

UK Ministry of Defence Environmental Monitoring in Bosnia
August 2002 Survey Report
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Dstl CR/08855
Date 28 November 2003



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Executive Summary

The report is concerned with an enhanced environmental monitoring survey carried out in Bosnia to assess the concerns about the peacetime radiological hazards and risks associated with the use of depleted uranium (DU) munitions during the Balkans conflict. The survey also addressed issues arising from caesium in the environment originating from the Chernobyl accident.

This report presents the methodology and results of an extensive environmental survey in the UK-led area of responsibility in Bosnia in August 2002. It also contains an analysis of the results, advice and recommendations to the UK Ministry of Defence (MOD).

In excess of 250 environmental samples were collected from UK bases in Bosnia and analysed for the presence of uranium, caesium and heavy metals. The significance of the results of the analysis of uranium and caesium have been assessed by comparison with the Generalised Derived Limits (GDLs) for uranium and caesium published by the UK National Radiological Protection Board (NRPB).

There are no significant risks to UK forces in Bosnia arising as a result of exposure to any form of uranium including depleted uranium in the environment in and around UK bases. All mean values of uranium in the environment are well below 10% of the relevant NRPB GDLs for uranium. Levels of uranium in soils and waters are typical of those associated with natural uranium in the environment.

Whilst there is evidence of caesium originating from Chernobyl in the environment in Bosnia, the resultant risk to UK forces based at existing UK locations is not significant. All mean values of caesium in the environment in and around UK bases are below 10% of the relevant NRPB GDL for caesium. There are locations elsewhere in Bosnia where the activity concentration of caesium may exceed 10% of the NRPB GDL. It is recommended that any prospective new location for a UK base be subject to a risk assessment for caesium prior to being selected and developed.

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1 INTRODUCTION AND BACKGROUND

1.1 Introduction

This is the third report describing the UK's enhanced environmental monitoring programme in the Balkans. It summarises the background to the work and contains the results of an extensive environmental survey in the UK-led Area of Responsibility (UK-AOR) in Bosnia in August 2002 and an interpretation of these results from a radiological protection perspective.

In order to address concerns over environmental health issues and the safety of troops engaged in peacekeeping operations, the Minister of State for the Armed Forces announced on the 9th of January 2001 that the UK would enhance its existing environmental surveillance programme in the Balkans (Reference 1). One area of particular concern related to the use of depleted uranium (DU) munitions during the Balkans conflicts in the 1990's. Consequently a programme was put together for an enhanced environmental monitoring programme in the Balkans in order to assess the radiological hazard. This particular report is concerned with an environmental survey in Bosnia designed to:

- a. Collect environmental samples from locations in and around UK bases in Bosnia and analyse for the presence of certain radionuclides.
- b. Analyse the results and compare with the UK National Radiological Protection Board (NRPB) recommended limits for these radionuclides in the environment.
- c. Provide advice to the Ministry of Defence (MOD) regarding the radiological risks to UK forces in Bosnia arising from potential exposure to DU and other radionuclides.

This report summarises the background to the work and the methodology used for the survey in Bosnia. It contains the results of an extensive environmental survey in the UK-AOR in Bosnia in August 2002. It also contains an analysis of the results, advice and recommendations to MOD. This report builds on an earlier report of a similar environmental survey in Kosovo during 2001 (Reference 2). This earlier report should be referred to if more details are required about the philosophy and protocols used for the surveys in the Balkans.

1.2 Reconnaissance Visit – May 2002

A small team of MOD radiation protection specialists made a reconnaissance visit to the UK-AOR in May 2002 to gain an understanding of local conditions and develop plans for the main environmental survey. Local Army Environmental Health Technicians and Officers accompanied the reconnaissance team.

The team visited all locations in the UK-AOR in Bosnia where UK troops were resident. Following a walk around a location and discussions with a local representative, sites likely to be suitable for soil sampling were indicated on a plan of the location, and indicative "grab" samples of soils taken. These soil samples were subsequently analysed in the UK for the presence of artificial and naturally occurring radionuclides, for screening purposes only. This was to ensure that the sampling protocols and analytical techniques to be used during the main survey were applicable and appropriate to the radionuclides likely to be found to be present in Bosnia. The presence of caesium-137 and caesium-134 was subsequently confirmed in some soil samples, reiterating the need to address this issue during the course of the main survey.

Information provided during the reconnaissance visit indicated that virtually all food and drink consumed by UK troops is imported from EU sources outside Bosnia. Bottled water for

drinking was imported, although potable water was locally supplied for washing and cooking. This potential ingestion pathway was subsequently taken into account in the survey strategy.

2 SURVEY STRATEGY

2.1 Introduction

The survey strategy used during the course of the earlier environmental survey in Kosovo (Reference 3) had been submitted for public consultation, and subsequently had been found to be effective in practice in Kosovo. The strategy addressed the two key areas of radiological interest: uranium (naturally occurring and DU) and caesium (deposited in the soil as a result of the Chernobyl accident). It also addressed the need for sophisticated laboratory analyses (i.e. mass spectrometry) to confirm the presence of natural uranium (U) or DU in soil and cost-effective screening of samples (i.e. by X-ray fluorescence and/or gamma spectrometry) so that more sophisticated and expensive forms of analysis could be targeted on samples most likely to give useful results.

Although the survey needed to address the two key areas of radiological interest identified above (uranium and caesium), it must be remembered that a variety of naturally occurring and man-made radioactive materials are used in industrial processes. Items containing such materials may have been damaged during the conflict and screening for these other radionuclides (principally radium-226, cobalt-60, Cs-137 and iridium-192) was included in the survey.

Wherever possible, the survey and analyses were designed to allow collection of information useful to the broader environmental assessment programme, for example by providing information on the presence or absence of heavy metals.

The primary purpose of the survey was to identify any radiological hazards and, wherever possible, quantify those hazards in a form that would enable a risk assessment to be carried out later. This risk assessment may sometimes need to be site specific, but will more usually be based on a "screening assessment" when levels of radionuclides and the types of samples collected allow national and internationally recognised standards and guidelines to be used for comparative purposes.

The UK National Radiological Protection Board (NRPB) publishes Generalised Derived Limits (GDL) for various radionuclides in the environment, including caesium (Reference 4), and uranium (Reference 5). The NRPB recommended GDL for a radionuclide is an activity concentration of that radionuclide in a medium (soil, water, air, foodstuff) expressed in becquerel (Bq) per unit mass or volume. Exposure of a person to the radionuclide in the soil/water/air/foodstuff at the GDL for a period of 1 year may give rise to a 1 millisievert (mSv) whole body dose of radiation. 1 mSv is the internationally accepted annual whole body dose limit for a member of the public. NRPB recommend that activity concentrations in excess of 10% of the GDL require further investigation.

The future strategy for the management of these risks, whilst a subsequent issue, was borne in mind in the design of the survey programme.

2.2 Factors affecting strategy

Levels of radionuclides, both naturally occurring and man made, will vary from site to site and spatially within a site. Radionuclides in soils will vary with depth and be dependent on soil characteristics and mixing patterns since deposition. Made-up ground will not necessarily contain materials characteristic of other "natural" areas on the site and civil engineering works, occupancy and site usage (i.e. industrial verses residential activities) will influence resultant pathways to man.

It is theoretically possible to monitor and sample every single "square foot" of an area of interest, given enough time and resource. However, such an approach is clearly impractical when surveying large areas of ground. In essence, only minimal additional benefit is obtained for significantly increased cost as the intensity of the sampling increases. The scientific "added value" of such an intense approach over a properly planned sampling programme is also questionable. Hence, this survey was designed to characterise site-specific areas of interest by means of representative sampling and the use of measurement techniques that took account of the likely background levels of naturally occurring radionuclides.

The options for environmental sampling and the subsequent detection and measurement of uranium and caesium are described in detail in the proposal for the environmental survey in Kosovo (Ref.3) and will not be discussed further in this report. However the methodologies adopted during the survey in Bosnia are summarised in the next section.

3 SURVEY METHODOLOGY

3.1 Site Selection

The survey protocol was based on the strategy outlined by the Construction Industry Research and Information Association (CIRIA) (Reference 6), British Standards (Reference 7) and soil sampling protocols used by the British Geological Survey (BGS) in their survey of uranium levels in the UK (Reference 8). In applying the guidance in these documents, account was taken of the earlier conclusion that the primary objective was to undertake a screening assessment that would allow generic risk assessments rather than a very detailed survey that examined every "square foot" of land in areas of potential concern.

Areas of potential concern were considered to be those where monitoring was required to implement MOD's undertaking to carry out enhanced environmental surveillance. In the case of Bosnia, this consisted of locations where UK troops work or reside. There were no reported locations in the UK-AOR where DU munitions are known to have been used. This is in contrast to Kosovo, where there were 8 reported locations where DU munitions had been used.

The main UK sites were categorised as Category A or Category B sites. Category A sites comprised work and residential locations of significant size or population and Category B sites comprised smaller outstation locations. The environmental survey focussed on Category A sites as these were the most significant in terms of potential exposure through the greatest occupancy and numbers of potentially exposed persons for which MOD has direct responsibility.

A detailed proposal for the survey in Bosnia was developed in conjunction with MOD. Full details are to be found in Reference 9.

3.2 Protocol for Category A Sites - Direct Measurements

The survey protocol for Category A sites, as detailed in Ref. 3 and Ref. 9 and summarised in Table 1, consisted of direct measurements with gamma monitoring equipment and the collection of air, dust, water and soil samples for subsequent analysis.

