l	milli bequerel per liter
µBq/m^{3}	micro bequerel per cubic meter
mSv	millisievert, unit for effective dose
µSv/h	micro Sievert per hour, unit for ambient dos equivalent rate. Unit used for exposure to gamma radiation in air.
nSv/h	nano (10^{-9}) Sievert per hour
Sv/mg	committed effective dose per unit of intake of depleted uranium
Sv/Bq	committed effective dose per unit of intake
µR/h	micro Roentgen per hour, older unit used for measurements of gamma radiation, 1 µR/h is equal to 0.01 µSv/h.
cps	counts per second
µg/kg	microgram per kg
mg/kg	milligram per kg
mg/l	milligram per liter
ml/min	milli liter per minute
m^{3}/min	cubic meter per minute
particles/ cm^{2}*sec	particles in units throgh 1 square cm.
µg/cm^{2}	micro gram per square centimeter
g/m^{2}	gram per square meter
g/m^{3}	gram per cubic meter
ppm	parts per million, 1 ppm is equal to 1mg/kg
ppb	parts per billion, 1 ppb is equal to 1 mg/kg

eU	equivalent uranium concentration. The concentration of uranium-238 assuming equilibrium within the uranium series. The abbreviation eU is for example used for gamma spectrometric measurements during which the uranium-238 concentration is determined by measurements of the gamma radiation from the uranium-238 daughter nuclide bismut-214. During such measurements it is assumed that there is equilibrium within the uranium series.
s	seconds
min	minutes
d	days
y	year
MeV	Mega electron Volt
mol/L	molality per litre

APPENDIX R

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GLOSSARY

Activity	The number of nuclear transformations occurring in a given quantity of material per unit time. The unit is 'per second' and with the name bequerel (Bq – see below).
Activity concentration	Bq per unit mass or volume (for Bq, see below).
Acute biochemical effects	High exposure of radiation doses can cause noticeable/significant consequences such as symptoms of illness or damage to normal body functions.
Alpha particle (α)	A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. The charged particle is identical with the helium nucleus, but of nuclear origin. It comprises two neutrons and two protons, and has a mass number of 4 and an electrostatic charge of +2. On capturing two electrons it forms an atom of helium indistinguishable from any other helium atom.
APC	Armoured Personnel Carrier.
Atom	The smallest particle of an element that cannot be divided or broken up by chemical means. It consists of a central core called the nucleus, which contains protons and neutrons and an outer shell of electrons.
Bio-indicators	Moss, mushrooms, bark and lichen etc. Analysis of these samples can indicate the possible presence of DU as evidence of earlier or ongoing air contamination.
Background radiation	The order of radiation from which a member of the general population is exposed from natural sources, such as terrestrial radiation from naturally occurring radionuclides in the soil, cosmic radiation originating from outer space, and naturally occurring radionuclides deposited in the human body.
Beta particle (β)	Charged particle emitted from the nucleus of an atom. A beta particle has a mass and charge equal in magnitude to that of the electron. The charge may be either +1 (positron) or –1 (negatron).
Committed effective dose	Following an intake into the body of a radioactive

	material there is a period during which the material gives rise to an equivalent dose to one or several organs and an effective dose to the whole body. The committed effective dose is the time integration of the effective dose rate. If the time interval is not specified it is implied that the value is 50 or 70 years, as defined by the regulator or assessor.
Careful measurements	This method was often used to complement the measurements derived from line up service. It consisted of measurements made with the *Inspector* beta/gamma instrument, involving more careful removal of any covering of dust, grass etc., and measuring over a longer time period, to detect any possible shielded beta radiation from widespread contamination.
Contamination point	Small area of localised DU surface contamination found by field beta measurements, typically at the point of a penetrator impact.
Decay (radioactive)	Transformation of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.
Decay chain or series	A sequence of radioactive decays beginning with one nucleus. The initial nucleus decays into a secondary nucleus ‘or progeny nucleus’ that differs from the first by whatever particles were emitted during the decay. If further decay takes place, the subsequent nuclei are also usually called progeny.
Decay product	A new isotope formed as a result of radioactive decay. A nuclide resulting from the radioactive transformtion of a radionuclide, formed either directly or as the result of successive transformations in a radioactive series. A decay product may be either radioactive or stable.
Decontamination	Clean up of site targeted with DU. Removal of radioactive contamination.
Depleted uranium (DU)	Uranium having a percentage of uranium-235 less than the naturally occurring distribution of U-235 found in natural uranium (less than 0.711 weight percent U-235).
Dose rate	Absorbed dose delivered per unit time.
DU round	Complete DU projectile, including jacket and penetrator.
Effective committed dose	Following an intake of a radioactive material there is a period during which the material gives rise to an effective dose. The effective committed dose is the

	time interval of the effective dose rate. The name of the unit is sievert (Sv), usually expressed as 'millisieverts' (mSv or 10^{-3} sievert) or 'microsieverts' (µSv or 10^{-6} sievert).
Fragment	Small, solid pieces of a broken DU penetrator or jacket.
Gamma particle (γ)	Short-wavelength electromagnetic radiation of nuclear origin. Penetrating radiation.
Half-life (radioactive)	Time required for a radioactive substance to lose 50% of its activity by decay. Each radionuclidehas a unique half-life.
ICP-MS	Inductively coupled plasma mass spectrometry. An instrument that can measure very low resolution.
Ignition residue	Ash after heating to ignition.
Individual survey	Single individuals or groups of two individuals together conducted surveys by sweeping, as line up survey, in predetermined directions and areas. This method was used in very special circumstances when very little was known about the precise areas of a given site within which DU had been used.
Insignificant risks	Low levels of contamination – of the same order of magnitude as natural uranium levels.
Insignificant radiological risk	When the corresponding dose are < 1 mSv or below WHO health standards, recommendations or guidelines respectively.
Insignificant toxicological risk	When the corresponding concentrations/intakes are < 1 mSv or below WHO health standards, recommendations or guidelines respectively.
Isotopes	Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons and therefore in the mass number.
Isotopic concentration	Unit mass (e.g. mg) of an isotope (e.g. U-238) per unit mass or volume in which the isotope occurs.
Jacket	The non-DU part of a projectile that holds the DU penetrator.
Line up survey	A number of people (most often 4-6) were lined up with 1-2 metres between each person. The group walked slowly forwards, maintaining their alignment with one another, while sweeping the instruments at ground level left and right perpendicular to the walking direction in such a way that approximately

	all the area was measured. The walking speed was 7 ± 2 metres per minute depending on the terrain.
Natural background concentration	The concentration or level of a substance that is derived solely from natural sources (i.e. of geological origin) after ISO 11074-1:1996.
Nuclide	A species of atom characterised by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N), and energy content, or, alternatively, by the atomic number (Z), mass number A=(N+Z), and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time.
Penetrator	The armour-piercing DU core of a DU weapon projectile.
Qualified at random survey	After a briefing on what to expect, how to conduct the survey and where to search, team members were sent out to search for radioactivity in the environment.
Radioactivity	Spontaneous nuclear transformations that result in the formation of new elements. These transformations are accomplished by emission of particles from the nucleus or by the capture of an orbital electron. Each of these reactions may or may not be accompanied by a gamma photon.
Radionuclide	A radioisotope or radioactive nuclide characterised by the constitution of its nucleus.
Reference case	Definition on how it is assumed that the attack happened, how much DU was used in the attack, size of the contaminated area, human exposure to DU, use of the contaminated area in the future and possible long term effects of DU.
Reference level	Ground-surface contamination of 10 g DU/m^2
Sievert (Sv)	The SI unit of any of the quantities expressed as equivalent or effective dose. The equivalent dose in sieverts is equal to the absorbed dose, in grays, multiplied by the radiation-weighting factor (1 Sv = 100 rem). The effective dose is the equivalent dose multiplied by the tissue-weighting factor.
Significant radiological risk	A ‘significant’ radiological risk is defined in this report to be one where the expected radiation dose would be > 1 mSv per event, or per year.
Significant risks	When the exposure of DU are higher than applicable health standards.