These measurements consisted of a walk-over radiation survey to establish background radiation levels and the spatial variability of activity. This ensured that locations chosen for random soil sampling or dose rate monitoring were representative of typical conditions on site. It also served to identify any possible locations where there was evidence of enhanced activity so that targeted soil sampling could be carried out in these areas.

3.3 Protocol for Category A Sites - Environmental Sampling

The BGS approach to sampling for uranium in the environment involves the characterisation of each location for uranium content, land use and soil conditions by sampling within the site boundary and the immediate surrounding area. This approach is equally applicable to the detection and measurements of other types of radioactive material. In this study, the sampling was risk based and aimed at characterising the exposure to likely receptors (such as people, animals, plants or watercourses) by the collection and analysis of soil, water, air and dust samples.

3.4 Protocol for Category A Sites - Soil Sampling

An objective of 20 composite soil samples was set. Soil samples to establish inherent (i.e. natural and post-conflict) levels of uranium were taken from undisturbed areas of ground. Ground covered by "imported" materials such as hardcore, tarmac and concrete will not be of significance as any deposited material is likely to have been washed away or become ingrained into what are relatively "massive" structures with considerable resistance to erosion. Similarly, any soil underneath these areas need not be sampled as it will be inaccessible in most circumstances and unlikely to make a significant contribution to any exposure pathway. Furthermore, any contamination migrating from under these areas will be detected in water samples and any significant gamma ray exposure will be determined by the walk-over survey.

3.5 Protocol for Category B sites

Category B sites were generally much smaller than Category A sites and the protocols described in the previous section were modified to suit these sites. For example, Category B sites in rural areas were often very small and opportunities for collecting soil samples were limited. Similar considerations applied to the sites in built up areas where there was little undeveloped ground and few, if any, watercourses. The survey protocol for Category B sites, as detailed in Ref. 3 and Ref. 9, and summarised in Table 2, consisted of direct measurements with gamma monitoring equipment and the collection of dust, water and soil samples for subsequent analysis.

4 DELIVERY OF SURVEY

4.1 Health and Safety

Thermal stress was identified as a major risk as the survey was to be carried out in temperatures of up to 35-40°C and much of the work was in the open with little possibility of shade. Team members were briefed on the importance of acclimatisation and of not working outside around mid-day, the importance of wearing sensible protective clothing to cover as much of the skin as possible and of protecting any exposed skin with sun-block. Team members were also advised to drink up to 10 litres of water per person per day to prevent dehydration. Other health precautions involved the inoculation of team members against any diseases likely to be encountered and the wearing of gaiters to protect against ticks and animal and snake bites when working in areas of long grass. The monitoring teams were also provided with a military security escort and radios so that assistance could be summoned in the event of an accident or incident.

The possibility of encountering buried munitions or services while coring to 300mm were also addressed. Local staff provided assistance on the location of buried services and the detection of unexploded ordnance, and Cable Avoidance Tools were used prior to coring.

4.2 Direct measurements –Category A and B sites

Walk-over surveys were carried out with sodium iodide (NaI) scintillation detectors. They were used in a mode giving gross measure of gamma activity rather than radiation dose rates and so the data was used for comparative purposes rather than in a quantitative manner.

Detailed measurements of gamma dose rate were made at each soil sampling location using Mini Instruments 6/80 ratemeters fitted with type MC-70 or MC-71 compensated Geiger Muller or with the Exploranium GR130 operating in dose rate mode.

4.3 Soil sampling - Category A & B sites

Provisional soil sampling locations had been identified and marked on plans during the course of the earlier reconnaissance visit to Bosnia. These had been chosen by observation and with advice from local staff. This ensured that monitoring was focussed on the areas likely to be occupied for the longest periods or on areas where troops might come into prolonged contact with natural ground. The locations had been chosen to cover as wide an area as possible and included a number of locations just outside the site where access was permissible and practicable. It was occasionally necessary to slightly change the designated sampling location where conditions had significantly changed in the period between the reconnaissance visit and the survey, or it was judged impractical or dangerous to proceed along planned lines. Some examples of this were civil engineering work disturbing the ground and undergrowth (nettles, brambles etc).

Soil and root mat samples were taken using a 50mm diameter hand operated Dutch auger with sufficient material being collected to permit a range of analyses. The vegetation on most of the areas of undisturbed ground where sampling took place was sparse and very dry. The associated root mat (if any) was very friable. The design of the Dutch auger was such that it was not possible to extract under these conditions a root mat sample in isolation from the soil immediately below it. Hence, root mat (if any) was incorporated into a 0-150mm composite sample. It was normally possible to take an additional sample down to a depth of 300mm.

Whenever possible, each soil sample consisted of a composite of material from the required depth from 5 cores located at the corners and centre of a square. The preferred spacing from the square centre to corner was approximately 10m, but sometimes this had to be altered due to site-specific restrictions such as access, buildings, trees, shrubs, hardcore, concrete and/or disturbed ground. Where the sampling location was essentially linear, such as along boundary fences or drainage ditches, the cores were taken in a straight line.

For each sampling site, the location was marked on a site plan and photographs were taken of the general area and of soil samples. One log sheet containing comprehensive information on each composite sample was completed for every location and each sample was placed in a self-seal polythene bag labelled with a unique sample reference number generated using a pre-planned protocol.

Soil sampling was carried out using the techniques described above. However, due to the lack of undisturbed or even any exposed soil and the small size of some sites it was not always possible to collect the planned number of samples. The number of auger flights per sample and/or the auger flight spacing also had to be reduced at some sites to meet particular circumstances. Full details of the measurements taken were recorded on the sample log sheets and site plans.

The protocol allowed for the collection of additional soil samples from areas where any walk-over survey instrument readings exceeded twice the local background. This scenario did not arise at any of the Category A or B sites.

4.4 Dust Sampling - Category A and B sites

Dust samples were taken from roads, any vehicle wash areas and building entrances at each site. Each sample location was marked on a site plan and at least 20g of material was swept up with a dustpan and brush. Each dust sample was placed in a self-seal polythene bag labelled with a unique serial number and details of the sample recorded on log sheets.

4.5 Air Sampling – Category A sites

A minimum of one airborne dust sample was collected at each site using a mains powered sampler operating at a nominal air flow rate of 60 litre min⁻¹. The sampler was set up as soon as practicable and run for a minimum of 6 hours or longer if this was compatible with other sampling activities on site. The intention was to collect sufficient dust to bring the limit of detection of the chosen analysis technique down to better than 10% of the relevant NRPB GDL. At the end of each sampling period, the filter was removed from the sampler and placed in a self-seal polythene bag labelled with a unique serial number before the sample log sheet was completed.

The availability of the 240V supply and the range of the extension leads limited the possible air sampling locations. Whenever possible, the samplers were set up downwind towards the boundary of the site at a height of about 0.8m and away from turbulence created by obstructions such as buildings. It is known that the air flow through an air sampler reduces over time as the filter became clogged with dust and so air flow readings were taken at regular intervals during the sampling period and recorded on a sample log sheet. The total volume of air sampled was then calculated by integration.

4.6 Water Sampling – Category A and B sites

Water samples were taken from the potable water supply and from any surface watercourses inside the site or immediately adjacent to it. There were no watercourses to be sampled on the majority of sites; there were no lakes or rivers passing through any of the sites, and ponds and ditches on some sites had dried up in the heat of the summer. Where a

sample had been obtained, it was from a puddle, pond or ditch rather than a large freshwater site such as lake or river.

Samples were either collected directly into 175ml “Nalgene” screw top bottles or were taken with a disposable syringe when there was insufficient depth of water to allow use of the sample bottle. The disturbance (and hence collection) of sediments was avoided as far as was possible during the procedure and the samples were not filtered, treated or stabilised on site. The minimum sample volume collected was 30ml and information on each sample and its location was recorded on a sample log sheet.

4.7 Summary of sites and samples

A summary of the sites visited and number and type of samples obtained from each site is contained in Table 3.

5 ANALYSIS OF SAMPLES

A schedule and programme of analyses using gamma or alpha spectroscopy, followed by a combination of X-ray fluorescence spectroscopy (XRF), inductively-coupled plasma quadrupole mass spectroscopy (ICP-QMS) and inductively-coupled plasma atomic emission spectroscopy (ICP-AES), was drawn up. The choice of analytical technique was determined by sample type and nature, and the type of information required for risk assessment purposes.

5.1 Gamma spectroscopy

All soil sampling locations were subject to a walk-over survey and gamma dose rate measurements. This would have revealed any potential major radiological protection problems with gamma emitting radionuclides.

All soil, water and dust samples were subject to initial screening in the DstlRPS Radiochemical Laboratory, following UKAS accredited methods. The purpose of this was to detect the possible presence of significant artificial gamma emitters such as cobalt-60, caesium-137 and iridium-192, which may present contamination problems in low-level counting laboratories. It also provided useful information to other laboratories analysing the samples, to allow them to carry out a risk assessment for the handling of the samples.

Samples were screened “as received” from Bosnia. Sub-samples were taken, and placed in standard geometry counting pots. The samples were then placed in one of four high purity liquid nitrogen cooled germanium detector gamma spectrometers linked to automatic sample changers. Counting was for a period of between 5,000 to 16,000 seconds, determined by the activity and counting statistics, with a control sample counted for 16,000 seconds with every batch. Sub-samples were recombined with the original sample after counting.

Results were expressed in terms of the activity concentration in becquerel per kilogram (Bq kg^{-1}) for each radionuclide reported. Confidence limits were calculated for each result, determined using a UKAS accredited algorithm. These were expressed either as an uncertainty on the reported result, or as a bound on the limit of detection. For all radionuclides other than Cs-137, the results are of value for screening purposes only, and do not directly inform the environmental risk assessment process. However, gamma spectroscopy has a sufficient limit of detection for Cs-137 in soil dust and water to allow a risk assessment to be made in the context of NRPB GDL recommendations for Cs-137.

All soil, water and dust samples were screened by October 2002, prior to samples being sent to the laboratory at BGS for further analysis.

5.2 Alpha spectroscopy

All air sample filters were analysed using UKAS accredited methods in the DstlRPS Radiochemical Laboratory. The samples were digested in acid, filtered, passed through an ion exchange column to extract the uranium, electroplated onto discs and counted in an alpha spectrometer for 30,000s. The yield was measured using a radiochemical tracer. The total activities of U-234, 235 and 238 were determined for each sample. Results were then calculated in terms of activity concentration of each uranium radionuclide in air in units of becquerel per cubic metre (Bq m^{-3}), using the volume of air sampled for each filter.

5.3 XRF analysis

All soil and dust samples were subject to XRF analysis to UKAS accredited methods at the laboratories of BGS. All samples were prepared for analysis by drying, crushing and sieving them to < 2mm particle size. A sub-sample was then taken, crushed in a ball mill to <50 µm and pelletising with a wax binder prior to analysis by XRF spectroscopy. Elemental concentrations of total uranium (not isotopic) and lead were reported. Approximately 10% of samples, chosen at random by the BGS laboratory, were subject to duplicate analysis..

5.4 ICP-QMS analysis

Approximately 10% of soil and dust samples were subject to further analysis by ICP-QMS using UKAS accredited methods. This was carried out to determine isotopic ratios of uranium, and thus imply the origin of the material in the soil samples as being of natural or artificial in origin.

Samples for ICP-QMS analysis were selected by DstlRPS on the basis of (a) approx. 10% of samples per site, with a minimum of 1 per site and (b) samples exhibiting the highest total uranium, as determined by XRF, for each site. Duplicate samples, as described in section 5.3 above, were also carried through for ICP-QMS analysis.

Sub-samples from the initial sample preparation process, as described in section 5.3 above, were first subjected to a hydrofluoric/perchloric/nitric mixed acid attack and the total uranium concentrations measured. The uranium in solution was then separated and pre-concentrated on an ion-exchange column before measurement of the uranium isotopes by ICP-QMS

Results were reported to DstlRPS by August 2003. Results were expressed in terms of total uranium per unit mass, and isotopic ratios of U-238:U-234, U-238:U-235 and U-238:U-236. The laboratory advised that data associated with the total uranium determination to be considered accurate to no more three significant figures. It also estimated the total uncertainty on the calculation of isotopic ratios, including sampling and measurement processes.

All water samples were subject to uranium isotopic analysis to UKAS accredited methods. All samples were provided to the laboratory unfiltered and unacidified, following the advice from the laboratory prior to the survey. Some non-potable water samples contained a significant amount of sediment. All the samples were initially acidified to 5% v/v with nitric acid and the total uranium concentrations determined. Additional nitric acid was then added to all samples to adjust the acid concentration to 10% nitric acid. All samples were centrifuged and, where deemed necessary, the samples were also filtered; the supernatant was decanted from any residual solid material and retained. The uranium in solution was then separated and pre-concentrated on an ion-exchange column before measurement of the uranium isotopes by ICP-QMS. Results were reported to DstlRPS by August 2003. Results were expressed in terms of total uranium by mass per unit volume, and isotopic ratios of U-238:U-234, U-238:U-235 and U-238:U-236. The laboratory advised that data associated with the total uranium determination to be considered accurate to no more three significant figures. It also estimated the total uncertainty on the calculation of isotopic ratios.

5.5 ICP-AES analysis

Opportunity was taken to have all soil and dust samples analysed for the presence of a selection of heavy metals. This analysis was in addition to those originally specified in the proposal for the environmental survey, but was deemed to be a pertinent, efficient and economic way of providing additional data to help inform on non-radiological aspects of

potential environmental contamination issues which may affect UK troops in Bosnia. It used sub-samples taken from the same soil and dust samples.

Further information relating to the ICP-AES analysis, the results and associated risk assessment for heavy metals are contained in a separate Dstl report to be published at a later date.

6 RESULTS OF ANALYSES

All the results from alpha and gamma spectroscopy, XRF and ICP-QMS have been sorted according to the site at which the sample was taken, the location of the sample and the type of sample. A summary of the results reported for each site are presented in Tables 4 to 16 in this report.

The summaries of results for each site contain:

- (a) A unique three-letter site identification code for site.
- (b) A unique sample identity code, indicating sample type, sample location, sample sequence number, date of sampling.
- (c) Results of the Cs-137 analysis by gamma spectroscopy for soil, dust and water samples expressed in terms of activity concentration in Bq kg^{-1} .
- (d) Results of the XRF analysis of dust and soil samples for total uranium (in parts per million (ppm) by mass).
- (e) U-238 and U-235 activity concentration; this has been calculated from the total uranium values given by the XRF analysis and the assumption that natural uranium has specific activities of $1.24 \times 10^4 \text{ Bqg}^{-1}$ for U-238, and $8.0 \times 10^4 \text{ Bqg}^{-1}$ for U-235 and natural isotopic ratio of $\text{U-238:U-235} = 137.9$. These values have been taken from the Royal Society report on DU (Reference 10).
- (f) Results of ICP-QMS analysis of total uranium for all water samples, and the soil and dust samples selected for further analysis, reported in $\mu\text{g l}^{-1}$ or mg kg^{-1} respectively.
- (g) *Calculated* U-238 and U-235 activity concentration, inferred from total U as in (f) above, assuming natural U specific activities of $1.24 \times 10^4 \text{ Bqg}^{-1}$ for U-238, and $8.0 \times 10^4 \text{ Bqg}^{-1}$ for U-235 and natural isotopic ratio of $\text{U-238:U-235} = 137.9$
- (h) Reported isotopic ratios of U-238:U-235 and U-238:U-234 from ICP-QMS
- (i) Measured environmental dose rate, expressed in units of nanosievert per hour (nSv h^{-1}) for soil sample locations.
- (j) *Calculated* mean values, grouped for soil and dust samples, for parameters (c), (d), (e), (i) as above.
- (k) Results of alpha spectroscopy of air samples, normalised to unit volume, in units of Bq m^{-3} .

(Note: If actual U isotopic ratios measured in (h) had subsequently been found to be significantly at variance with the assumption of natural U isotopic ratios used in (e) and (g) above, the values would have needed to be recalculated with the actual measured isotopic ratio. In the event, this was not required).

Results have been entered or calculated from measured values, taking into account the advised reported uncertainty in the determination by the laboratory concerned.

Results that have been reported as below a detection or reporting threshold of value n have been recorded as " $<n$ " in the tables. Where these results have been used in a statistical

analysis, their value has been taken as the threshold value “n”. This will result in a “worst-case” value and lead to an over-estimation rather than an underestimation of the risk from the radiological hazards.

In the case of the ICP-QMS analyses, all U-236 results were reported as “below quantitative limit”. These results have not been included in the summary, for reasons of clarity.

The samples were screened by default for the presence of artificial gamma emitting radionuclides such as americium-241 and cobalt-60. No concentrations were measured above detection thresholds (1 Bq kg^{-1} and 3 Bq kg^{-1} respectively), and as such, for reasons of clarity, the results are not included in the site summaries.

7 INTERPRETATION OF RESULTS

7.1 Application of NRPB GDLs

The survey philosophy was to compare measured and derived values of uranium and caesium in environmental samples with corresponding NRPB GDLs for radionuclides in those environments. NRPB recommended GDLs for uranium are contained in Ref. 5, GDLs for caesium are in reference 4. NRPB recommend further site specific investigations if mean values exceed 10% of the relevant GDL, which would be equivalent to an annual dose of around 0.1 mSv using pessimistic dose calculations.

Uranium occurs naturally in the environment, but enhanced levels can be found resulting from human activity. The annual dose limit of 1 mSv implicit in the NRPB GDLs does not apply to natural radiation but only to exposures from controlled sources. Therefore the GDLs relate only to possible incremental activity concentrations resulting from human activities, and not the total concentration. Ambient levels in the area of interest should be subtracted from any measured activity concentrations before comparison with the appropriate GDLs

Detailed data relating to ambient levels of uranium in the area of interest prior to the conflict in Bosnia, and the use of DU, is not available. The philosophy of the interpretation of data has therefore been made on an initial worst-case assumption that all uranium measured is derived from human activities.

GDLs vary according to sample type (soil, water, air), and it is convenient to make comparisons across sites in these groupings.

7.2 Soil – Uranium

Table 17 contains a summary of all soil analyses for Cs-137 (by gamma spectroscopy), and total uranium by XRF. The mean value for each site, derived from the relevant data in Tables 4 to 16, has been quoted in the table.

The mean value for each site has been compared with the relevant NRPB GDL, and is expressed as a percentage of GDL.

Results in Table 17 show that all calculated mean U values are well below 10% of the relevant GDLs. The maximum mean U-238 value was not in excess of 0.2% of relevant GDL at any of the sites surveyed. Calculated mean U-235 values are not in excess of 0.03% of relevant GDL for any of the sites surveyed.

There does not appear to be any justification for further site-specific investigations at any sites with respect to uranium concentrations in soils.

Uranium occurs naturally in soils. The range of uranium in soil samples, as determined by XRF, was less than 1ppm through to 3ppm. This is typical of non-granite soils and is indicative of the measured uranium being of natural origin, and thus not within the scope of application of the NRPB GDL approach.