Significant toxicological risk	A ‘significant’ toxicological risk means that the expected concentration or intake would exceed WHO health standards (WHO 1998A, 1998B), recommendations or guidelines.
Soil	The upper layer of the Earth’s crust composed of mineral parts, organic substance, water, air and living matter (ISO 11074-1, 1996).
Specific activity	Radioactivity per gramme of a radionuclide.
Undetectable DU contamination	Low DU contamination. Not possible to differentiate from uranium present naturally in the soil.
Widespread contamination	When a large number of penetrators hit hard surfaces they become aerosolised. As the aerosols disperse and fall out, the resulting contamination of the ground surface may be localised or spread over the area, depending on the properties of the aerosols and the prevailing meteorological conditions.

APPENDIX S

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REFERENCES

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

Adamo, P., Violante, P., Violante, A., 1989. *Contenuto di radionuclidi nel tallo di Stereocaulon vesuvianum* (Pers.). *Atti S.IT.E.* 7,173-176.

Agapov A.M., Novikov G.N. and Pavlovski O.A., 2001. *Use of ammunition with depleted uranium in Yugoslavia*. Journal "MOST", S-Petersburg, #43, April 2001, p.30-33. (in Russian).

Åkerblom G. and Mellander H., 1997. *Geology and radon.* In Durrani S.A. & Ili´c R. *Radon Measurements by Etched Track Detectors.* World Scientific, Singapore, 21-49.

Andersson A., Dahlman B., Gee D. and Snäll S., 1985. *The Scandinavian alum shales. Geological Survey of Sweden.* Avhandlingar och uppsatser, Nr 56,. 55 p.

ATSDR, 1999. *Toxicological profile for uranium, draft for public comment.* Research Triangle Institute for Agency for Toxic Substances and Disease Registry, Atlanta. USA.

Beckett P.J., Boileau L.J.R., Padovan D., Richardson D.H.S. & Nieboer E., 1982. *Lichens and mosses as monitors of industrial activity associated with uranium mining in northern Ontario, Canada – Part 2: Distance dependent uranium and lead accumulation patterns.* Environmental Pollution 4B, 91-107.

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

Bogatov S.A., Gorshkov V.E., Tkalya E.V. and Al'himovich N.N.,1995. *The Method of Reconstruction of Air Activities Following a Nuclear Accident.* Radiat. Prot. Dosim. 62(3), pp 139-149 (1995).

Boileau L.J.R., Beckett P.J., Lavoie P. & Richardson D.H., 1982. *Lichens and mosses as monitors of industrial activity associated with uranium mining in northern Ontario, Canada – Part 1: Field procedures, chemical analysis and interspecies comparison. Environmental Pollution* 4B, 69-84.

Bou-Rabee F., 1995. *Estimating the Concentration of Uranium in Some Environmental Samples in Kuwait After the1991 Gulf War.* Appl. Rad. Isot. 46(4), 217-220.

Brezzi, G., 1999-2000. *Valutazione dell'indice di biodiversità dei licheni di alcune aree del Lazio.* Tesi di Laurea. Dip. Biologia Vegetale, Università "La Sapienza". Roma.

Browne E., Firestone R.B., Shirley V., 1986. *Table of isotopes.* Lawrence Berkeley Laboratory, University of California. John Wiley & Sons Inc., New York.

Brummitt R.K. & Powell C.E., (eds.) 1992. *Authors of plant names.* Royal Botanic Gardens, Kew.

Burger M., 2002. *UNEP DU Post–Conflict Assessment 2001: Serbia/Montenegro. Report of the Swiss Team.* Spiez Laboratory Report with 1 annex. Switzerland.

Cantaluppi C. and Degetto S., 2000. *Usi Civili e Militari dell'Uranio Impoverito: Problemi Ambientali e Sanitari.* Atti del XXXI Congresso Nazionale AIRP, Ancona, Sett. 2000.

CHPPM. 2000. Health risk assessment consultation No. 26-MF-7555-00D. *Depleted uranium -Human exposure assessment and health risk characterization in support of the environmental exposure report «Depleted uranium in the Gulf» of the Office of the Special Assistant to the Secretary of Defense for Gulf War Illnesses.* Medical Readiness and Military Deployments (OSAGWI), OSAGWI Levels I, II, and III Scenarios, 15 September 2000.