7.3 Soil - Caesium

In the case of Cs-137, none of the mean values exceeds 10% of the relevant NRPB GDL. Typical values are around 3%; the maximum value is 7.8% for site code GLA.

There does not appear to be any justification for further site-specific investigations at any of the sites with respect to Cs-137 concentrations in soils.

7.4 Water-potable

Potable water was defined as any water source within the site that may have been used for drinking purposes. It includes water used for washing and food preparation. Such supplies may have been via direct mains connection (often the case in towns), or via bulk water tanker (in more remote areas).

Bottled drinking water was commonly available at sites. The water appeared to originate from a common source outside of Bosnia, and contained statutory analytical information in accordance with EU requirements.

Table 18 contains a summary of all potable water analyses for Cs-137 (by gamma spectroscopy), and total U by ICP-QMS. In view of the small number of samples collected, where more than one sample was obtained, the maximum value for each site has been quoted in the table.

The maximum value for each site has been compared with the relevant NRPB GDL (Cs-137 – 100 Bq l⁻¹, U-238 – 30 Bq l⁻¹, U-235 – 30 Bq l⁻¹), and is expressed as a percentage of GDL.

In the case of Cs-137, none of the maximum values exceeds 10% of the relevant NRPB GDL. The maximum value was less than 3% of the relevant NRPB GDL.

There does not appear to be any justification for further site-specific investigations at any sites with respect to Cs-137 concentrations in potable waters.

In the case of U-238 and U-235, none of the maximum values for Category A or B sites exceeds 10% of the relevant GDL. The maximum value was not in excess of 0.08%.

There does not appear to be any justification for further site-specific investigations at any sites with respect to uranium concentrations in potable waters.

7.5 Water - non-potable

Table 18 also contains a summary of all non-potable water analyses for Cs-137 (by gamma spectroscopy), and total U by ICP-QMS. In view of the small number of samples collected, the maximum value for each site has been quoted in the table.

NRPB GDLs for freshwater are intended to be used for inland lakes and rivers. Pathways include ingestion of fish and drinking water, external irradiation, and inhalation of re-suspended sediments. As such, they are not applicable to samples taken from puddles and ditches and small ponds. Ingestion of fish and drinking water is clearly not an issue for these locations. Inhalation of re-suspended sediments would in any case be characterised by air and dust sampling. It is therefore not relevant to compare measured and derived values of Cs-137 and uranium in puddles etc with relevant NRPB GDLs for freshwater.

In any event, the ingestion of any water from a puddle would present far greater biological hazards than any conceivable radiological hazard, and as such there does not appear to be any justification for further site-specific investigations at any sites with respect to caesium or uranium concentrations in puddles.

7.6 Air

Table 19 contains a summary of all air sample analyses for U-238, 235 and 234 by alpha spectroscopy and a comparison with the relevant NRPB GDLs, expressed as a percentage of GDL. Duplicate samples were obtained at site code SIP; the maximum value, derived from the relevant data in Table 16, has been quoted in Table 19.

Samples were not analysed for Cs-137, since inhalation of Cs-137 would not be a significant pathway in the event of widespread contamination of ground by Cs-137. External irradiation and consumption of food would be the dominant pathways.

In the case of U-238, 235 and 234, none of the values for the two Category A sites sampled exceeds 10% of the relevant GDL. The maximum value was not in excess of 0.8%.

There does not appear to be any justification for further site-specific investigations at any sites with respect to uranium concentrations in air.

7.7 Dust

Following the advice of an organisation received as a result of the public consultation process, dust samples were taken at all sites. They were not intended to be used for primary assessment purposes, but to be used in the event that any site-specific assessments were required.

There is no recommended NRPB GDL for dust, so a comparison may be made with the GDL for "well mixed soil". In the case of Cs-137, the dominant exposure pathway is external exposure from the ground down to a depth of approximately 300mm. This is not applicable to minor quantities of dust lying on the ground. Hence, a comparison with GDL for Cs-137 in well-mixed soil is of no informative value.

In the case of uranium, the NRPB model includes pathways from well mixed soils include ingestion and inhalation pathways, as well as external exposure. Hence, a comparison with the relevant GDL may be of some *limited* informative value.

Table 20 contains a summary of all dust analyses for Cs-137 (by gamma spectroscopy), and total uranium by XRF. The mean value for each site, derived from the relevant data in Table 4 to 16, has been quoted in the table.

Results show that calculated mean U-238 and U-235 values for dust are not in excess of 0.1% of the GDL for any of the sites surveyed, well below 10% of the GDL for soil. There does not appear to be any justification for further site-specific investigations at any sites with respect to uranium concentrations in dusts.

7.8 Multiple radionuclides

NRPB GDLs are formulated on the basis of dose arising as a result of exposure to a single radionuclide (but including associated decay products). In the context of the radionuclides reported as part of this survey, there is the potential for exposure from Cs-137 (and to a much lesser extent Cs-134), and independently from U-238 and U-235 arising from human activity.

The analysis of soil samples has indicated a total uranium content typical of what would occur from natural sources. Thus, it would appear not be appropriate to consider the contribution from uranium to the overall GDL. However, for the sake of completeness, it will be pessimistically assumed that the uranium has arisen from human activity.

NRPB recommend that the overall impact should be assessed by calculating the percentage of the GDL for each route, and then ensuring that the sum of the percentage GDLs does not exceed the screening value of 10%.

The GDLs from soil are dominated by that arising from Cs-137. The percentage GDLs associated with U-238 and U-235 measurements are less than 0.2%, and will not result in any of the summed GDLs exceeding 10%,

There is no GDL for caesium in air, since NRPB has assessed that the inhalation pathway will always be negligible compared with the external dose arising from the ground. Hence, there is no need to consider a combination of caesium and uranium in air.

In the case of potable water, the GDLs are dominated by that arising from Cs-137. The percentage GDLs for U are typically less than 0.1%, and again the impact on the summed GDLs is negligible.

7.9 ICP-QMS isotopic ratio data – soils and dust

The environmental survey in Bosnia was carried out primarily to address concerns about the use of DU ammunition. There is an inherent background of naturally occurring uranium in the environment. This may be characterised by the ratio of naturally occurring isotopes of U 238:U-235 (137.9 for natural uranium, by mass) in a sample.

The U-238:U-235 isotopic ratio in DU is typically around 500 (depending on the source of the DU) (Ref. 10). If the ratio of U-238:U-235 in an environmental sample is *significantly* higher than 137.9, this may indicate that some or all of the uranium in the sample *may* not be from a natural source, and it *may* contain some DU.

U-238 has a very long half life (4.5×10^9 years). It decays into a series of decay products, one of which is U-234. U-238 has been in the earth's crust since the formation of the earth about 4.5×10^9 years ago, and if undisturbed, would be expected to be in secular equilibrium with its decay products. The ratio of U-238:U-234 is 18116 (by mass) for uranium in secular equilibrium.

DU contains *much* less U-234 than natural uranium as a result of the uranium enrichment process. If the isotopic ratio of U-238:U-234 in an environmental sample is significantly higher than 18116, this may indicate that some or all of the uranium in the sample *may* not be from a natural source, and it *may* contain some DU.

There is thus some potentially useful information to be gained by looking at the isotopic ratios in the samples analysed by ICP-QMS, and comparing them with the ratios typical of uranium from a natural source.

The ICP-QMS procedure is subject to random and systematic uncertainties associated with both sample preparation and the measurement process itself. The laboratory has assessed these uncertainties, and advised DRPS of the significance of these errors with respect to the interpretation of isotopic ratio information. The total uncertainties at 95% confidence levels (sampling and measurement) on the reported isotopic ratios are equivalent to ± 2 in the case of the U-238:U-235 ratio, and ± 3000 in the case of U-238:U-234 ratio.

Thus, if the reported U-238:U-235 ratio for a sample is outside of the range 137.9 ± 2.0 , i.e. 135.9 to 139.9, then this *may* indicate a sample requiring further investigation to establish the reason for the reported isotopic ratios lying outside the expected range. It should be borne in mind that at the 95% confidence limit associated with the quoted range of isotopic ratios, 5% of the samples would thus be expected to lie outside the range, assuming the uranium to be of natural origin. However, it may indicate non-equilibrium uranium in the sample and/or the presence of DU.

Similarly, if the reported U-238:U-234 ratio for a sample is outside of the range 18116 ± 3000 , i.e. 15116 to 21116, then this may indicate a sample requiring further investigation.

Tables 4 to 16 also contain the reported uranium ratios for all soil and dust samples subjected to ICP-QMS analysis. These have been compared with the uncertainty range identified above to verify whether a result lies within or outside the expected range for natural uranium.

For U-238:U-235 ratios, all results lie within the expected uncertainty range.

For U-238:U-234 ratios, all results lie within the expected uncertainty range.

It is concluded that the uranium isotopic ratios are typical of those associated with natural uranium in soils and dusts at all sites visited.

7.10 ICP-QMS isotopic ratio data – waters

U-238:U-235 and U-238:U-234 isotopic ratios were measured as part of the ICP-QMS analysis of the water samples.

Tables 4 to 16 contain the uranium ratios for all water samples subjected to ICP-QMS analysis.

For U-238:U-235 ratios, all results lie within the expected range for natural uranium, with the exception of sample W/KNE/01/18/08/02 where the U-238:U-235 ratio is 144.7. However the laboratory carrying out the analysis has advised that the U content in this sample was exceptionally low, resulting in increased uncertainties associated the processing of this particular sample, thus accounting for the slightly higher than normal ratio. In any case, the total U content is of no radiological significance (see section 7.4).