Clauzade G. & Roux C., 1985. *Likenoj de Okcidenta Europo. Ilustrita Determinlibro. Bull.* Soc. Bot. Centre-Ouest, n. s., nr. spéc. 7.

Crançon P. 2001. *Migration de l'uranium dans un Podzol . Le Role des Colloides dans la Zone non saturee et la Nappe: Application aux Llandes de Gascogne*. Ph. Dr. thesis, University of Grenoble 1, France.

Currie L.A., 1968. *Limits for qualitative detection and quantitative determination.* Anal. Chem., 40; 586-593.

DOE, 2000. *Exposure Assessment Project at the Paducah Gaseous Diffusion Plant.* Dec. 2000. http:/www.eh.doe.gov/benefits/docs/200012paducah.pdf

DOF, 2000. *Depleted Uranium in the Gulf (II).* Environmental Exposure Report. US Department of Defense. December 13, 2000.

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

EU, 1996. *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. L 159.Vol. 39. 26 June 1996.

EU, 1998. *Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.* Official Journal of the European Communities. L 330/32. December 1998.

EU, 2001. *Draft modification to OJ L330/46 of 5.12.98 (version 13/03/01). Annex II,* Monitoring.

European Commission 2001. *Opinion of the Group of Experts Established according to Article 31 of the EURATOM Treaty. Depleted Uranium.*

EURACHEM/CITAC Guide 2000. *Quantifying uncertainty in analytical measurement.* 2nd Edition, 2000.

Exploranium G.S. Ltd., 1989. *Portable Gamma Ray Spectrometer, Model GR-256 with GPS-21 Detector.* Manual. Exploranium G.S. Ltd. Bolton, Ontario, Canada. Rfv. #4 – 10/26/89.

Feige G.B., Niemann L. & Jahnke S., 1990. *Lichen and mosses – silent chronists of the Chernobyl accident.* Bibliotheca Lichenologica 38: 63-77.

Ferry B.W., Baddeley M.S. & Hawksworth D.L., (Eds.) 1973. *Air Pollution and Lichens.* University of Toronto Press, Toronto.

Garty J., Galun M. & Kessel M., 1979. *Localization of heavy metals and other elements accumulated in the lichen tallus.* New Phytologist 82, 159-168.

Goldstein S. J., Rodriguez J. M. and Lujan N., 1997. *Measurement and Application of Uranium Isotopes for Human and Environmental Monitoring.* Health Phys. 72(1), 10-18.

Haas J.R., Bailey E.H. & Purvis O.W., 1998. *Bioaccumulation of metals by lichens: Uptake of aqueous uranium by Peltigera membranacea as a function of time and pH.* American Mineralogist 83, 1494-1502.

Harley N.H., Foulkes E.C., Hilborne L.H., Hudson A., Anthony C.R., 1999. *A review of the scientific literature as it pertains to Gulf war illnesses.* RAND. Washington, USA. 1999. http://www.gulflink.osd.mil/library/randrep/du/

Hofmann W., Attarpour N., Lettner H. & Türk, R., 1993. *^{137}Cs concentrations in lichens before and after the Chernobyl accident.* Health Physics 64, 70-73.

Holm E. and Persson B.R.R., 1978. *Global fallout of curium.* Nature, 273, 289-290.

IAEA, 1979. *Gamma-ray surveys in uranium exploration.* International Atomic Energy Agency, Technical reports series No. 186. p 90.

ICRP, 1974. *Report of the Task Group on Reference Man, 1974.* Commission on Radiation Protection (ICRP), Publication No. 23. Pergamon Press, 1975.

ICRP, 1983. *Radionuclide transformations. Energy and intensity of emissions. Annals of the ICRP.* ICRP publication 38, Vol. 11-13, 1983. Pergamon Press. 1983.

ICRP, 1991. *Recommendations of the International Commission on Radiological Protection.* ICRP publication No. 60. Pergamon Press 1991.