For U-238:U-234, many ratios lie outside the expected uncertainty range of 15116 - 21116, assuming U-234 is in secular equilibrium with U-238. The minimum value is 7023 (site code PRI) through to 24669 (site code MGB). This is not unusual for surface or underground freshwater samples. Ivanovich et al (Reference 11) reports U-238:U-234 ratios ranging from 7500 through to 23438 for surface water samples, and 1563 through to 31250 for underground water samples.

The mechanism responsible for this disequilibrium is thought to be preferential leaching of U-234 or its precursors Thorium-234 and Protactinium-234(m) from the matrix in which the original U-238 was bound. The alpha particle emitted by the initial decay of U-238 disrupts the matrix, causing fractures and dislocations that subsequently allow preferential dissolution, thus changing U-234 concentrations in some groundwaters .

7.11 Isotopic ratio data – air

The air filter samples were analysed by alpha spectroscopy, providing information about the activity of each of the radionuclides U-238, U-235, U-234. The results were reported in terms of *activity* per filter sample, and were then normalised to unit volume of sampled air (see Table 5 & Table 16 for information about sites where air samples were taken).

Results above the limit of detection were reported for all samples in the case of U-238 and U-234. This has allowed the calculation of the *activity* ratio U-238:U-234 for these four samples, and these are included in Table 5 and Table 16. It should be noted that there were considerable uncertainties associated with the determinations of each radionuclide, and these are reflected in turn in the uncertainties in the calculated ratios in Table 5 and Table 16.

It is important to note that this activity ratio is not the same quantity as the mass ratio for U-238:U-234 quoted in Tables 4 through to 16 for soil, dust and water samples, and discussed in sections 7.9 and 7.10 above. However, the activity ratio is related to the mass ratio by virtue of the specific activity of the radionuclide expressed in terms of Bq per unit mass.

The U-238:U-234 *activity* ratio would be expected to be 1.0 for natural uranium in secular equilibrium (see section 7.9 above). Ref. 11 quotes the activity fraction of DU as U-238 = 83.35% and U-234 = 15.53% , thus implying a U-238:U-234 activity ratio of 5.37.

The U-238:U-234 activity ratios calculated in Table 5 and Table 16 range from 0.9 through to 1.2. When the uncertainties are taken into account, all ratios are consistent with the natural uranium ratio of 1.0.

The levels of U-235 determined by alpha spectroscopy were below reporting levels. It is therefore not appropriate to carry out this analysis for the activity ratio U-238:U-235.

7.12 Lead and other heavy metals

As previously discussed in Section 5.3 and 5.5 of this report, the concentration of lead (by XRF) and cadmium, arsenic, zinc, copper, nickel and chromium (by ICP-AES) was also reported as part of the analyses. The interpretation of these results is outside the scope of this report addressing radiological issues. The health risks associated with these heavy metals will be addressed in a further Dstl report.

Uranium in soils etc can present chemical toxicity problems. However, all the interpretation of soil etc analyses discussed earlier in this chapter indicated the uranium to be of natural origin; there was no evidence to indicate the presence of DU. The amount of (natural) uranium was typical of those found in soils etc elsewhere in Europe. It is not appropriate to further consider the chemical toxicity of uranium within the scope of this environmental survey, since the uranium is clearly not anthropogenic in origin.

8 CONCLUSIONS AND RECOMMENDATIONS

There are no significant risks to UK forces in Bosnia arising as a result of exposure to any form of uranium including depleted uranium in the environment in and around UK bases. All mean values of uranium in the environment are well below 10% of the relevant NRPB GDLs for uranium.

Levels of uranium in soils waters and air are typical of those associated with natural uranium in the environment.

Whilst there is evidence of caesium originating from Chernobyl in the environment in Bosnia, the resultant risk to UK forces based at existing UK locations is not significant. However, there may be locations elsewhere in Bosnia where the activity concentration of caesium may exceed 10% of the NRPB GDL, and thus trigger a site specific radiological risk assessment. It is recommended that any prospective new locations for a UK base is subject to a risk assessment for caesium prior to being selected and developed.

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Table 1 – Survey Protocol for Category A Sites

CATEGORY	ITEM	DESCRIPTION	OCCURRENCE	OUTPUT
Direct Measurement	Walk-over Survey	Survey of undisturbed areas of land inside and just beyond site boundary using GR130 or equivalent scintillation detector	Once per site	Qualitative information characterising non-targeted sampling sites Identification of sites for targeted sampling
	Dose rate monitoring	Environmental dose rate measurement using GR130 or Mini Instruments 6-80 over a 300 second integration time	Once at every soil sampling site location	Dose rate measurement to allow calculation of gamma doses from radionuclides in the ground
Environmental Sampling	Soil	Samples taken from identified locations by auger with 5 auger flights per composite sample Minimum 250g per composite sample. Samples from surface vegetation at 0 - 25mm and soil from 25-150 and 150-300mm.	20 samples per site Additional samples from areas identified as anomalous during walk-over survey	Soil samples for laboratory analysis for radionuclides and heavy metals Gamma spectroscopy for common radionuclides XRF analysis for total uranium and heavy metals ICPMS for uranium isotope ratios when indicated by XRF
	Dusts	Samples of road dust and dust from office and accommodation blocks. Minimum 20g per sample	6 samples per base from roads 1 sample from major office and accommodation blocks	Analysis as for soil samples
	Airborne dust	Sample of airborne dust taken at 60 litres per minute, subject to availability of power supply. Minimum duration 6h	1 downwind sample away from sources of dust such as roads	Analysis for uranium by alpha spectrometry and for caesium by gamma spectrometry
	Water	30ml samples taken from water courses and filtered on site	1 per water course entering and leaving the site	ICPMS analysis for uranium and heavy metals

Table 2 – Survey Protocol for Category B Sites

CATEGORY	ITEM	DESCRIPTION	OCCURRENCE	OUTPUT
Direct Measurement	Walk-over Survey	Survey of undisturbed areas of land inside and just beyond site boundary using GR130 or equivalent scintillation detector	Once per site	Qualitative information characterising non-targeted sampling sites Identification of sites for targeted sampling
	Dose rate monitoring	Environmental dose rate measurement using GR130 or Mini Instruments 6-80 over a 300 second integration time	Once at every soil sampling site location	Dose rate measurement to allow calculation of gamma doses from radionuclides in the ground
Environmental Sampling	Soil	Samples taken from identified locations by auger with 5 auger flights per composite sample. Minimum 250g per composite sample Samples from surface vegetation at 0 - 25mm and soil from 25 –150 and 150-300mm	Not less than 4 samples per site, up to a maximum of 10 samples for larger sites Additional samples from areas identified as anomalous during walk-over survey	Soil samples for laboratory analysis for radionuclides and heavy metals. Gamma spectroscopy for common radionuclides XRF analysis for total uranium and heavy metals ICPMS for uranium isotope ratios when indicated by XRF
	Dusts	Samples of road dust and dust from office and accommodation blocks. Minimum 20g per sample	Not less than 1 sample of road dust per site 1 sample from major office and accommodation blocks	Analysis as for soil samples
	Airborne dust	N/A	N/A	N/A
	Water	30ml samples taken from water courses and filtered on site	1 per water course entering and leaving the site	ICPMS analysis for uranium and heavy metals

Table 3 – Sites Visited and Samples Obtained

SITE CODE	SITE NAME	SITE TYPE	DATE(S) VISITED	SOIL SAMPLES	DUST SAMPLES	AIR SAMPLES	WATER SAMPLES	COMMENTS
BGR	Bos Gradiska	B	17/08/02	12	2	n/a	2	
BLM	Banja Luka Metal Factory	A	15/08/02	38	6	1	3	
GLA	Glamoc Compound	B	18/08/02	8	2	n/a	1	
KNE	Knezovo	B	18/08/02	10	1	n/a	2	
KVA	Kotor Varos	B	18/08/02	10	2	n/a	2	
LIS	Lisina	B	16/08/02	12	2	n/a	1	
MAN	Manjaca	B	19/08/02	10	2	n/a	0	No potable water available during visit – supply pump failure
MGB	Mrkonjic Grad Bus Depot	B	17/08/02	12	1	n/a	2	
MGS	Mrkonjic Grad Shoe Factory	B	17/98/02	10	1	n/a	1	
PRI	Prijedor	B	16/08/02	10	2	n/a	2	
PRN	Prnjavor	B	17/08/02	12	2	n/a	2	
RAD	Radaljica	B	19/08/03	10	1	n/a	1	
SIP	Sipovo	A	15/08/03 – 19/08/03	42	6	3	5	

Table 4 – Summary of Results for Site Code BGR

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env. Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/BGR/01/17/08/02/0-150	11.1	3	37.1	1.7	2.79	34.4	1.6	18627	137.9	80
S/BGR/01/17/08/02/150-300	7.9	2	24.7	1.2						80
S/BGR/02/17/08/02/0-150	8.4	2	24.7	1.2						60
S/BGR/02/17/08/02/150-300	5.4	2	24.7	1.2						60
S/BGR/02/17/08/02/150-300 (DUP)		2	24.7	1.2						
S/BGR/04/17/08/02/0-150	10.0	2	24.7	1.2						60
S/BGR/04/17/08/02/150-300	5.7	2	24.7	1.2						60
S/BGR/05/17/08/02/0-150	18.3	3	37.1	1.7						70
S/BGR/05/17/08/02/150-300	12.2	3	37.1	1.7						70
S/BGR/06/17/08/02/0-150	10.9	3	37.1	1.7	3.16	39.0	1.8	19011	138.1	50
S/BGR/06/17/08/02/150-300	7.1	3	37.1	1.7						50
S/BGR/07/17/08/02/0-150	12.2	3	37.1	1.7						70
S/BGR/07/17/08/02/150-300	13.6	3	37.1	1.7						70
Mean	10.2	3	31.4	1.5	n/a	n/a	n/a	n/a	n/a	65
D/BGR/01/17/08/02	4.0	1	12.4	0.6						
D/BGR/02/17/08/02	9.5	1	12.4	0.6	1.41	17.4	0.8	18440	137.9	
Mean	6.8	1	12	1	n/a	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/BGR/01/17/08/02	<0.6	0.75	9.E-03	4.E-04	14293	138.3	Potable
W/BGR/02/17/08/02	<0.4	1.69	2.E-02	1.E-03	18672	137.8	Puddle

Table 5 – Summary of Results for Site Code BLM

SOIL & DUST	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSv h ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
Sample I.D.										
S/BLM/01/15/08/02/0-150	24.4	4	49.4	2.3	4.98	61.5	2.9	18311	137.9	40
S/BLM/01/15/08/02/0-150 (DUP)		3	37.1	1.7						
S/BLM/01/15/08/02/150-300	5.3	3	37.1	1.7						40
S/BLM/02/15/08/02/0-150	17.0	3	37.1	1.7	3.12	38.6	1.8	18744	138.2	60
S/BLM/02/15/08/02/150-300	4.8	3	37.1	1.7						60
S/BLM/03/15/08/02/0-150	13.6	3	37.1	1.7						60
S/BLM/03/15/08/02/150-300	6.7	2	24.7	1.2						60
S/BLM/04/15/08/02/0-150	12.3	2	24.7	1.2						60
S/BLM/04/15/08/02/150-300	8.7	3	37.1	1.7						60
S/BLM/05/15/08/02/0-150	17.2	2	24.7	1.2						60
S/BLM/05/15/08/02/150-300	5.4	2	24.7	1.2						60
S/BLM/06/15/08/02/0-150	11.5	2	24.7	1.2						65
S/BLM/06/15/08/02/150-300	7.1	2	24.7	1.2						65
S/BLM/06/15/08/02/150-300 (DUP)		2	24.7	1.2						
S/BLM/07/15/08/02/0-150	15.1	2	24.7	1.2						60
S/BLM/07/15/08/02/150-300	4.4	2	24.7	1.2						60
S/BLM/08/15/08/02/0-150	12.0	2	24.7	1.2						70
S/BLM/08/15/08/02/150-300	12.7	2	24.7	1.2						70
S/BLM/09/15/08/02/0-150	15.6	2	24.7	1.2						60
S/BLM/09/15/08/02/150-300	7.8	2	24.7	1.2						60
S/BLM/10/15/08/02/0-150	11.2	1	12.4	0.6						50
S/BLM/10/15/08/02/150-300	9.0	2	24.7	1.2	3.06	37.7	1.8	20146	138.1	50
S/BLM/11/15/08/02/0-150	3.7	2	24.7	1.2						75
S/BLM/11/15/08/02/0-150 (DUP)		2	24.7	1.2						
S/BLM/11/15/08/02/150-300	3.9	3	37.1	1.7						75
S/BLM/12/15/08/02/0-150	14.4	3	37.1	1.7						70
S/BLM/12/15/08/02/150-300	3.7	4	49.4	2.3	4.04	49.8	2.3	17044	137.8	70
S/BLM/13/15/08/02/0-150	19.0	3	37.1	1.7						65
S/BLM/13/15/08/02/150-300	13.0	3	37.1	1.7						65
S/BLM/14/15/08/02/0-150	17.9	3	37.1	1.7	3.13	38.7	1.8	18519	138.2	75
S/BLM/14/15/08/02/150-300	16.8	3	37.1	1.7						75
S/BLM/15/15/08/02/0-150	11.4	3	37.1	1.7						65
S/BLM/15/15/08/02/150-300	9.1	3	37.1	1.7						65
S/BLM/16/15/08/02/0-150	8.8	2	24.7	1.2	3.25	40.1	1.9	18446	137.8	70
S/BLM/16/15/08/02/150-300	7.7	2	24.7	1.2						70
S/BLM/16/15/08/02/150-300 (DUP)		2	24.7	1.2						
S/BLM/17/15/08/02/0-150	9.0	2	24.7	1.2						65
S/BLM/17/15/08/02/150-300	6.1	3	37.1	1.7						65
S/BLM/18/15/08/02/0-150	12.3	2	24.7	1.2						50
S/BLM/18/15/08/02/150-300	6.0	2	24.7	1.2	2.08	25.7	1.2	18931	137.9	50
S/BLM/19/15/08/02/0-150	11.7	2	24.7	1.2						50
S/BLM/19/15/08/02/150-300	6.9	2	24.7	1.2						50
Mean	10.6	2	30.0	1.4	n/a	n/a	n/a	n/a	n/a	62

Table 5 (Cont'd)

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS				
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235
D/BLM/01/15/08/02	<0.9	<1	<12.4	<0.6					
D/BLM/02/15/08/02	7.9	<1	<12.4	<0.6					
D/BLM/03/15/08/02	9.2	<1	<12.4	<0.6					
D/BLM/04/15/08/02	<0.5	<1	<12.4	<0.6					
D/BLM/05/15/08/02	5.9	<1	<12.4	<0.6	1.72	21.2	1.0	18339	138.2
D/BLM/06/15/08/02	<1.6	<1	<12.4	<0.6					
Mean	4.3	<1	<12.4	<0.6	n/a	n/a	n/a	n/a	n/a

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U 238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/BLM/01/15/08/02	<0.3	0.44	5.E-03	3.E-04	13224	137.6	Potable
W/BLM/02/15/08/02	<0.5	0.94	1.E-02	5.E-04	20680	137.6	Puddle
W/BLM/03/15/08/02	<0.4	1.99	2.E-02	1.E-03	16220	138.2	Ditch

AIR

Sample I.D.	Alpha spectroscopy			
	U-238 Bqm ⁻³	U-235 Bqm ⁻³	U-234 Bqm ⁻³	238/235 ratio (by activity)
A/BLM/01/15/08/02	3.3E-04	<5.0E-05	3.0E-04	1.1+/-0.4

Table 6 – Summary of Results for Site Code GLA

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/GLA/01/18/08/02/0-150	37.4	2	24.7	1.2						60
S/GLA/01/18/08/02/150-300	40.0	3	37.1	1.7						60
S/GLA/02/18/08/02/0-150	64.3	2	24.7	1.2						80
S/GLA/03/18/08/02/0-150	78.8	3	37.1	1.7	3.30	40.7	1.9	19277	138.2	60
S/GLA/03/18/08/02/0-150 (DUP)		3	37.1	1.7	3.25	40.2	1.9	20563	138.1	
S/GLA/04/18/08/02/0-150	41.8	3	37.1	1.7						70
S/GLA/05/18/08/02/0-150	36.7	2	24.7	1.2						60
S/GLA/06/18/08/02/0-150	120.3	2	24.7	1.2						65
S/GLA/07/18/08/02/0-150	205.6	2	24.7	1.2						65
Mean	78.1	2	30.2	1.4	n/a	n/a	n/a	n/a	n/a	65
D/GLA/01/18/08/02	18.3	2	24.7	1.2	2.02	24.9	1.2	18663	138.4	
D/GLA/01/18/08/02 (DUP)		<1	<12	<1	2.03	25.1	1.2	18372	138.4	
D/GLA/02/18/08/02	11.1	1	12.4	0.6						
Mean	14.7	2	23.8	1.1	n/a	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/GLA/01/18/08/02	2.4	0.46	6.E-03	3.E-04	17218	137.9	Potable
W/GLA/01/18/08/02 (DUP)		0.46	6.E-03	3.E-04	17231	137.5	

Table 7 – Summary of Results for Site Code KNE

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/KNE/01/18/08/02/0-150	68.5	3	37.1	1.7	2.59	32.0	1.5	20859	137.6	60
S/KNE/01/18/08/02/150-300	14.4	3	37.1	1.7						60
S/KNE/02/18/08/02/0-150	54.9	3	37.1	1.7						70
S/KNE/02/18/08/02/150-300	25.2	3	37.1	1.7						70
S/KNE/03/18/08/02/0-150	58.3	2	24.7	1.2						80
S/KNE/03/18/08/02/150-300	13.5	3	37.1	1.7						80
S/KNE/03/18/08/02/150-300 (DUP)		2	24.7	1.2						
S/KNE/04/18/08/02/0-150	50.5	2	24.7	1.2						70
S/KNE/04/18/08/02/150-300	42.7	3	37.1	1.7	2.58	31.9	1.5	19276	138.4	70
S/KNE/05/18/08/02/0-150	8.5	2	24.7	1.2						30
S/KNE/05/18/08/02/150-300	17.6	3	37.1	1.7						30
Mean	33.9	3	33	2	n/a	n/a	n/a	n/a	n/a	63
D/KNE/01/18/08/02	<4.9	<1	<12.4	<0.6	2.40			19064	137.8	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/KNE/02/18/08/02	<0.2	0.20	3.E-03	1.E-04	11379	137.7	Pond
W/KNE/01/18/08/02	<0.5	0.01	2.E-04	8.E-06	<q.l.	144.7	Potable