ICRP, 1993. *Protection against Radon-222 at home and at work.* Report of the International Commission on Radiological Protection, ICRP publication No. 65. Pergamon Press 1993.

ISO/TEC Guide 17025. *General Requirements for the Competence of Testing and Calibration Laboratories.* American Association for Laboratory Accreditation (A2LA). Fredrick, Maryland USA.

Jeran Z., Byrne A.R. and Batiæ F., 1995. *Transplanted epiphytic lichens as biomonitors of air-contaminated by natural radionuclides around the •irovski Vhr Uranium mine, Slovenia.* Lichenologist, 27(5): 375-385.

Jeran Z., Jaæimoviæ R., Batiæ F., Smodiš B. and Wolterbeek H. Th., 1996. *Atmospheric heavy metal pollution in Slovenia derived from results for epiphytic lichens.* Fresenius Journal Anal. Chem, 354:681-687.

Jia G., Rosamilia, S. and Gaudino S., 2001. *A new method for determination of uranium isotopes in water, vegetation and soil by alpha spectrometry.* Proceeding of the “International Congress on the Radioecology-Ecotoxicology of Continental and Estuarine Environments

(ECORAD)”, Aix-en-Provence, France, 3rd-7th September, 2001.

Keller M., Anet B., Burger M., Schmid E., Wicki A., Wirz Ch., SPIEZ LABORATORY in cooperation with Chambers G., European Parliament, Directorate-General for Research, Working Paper, Scientific and Technological Options Assessment Series, STOA 100 EN 05-2001. *Depleted Uranium: Environmental and Health Effects in the Gulf War, Bosnia and Kosovo.* WEB: www.europarl.eu.int

KFOR. 2000. *NATO/KFOR unclassified release to UNMIK. Subject: Depleted Uranium (DU).* KFOR Headquarters, Film City, Pristina, Kosovo, 17 September 2000.

Kogan R. M., Nazarov I. M. and Fridman Sh. D. 1971. *Gamma spectrometry of natural environments and formations.* Atomizdat. Moscow, 1969. Israel program for scientific translations. Jerusalem. p 1-337.

Loppi S. & De Dominicis V., 1996. *Lichens as long-term biomonitors of air quality in Central Italy.* Acta Botanica Neerlandica 45, 563-570.

McLean J., Purvis O.W. & Williamson B.J., 1998. *Role of lichen melanins in uranium remediation.* Nature 391, 649.

MCNP, 2000. *MCNP – A General Monte Carlo N-Particle Transport Code.* Version 4C. Los Alamos National Laboratory. April 10, 2000.

Mook W.G., and de Vries J.J., 2001. *Environmental Isotopes in the Hydrological Cycle. Principles and applications.* Volume 1. IAEA.

NAHRES-60, 2001. *Report on the NAT-9 quality control exercise on uranium isotopes in two soil samples.* International Atomic Energy Agency, Department of Nuclear Sciences and Applications, Division of Human Health, Section of Nutritional and Environmental Studies. IAEA Report NAHRES-60.

Nash K., Fried S., Friedman A.M. and Sullivan J.C. (1981) Redox behaviour, complexing, and adsorption of hexavalent actinides by humic-acid and selected clays. *Environmental Science and Technoogy,* 15, 834-837.

Nash T.H. III & Wirth V., (Eds.) 1988. *Lichens, Bryophytes and Air Quality.* Bibliotheca Lichenologica 30.

NATO AEP 49. *Sampling and Identification of Radiological Agents, Volume 2*: Forensic.

NATO, STANAG 4590, AEP-49. *Sampling and Identification of Radiological Agents Handbook, SIRA Handbook.*

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

Nieboer E. & Richardson D.H., 1981. *Lichen as monitors of atmospheric deposition. In Atmospheric pollutants in natural waters.* Ed. by S.J. Eisenreich, 339-88. Ann Arbor, Michigan, Ann Arbor Science.

Nimis P.L., 2000. *Checklist of the Lichens of Italy 2.0.* University of Trieste, Dept. of Biology, IN2.0/2 (http://dbiodbs.univ.trieste.it/).