Table 8 – Summary of Results for Site Code KVA

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/KVA/02/18/08/02/0-150	27.3	2	24.7	1.2						30
S/KVA/02/18/08/02/150-300	14.6	2	24.7	1.2						30
S/KVA/03/18/08/02/0-150	50.2	1	12.4	0.6	1.75	21.6	1.0	20207	137.6	40
S/KVA/03/18/08/02/150-300	14.6	2	24.7	1.2						40
S/KVA/04/18/08/02/0-150	28.5	2	24.7	1.2						50
S/KVA/04/18/08/02/0-150 (DUP)		2	24.7	1.2						
S/KVA/04/18/08/02/150-300	17.1	2	24.7	1.2						50
S/KVA/05/18/08/02/0-150	38.7	2	24.7	1.2						50
S/KVA/05/18/08/02/150-300	30.2	2	24.7	1.2	2.82	34.9	1.6	19038	137.9	50
S/KVA/06/18/08/02/0-150	47.7	2	24.7	1.2						60
S/KVA/06/18/08/02/150-300	22.6	2	24.7	1.2						60
Mean	31.2	2	24	1.1	n/a	n/a	n/a	n/a	n/a	46
D/KVA/01/18/08/02	<1.9	<1	<12.4	<0.6						
D/KVA/02/18/08/02	<2.7	<1	<12.4	<0.6	1.30			18171	137.9	
Mean	<2.7	<1	<12.4	<0.6	n/a	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/KVA/01/18/08/02	<0.4	0.46	6.E-03	3.E-04	13172	138.3	Potable
W/KVA/02/18/08/02	<0.4	2.41	3.E-02	1.E-03	17935	138.2	Puddle

Table 9 – Summary of Results for Site Code LIS

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/LIS/01/16/08/02/0-150	13.2	1	12.4	0.6						40
S/LIS/01/16/08/02/150-300	7.3	<1	<12.4	<0.6						40
S/LIS/02/16/08/02/0-150	29.6	<1	<12.4	<0.6						50
S/LIS/02/16/08/02/150-300	13	<1	<12.4	<0.6						50
S/LIS/03/16/08/02/0-150	30.1	<1	<12.4	<0.6						50
S/LIS/03/16/08/02/150-300	15.5	1	12.4	0.6	1.76	21.7	1.0	20169	138.3	50
S/LIS/03/16/08/02/150-300 (DUP)		<1	<12.4	<0.6						
S/LIS/04/16/08/02/0-150	31.2	<1	<12.4	<0.6						55
S/LIS/04/16/08/02/150-300	11.6	<1	<12.4	<0.6						55
S/LIS/06/16/08/02/0-150	16.7	1	12.4	0.6	3.50	43.2	2.0	19122	137.8	40
S/LIS/06/16/08/02/150-300	12.5	1	12.4	0.6						40
S/LIS/07/16/08/02/0-150	13.6	1	12.4	0.6						70
S/LIS/07/16/08/02/150-300	9.2	1	12.4	0.6						70
Mean	17.0	1	12.4	0.6	n/a	n/a	n/a	n/a	n/a	51
D/LIS/01/18/08/02	13.8	<1	<12.4	<0.6						
D/LIS/02/18/08/02	31.1	<1	<12.4	<0.6	1.57			18388	138.4	
Mean	22.5	<1	<12.4	<0.6	n/a	n/a	n/a	n/a	n/a	

WATER

	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/LIS/01/18/08/02	<0.4	0.46	6.E-03	3.E-04	13652	138.1	Potable

Table 10 – Summary of Results for Site Code MAN

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/MAN/01/19/08/02/0-150	<1.2	3	37.1	1.7						100
S/MAN/01/19/08/02/150-300	7.5	3	37.1	1.7						100
S/MAN/02/19/08/02/0-150	36.8	3	37.1	1.7						100
S/MAN/02/19/08/02/0-150 (DUP)		3	37.1	1.7						
S/MAN/02/19/08/02/150-300	20.9	4	49.4	2.3	4.38	54.1	2.5	19462	137.9	100
S/MAN/02/19/08/02/150-300 (DUP)					3.90	48.2	2.3	19405	138.2	
S/MAN/03/19/08/02/0-150	27.8	3	37.1	1.7						100
S/MAN/03/19/08/02/150-300	16.8	3	37.1	1.7						100
S/MAN/04/19/08/02/0-150	19.6	3	37.1	1.7						35
S/MAN/04/19/08/02/150-300	20.6	4	49.4	2.3	4.04	49.9	2.3	18568	137.9	35
S/MAN/05/19/08/02/0-150	26.4	3	37.1	1.7						70
S/MAN/05/19/08/02/150-300	15.6	4	49.4	2.3						70
Mean	19.3	3	40	2	n/a	n/a	n/a	n/a	n/a	81
D/MAN/01/19/08/02	<2.1	<1	<12.4	<0.6	2.52	31.1	1.5	18170	138.3	
D/MAN/02/19/08/02	<1.5	<1	<12.4	<0.6						
Mean	<2.1	<1	<12.4	<0.6	n/a	n/a	n/a	n/a	n/a	

WATER

	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
(No sample available)							

Table 11 – Summary of Results for Site Code MGB

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/MGB/01/17/08/02/0-150	20.7	2	24.7	1.2	2.51	31.0	1.5	18719	138.2	40
S/MGB/01/17/08/02/150-300	16.3	2	24.7	1.2						40
S/MGB/02/17/08/02/0-150	37.1	2	24.7	1.2						60
S/MGB/02/17/08/02/150-300	52.0	2	24.7	1.2						60
S/MGB/02/17/08/02/150-300 (DUP)		2	24.7	1.2						
S/MGB/03/17/08/02/0-150	58.0	2	24.7	1.2	2.40	29.7	1.4	19014	138.0	70
S/MGB/03/17/08/02/150-300	30.6	2	24.7	1.2						70
S/MGB/04/17/08/02/0-150	16.4	2	24.7	1.2						80
S/MGB/04/17/08/02/150-300	19.1	2	24.7	1.2						80
S/MGB/05/17/08/02/0-150	59.9	1	12.4	0.6						65
S/MGB/05/17/08/02/150-300	39.0	2	24.7	1.2						65
S/MGB/06/17/08/02/0-150	48.5	2	24.7	1.2						65
S/MGB/06/17/08/02/150-300	9.1	1	12.4	0.6						65
Mean	33.9	2	22.8	1.1	n/a	n/a	n/a	n/a	n/a	63
D/MGB/01/17/08/02	19.1	<1	<12.4	<0.6	1.65	20.4	1.0	18325	137.9	
D/MGB/01/17/08/02 (DUP)		<1	<12.4	<0.6						
Mean	19.1	<1	<12.4	<0.6	n/a	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/MGB/01/17/08/02	<0.4	0.51	6.E-03	3.E-04	19185	137.9	Ditch
W/MGB/02/17/08/02	<0.4	2.04	3.E-02	1.E-03	24669	138.0	Potable

Table 12 – Summary of Results for Site Code MGS

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/MGS/01/17/08/02/0-150	36.2	2	24.7	1.2						80
S/MGS/01/17/08/02/0-150 (DUP)		2	24.7	1.2						
S/MGS/01/17/08/02/150-300	40.2	3	37.1	1.7						80
S/MGS/02/17/08/02/0-150	6.2	5	61.8	2.9	6.78			21337	138.3	85
S/MGS/02/17/08/02/150-300	5.4	5	61.8	2.9	6.89			22066	138.4	85
S/MGS/03/17/08/02/0-150	37.6	3	37.1	1.7						90
S/MGS/03/17/08/02/150-300	25.5	3	37.1	1.7						90
S/MGS/04/17/08/02/0-150	26.2	2	24.7	1.2						100
S/MGS/04/17/08/02/150-300	27.6	3	37.1	1.7						100
S/MGS/05/17/08/02/0-150	16.9	4	49.4	2.3	5.58	68.9	3.2	20731	138.1	90
S/MGS/05/17/08/02/150-300	36.7	4	49.4	2.3	6.06	74.9	3.5	18142	137.4	90
Mean	25.9	3	40.4	1.9	n/a	n/a	n/a	n/a	n/a	89
D/MGS/01/17/08/02	17.2	2	24.7	1.2	2.62	32.4	1.5	18907	138.0	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/MGS/01/17/08/02	<0.3	0.64	8.E-03	4.E-04	7768	137.8	Potable

Table 13 – Summary of Results of Site Code PRI

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/PRI/01/16/08/02/0-150	17.2	3	37.1	1.7						70
S/PRI/01/16/08/02/150-300	15.8	3	37.1	1.7						70
S/PRI/01/16/08/02/150-300 (DUP)		3	37.1	1.7						
S/PRI/02/16/08/02/0-150	12.1	3	37.1	1.7						70
S/PRI/02/16/08/02/150-300	26.5	3	37.1	1.7						70
S/PRI/03/16/08/02/0-150	15.8	3	37.1	1.7						80
S/PRI/03/16/08/02/150-300	9.9	3	37.1	1.7						80
S/PRI/04/16/08/02/0-150	54.2	3	37.1	1.7	3.04	37.5	1.8	18183	138.0	65
S/PRI/04/16/08/02/150-300	50.3	2	24.7	1.2						65
S/PRI/05/16/08/02/0-150	44.2	4	49.4	2.3	3.36	41.4	1.9	18602	138.2	95
S/PRI/05/16/08/02/150-300	18.1	4	49.4	2.3	3.46	42.7	2.0	18822	138.0	95
Mean	26.4	3	38.2	1.8	n/a	n/a	n/a	n/a	n/a	76
D/PRI/01/18/08/02	<4.1	1	12.4	0.6						
D/PRI/02/18/08/02	<2.9	1	12.4	0.6	2.94	36.3	1.7	18333	138.2	
Mean	<4.1	1	12.4	0.6	n/a	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/PRI/01/18/08/02	<3.0	0.28	3.E-03	2.E-04	18002	138.1	Potable
W/PRI/02/18/08/02	<0.4	0.64	8.E-03	4.E-04	7023	138.0	Puddle