NIOSH, 1994. *Pocket guide to chemical hazards.* US Department of Health and Human

Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Pavlovski O.A., 2002. *External radiation as a factor of radiation exposure under the DU contaminated areas.* Preprint IBRAE RAS No 2002-03, Moscow, 2002 (in Russian).

Purvis O.W., Coppins B.J., Hawksworth D.L., James P.W. & Moore D.M., (eds.) 1992. *The Lichen Flora of Great Britain and Ireland.* Nat. Hist. Mus. Publ. and the British Lichen Society, London.

Ragnarsdottir K.V. and Charlet L., 2000. *Uranium behavior in natural environments. In Environmental Mineralogy: Microbial Interactions, Anthropogenic Influences, Contaminated Land and Waste Management.* (J. Cotter-Howells J., Batchelder M.,Campbell L. and Valsami-Jones E., eds.), 333-377. Mineralogical Society of Great Britain and Ireland.

RESRAD, 2001. *User's Manual for RESRAD Version 6.* Environmental Assessment Division Argonne National Laboratory. ANL/EAD-4, July 2001.

Ribeiro Guevara S., Arribe M.A., Calvelo S. & Roman Ross G., 1995. *Elemental composition of lichens at Naahuel Huapi national park, Patagonia, Argentina.* Journal of Radioanalytical Chemistry 198 (2), 437-448.

Richardson D.H.S., Beckett P.J. & Nieboer E., 1980. *Nickel in lichens, bryophytes, fungi and algae.* In Nickel in the environment. Ed. by J.O. Nriagu, 367-406. New York, John Wiley.

Richardson D.H.S. & Nieboer E., 1981. *Lichens and pollution monitoring.* Enddeavour, 5, 127-133.

Richardson D.H.S. & Nieboer E., 1980. *Surface binding and accumulation of metals in lichens. In Cellular interactions in symbiosis and parasitism.* Ed. by C.B. Cook, P. W. Pappas and E.D. Rudolph, 75-94. Columbus, Ohio, Ohio State University Press.

Sansone U., Barbizzi S., Belli M., Gaudino S., Jia G, and Rosamilia S., 2002. *Italian National Environmetal Protection Agency (ANPA) contribution to the UNEP DU Post-Conflict Assessment in Serbia and Montenegro 2001.* Prot. ANPA/AMB-LAB 60-2002.

Sansone U., Danesi P.R., Barbizzi S., Belli M., Gaudino S., Jia G., Ocone R., Pati A., Rosamilia S., Stellato L., 2001. *Radioecological survey in the areas targeted by depleted uranium ammunitions during the 1999 Balkans conflict.* The Science of the Total Environment, Elsevier, Vol. 281/1-3, 23-55.

Sansone U., Barbizzi S., Belli M., Gaudino S., Jia G., Rosamilia S., Stellato L., 2001a. *Uranio impoverito: l'evidenza delle misure.* Tutto_Misure, Anno III, 2/01, 172-176.

Sansone U., Barbizzi S., Belli M., Gaudino S., Jia G., Rosamilia S., Stellato L., 2001b. *Levels of depleted uranium in the soils of Kosovo.* Radiation Protection Dosimetry, Nuclear Technology Publishing (in press).

Saphymo-SRAT, 1969. *Scintillation meter S.P.P.2NF User Manual.* Saphymo-PHY, 5 Rue de Teatre, 91884, Massy, France.

S.E. International Inc., 1999. *Inspector User Manual.* S.E. International, Inc. Summertime, TN 38483, U.S.A.

Sloof J.E. & Wolterbeek H.Th., 1991. *Patterns in trace elements in lichens.* Water, Air and Soil Pollution 57-58, 785-795.

SPIEZ LABORATORY, 2000. *Depleted Uranium, Hintergrundinformation.*

Suschny O.,1968. *The measurement of atmospheric radioactivity.* World Meteorological Organization. Technical note No.94. WMO – No.231.TP.124. Geneva. Switzerland

Swanson V.E., 1960. *Oil yield and uranium content in black shales.* Geological Survey, Professional Papers 356-A. Washington.

Taylor H.W., Hutchinson E.A., McInnes K.L. and Svoboda J., 1979. *Cosmos 954: Search for airborne radioactivity on lichens in the crash area, Northwest Territories, Canada.* Science, N.Y., 205, 1383-1385.

Trembley M.L., Fahselt D. & Madzia S., 1997. *Localization of Uranium in Cladina rangiferina and Cladina mitis and Removal by Aqueous Washing.* The Bryologist, 100 (3), 368-376.

Triulzi C., Nonnis Marzano F., Vaghi M., 1996. *Important alpha, beta and gamma-emitting radionuclides in lichens and mosses collected in different world areas.* Annali di Chimica 86, 699-704.

UK, 2001. *The health hazards of depleted uranium munitions. Part I.* The Royal Society. 2001.

UNEP/UNCHS Balkans Task Force (BTF). 1999. *The potentials effects on human health and the environment arising from possible use of depleted uranium during the 1999 Kosovo conflict. A preliminary assessment.* Geneva. October 1999. 76.

UNEP, 2000. *NATO confirms to the UN use of depleted uranium during the Kosovo Conflict.* Press Release, 21 March 2000.

UNEP, 2001. *Depleted Uranium in Kosovo. Post-conflict environmental assessment.* United Nations Environmental Program, Geneva, 2001.

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

UNSCEAR, 2000. *Sources and effects of ionizing radiation.* United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly, with scientific annexes. Vol. 1. United Nations, New York, 2000. ISBN 92-1142238-8.

UNSCEAR 2000. *Exposures from natural radiation sources.* United Nations Scientific Committee on the Effects of Atomic Radiation. Forty-eight session of UNSCEAR, Vienna, 12 to 16 April 1996. Preliminary report. Draft. 1999.

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

U.S. Army Material Command, 2000. *Tank-Automotive and Armaments Command (TACOM) and army Material command (AMC) review of transuranics (TRU) in depleted uranium armor.* 19 January, 2000. Memorandum. ATTN:AMCSF (Mr. Pittenger), 5001 Eisenhower

Avenue, Alexandria, VA 22333-001.

U.S. EPA, 2000. *National Primary Drinking Water Regulations.* Radionucliods Final Rule, Environmental Protection Agency. 40 CFP Parts 9, 141, and 142. December 7, 2000.

Vukotich P., Andjelich T., Zekich R., Kovachevich M., Vasich V., Ristich N., 2001. *Field searching for ground contamination from depleted uranium at Cape Arza – Montenegro.* 2001 (unpublished report).

Waite T.D., Davis J.A., Payne T.E., Waychunas G.A, and Xu N., 1994. Uranium (VI) adsorption to ferrihydrite - application of surface complexation model Geochimica et Cosmochimica Acta, 58, 5465-5478.

WHO, 1998a. *Guidelines for drinking water quality. 2nd edition. Addendum to Volume 2: Health criteria and other supporting information.* World Health Organisation, Geneva, Switzerland.

WHO, 1998b. *Derived intervention levels for radionuclides in food.* World Health Organization, Geneva, Switzerland.

WHO, 2001. *Depleted uranium. Sources, Exposure and Health Effects. Department of Protection of the Human Environment. World Health Organization.* Geneva, April 2001.

Wirth, V. (1995). *Die Flechten Baden-Württembergs.* Ulmer & Co., Stuttgart.

WISE, 2002. *WISE Uranium Project.* http://www.antenna.nl/wise/uranium/index.html

APPENDIX T

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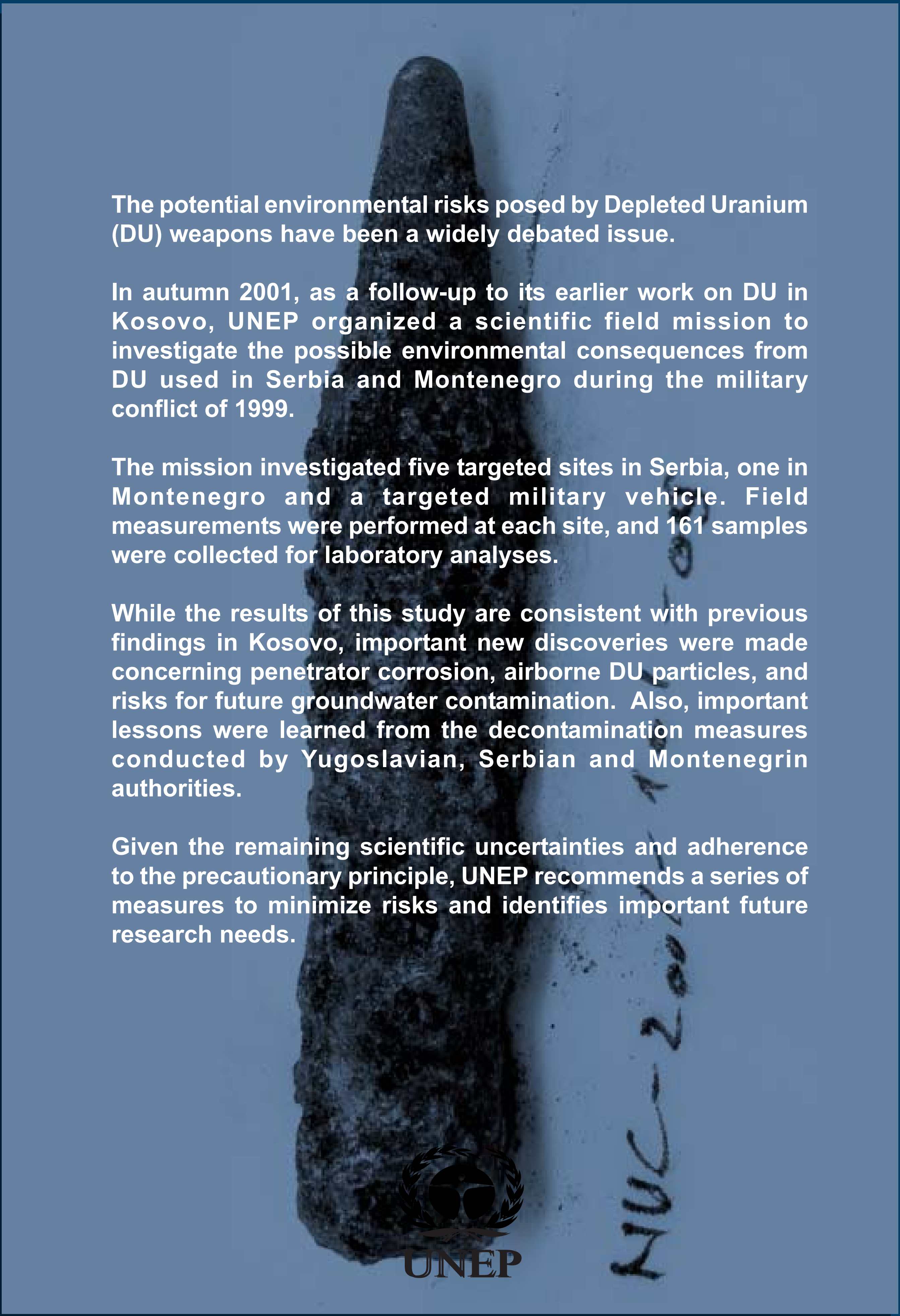

The potential environmental risks posed by Depleted Uranium (DU) weapons have been a widely debated issue.

In autumn 2001, as a follow-up to its earlier work on DU in Kosovo, UNEP organized a scientific field mission to investigate the possible environmental consequences from DU used in Serbia and Montenegro during the military conflict of 1999.

The mission investigated five targeted sites in Serbia, one in Montenegro and a targeted military vehicle. Field measurements were performed at each site, and 161 samples were collected for laboratory analyses.

While the results of this study are consistent with previous findings in Kosovo, important new discoveries were made concerning penetrator corrosion, airborne DU particles, and risks for future groundwater contamination. Also, important lessons were learned from the decontamination measures conducted by Yugoslavian, Serbian and Montenegrin authorities.

Given the remaining scientific uncertainties and adherence to the precautionary principle, UNEP recommends a series of measures to minimize risks and identifies important future research needs.

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