Table 14 - Summary of Results for Site Code PRN

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/PRN/01/17/08/02/0-150	16.9	3	37.1	1.7						60
S/PRN/01/17/08/02/0-150 (DUP)		3	37.1	1.7						
S/PRN/01/17/08/02/150-300	1.1	3	37.1	1.7						60
S/PRN/02/17/08/02/0-150	15.0	2	24.7	1.2	2.44	30.2	1.4	18296	138.4	50
S/PRN/02/17/08/02/150-300	11.2	2	24.7	1.2						50
S/PRN/03/17/08/02/0-150	10.7	3	37.1	1.7						60
S/PRN/03/17/08/02/150-300	9.4	3	37.1	1.7						60
S/PRN/04/17/08/02/0-150	6.3	3	37.1	1.7						60
S/PRN/04/17/08/02/150-300	7.7	3	37.1	1.7						60
S/PRN/05/17/08/02/0-150	7.5	3	37.1	1.7	3.24	40.0	1.9	18283	138.3	40
S/PRN/05/17/08/02/150-300	3.7	3	37.1	1.7						40
S/PRN/06/17/08/02/0-150	14.5	3	37.1	1.7						70
S/PRN/06/17/08/02/150-300	17.0	3	37.1	1.7						70
S/PRN/06/17/08/02/150-300 (DUP)		3	37.1	1.7						
Mean	10.1	3	35.3	1.7	n/a	n/a	n/a	n/a	n/a	57
D/PRN/01/17/08/02	1.6	<1	<12.4	<0.6	0.99	12.2	0.6	18217	138.1	
D/PRN/02/17/08/02	<0.4	<1	<12.4	<0.6						
Mean	1.0	<1	<12.4	<0.6	n/a	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/PRN/01/17/08/02	0.8	0.49	6.E-03	3.E-04	15495	137.5	Potable
W/PRN/02/17/08/02	<0.7	0.30	4.E-03	2.E-04	16475	137.4	Puddle

Table 15 – Summary of Results for Site Code RAD

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv.U 235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
S/RAD/01/19/08/02/0-150	54.1	3	37.1	1.7						60
S/RAD/01/19/08/02/150-300	44.6	3	37.1	1.7						60
S/RAD/02/19/08/02/0-150	130.3	3	37.1	1.7	3.38	41.7	2.0	19988	138.2	75
S/RAD/02/19/08/02/150-300	68.4	3	37.1	1.7						75
S/RAD/03/19/08/02/0-150	116.8	3	37.1	1.7						60
S/RAD/03/19/08/02/150-300	49.2	3	37.1	1.7						60
S/RAD/04/19/08/02/0-150	67.4	3	37.1	1.7						60
S/RAD/05/19/08/02/0-150	67.2	3	37.1	1.7						70
S/RAD/06/19/08/02/0-150	97.2	3	37.1	1.7	3.00	37.0	1.7	19127	137.7	75
S/RAD/07/19/08/02/0-150	31.1	3	37.1	1.7						80
S/RAD/07/19/08/02/0-150 (DUP)		3	37.1	1.7						
Mean	72.6	3	37.1	1.7	n/a	n/a	n/a	n/a	n/a	68
D/RAD/01/19/08/02	<1.2	2	24.7	1.2	2.70	33.3	1.6	17749	137.6	
D/RAD/01/19/08/02 (DUP)					2.51	31.0	1.5	17848	138.0	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/RAD/01/19/08/02	<0.3	0.42	5.E-03	2.E-04	11084	136.7	Potable

Table 16 – Summary of Results for Site Code SIP

SOIL & DUST	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS					Env Dose rate nSvh ⁻¹
		Total U ppm	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
Sample I.D.										
S/SIP/01/15/08/02/0-150	25.5	2	24.7	1.2						95
S/SIP/01/15/08/02/150-300	26.6	2	24.7	1.2						95
S/SIP/02/15/08/02/0-150	26.3	2	24.7	1.2						90
S/SIP/02/15/08/02/150-300	12.2	3	37.1	1.7	3.10	38.3	1.8	19549	138.3	90
S/SIP/03/15/08/02/0-150	31.3	2	24.7	1.2						90
S/SIP/03/15/08/02/150-300	21.6	2	24.7	1.2						90
S/SIP/04/16/08/02/0-150	38.8	3	37.1	1.7						70
S/SIP/04/16/08/02/150-300	28.2	3	37.1	1.7						70
S/SIP/05/16/08/02/0-150	25.6	3	37.1	1.7	3.54	43.7	2.1	19719	138.1	60
S/SIP/05/16/08/02/150-300	27.7	3	37.1	1.7						60
S/SIP/05/16/08/02/150-300 (DUP)		2	24.7	1.2						
S/SIP/06/16/08/02/0-150	20.2	2	24.7	1.2						50
S/SIP/06/16/08/02/150-300	23.6	3	37.1	1.7						50
S/SIP/07/16/08/02/0-150	34.8	2	24.7	1.2						70
S/SIP/07/16/08/02/150-300	12.9	3	37.1	1.7						70
S/SIP/08/16/08/02/0-150	12.3	3	37.1	1.7	2.95	36.4	1.7	19773	138.0	75
S/SIP/08/16/08/02/0-150 (DUP)					3.33	41.2	1.9	19304	137.9	
S/SIP/08/16/08/02/150-300	21.9	3	37.1	1.7						75
S/SIP/09/16/08/02/0-150	43.9	2	24.7	1.2						70
S/SIP/09/16/08/02/150-300	29.1	2	24.7	1.2						70
S/SIP/10/16/08/02/0-150	14.2	2	24.7	1.2						95
S/SIP/10/16/08/02/0-150 (DUP)		2	24.7	1.2						
S/SIP/10/16/08/02/150-300	55.7	2	24.7	1.2						95
S/SIP/11/16/08/02/0-150	39.7	3	37.1	1.7	2.95	36.5	1.7	19817	137.9	80
S/SIP/11/16/08/02/150-300	15.4	2	24.7	1.2						80
S/SIP/12/16/08/02/0-150	27.4	3	37.1	1.7	3.02	37.3	1.8	19180	138.2	95
S/SIP/12/16/08/02/150-300	27.9	3	37.1	1.7						95
S/SIP/13/16/08/02/0-150	1.4	3	37.1	1.7						95
S/SIP/13/16/08/02/150-300	14.4	3	37.1	1.7						95
S/SIP/14/16/08/02/0-150	18.9	3	37.1	1.7	3.07	38.0	1.8	20192	138.0	90
S/SIP/14/16/08/02/150-300	5.6	3	37.1	1.7						90
S/SIP/15/16/08/02/0-150	39.5	2	24.7	1.2						85
S/SIP/15/16/08/02/150-300	22.8	2	24.7	1.2						85
S/SIP/15/16/08/02/150-300 (DUP)		3	37.1	1.7						
S/SIP/16/16/08/02/0-150	26.5	3	37.1	1.7	3.43	42.4	2.0	19455	138.0	95
S/SIP/16/16/08/02/150-300	7.7	3	37.1	1.7						95
S/SIP/17/16/08/02/0-150	19.9	2	24.7	1.2						80
S/SIP/17/16/08/02/150-300	10.7	2	24.7	1.2						80
S/SIP/18/16/08/02/0-150	13.7	2	24.7	1.2						80
S/SIP/18/16/08/02/150-300	15.1	3	37.1	1.7	2.97	36.7	1.7	19015	137.8	80
S/SIP/19/16/08/02/0-150	20.1	2	24.7	1.2						85
S/SIP/19/16/08/02/150-300	5.5	2	24.7	1.2						85
S/SIP/20/16/08/02/0-150	45.6	2	24.7	1.2						60
S/SIP/20/16/08/02/0-150 (DUP)		2	24.7	1.2						
S/SIP/20/16/08/02/150-300	29.6	2	24.7	1.2						60
S/SIP/21/16/08/02/0-150	30.0	2	24.7	1.2						60
S/SIP/21/16/08/02/150-300	20.6	3	37.1	1.7	2.67	33.0	1.5	19641	138.0	60
Mean	23.6	2.5	30.3	1.4	n/a	n/a	n/a	n/a	n/a	80

Table 16 (Contd)

SOIL & DUST

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	XRF			ICP-MS				
		Total U ppm	Equiv. U- 238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Total U mg kg ⁻¹	Equiv. U-238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235
D/SIP/01/15/08/02	1.9	<1	<12.4	<0.6					
D/SIP/01/15/08/02 (DUP)		<1	<12.4	<0.6					
D/SIP/02/16/08/02	22.1	1	12.4	0.6	1.71	21.2	1.0	18749	137.9
D/SIP/03/16/08/02	2.9	1	12.4	0.6					
D/SIP/04/17/08/02	9.2	1	12.4	0.6					
D/SIP/05/17/08/02	38.3	1	12.4	0.6					
D/SIP/06/17/08/02	14.2	1	12.4	0.6	1.39	17.2	0.8	18150	137.9
Mean	15	1	12.4	0.6	n/a	n/a	n/a	n/a	

WATER

Sample I.D.	g Spect Cs - 137 Bqkg ⁻¹	ICP-MS					Type
		Total U mg l ⁻¹	Equiv U- 238 Bqkg ⁻¹	Equiv. U-235 Bqkg ⁻¹	Ratio 238/234	Ratio 238/235	
W/SIP/01/15/08/02	<0.4	2.23	3.E-02	1.E-03	21434	138.0	Ditch
W/SIP/02/15/08/02	2.1	0.45	6.E-03	3.E-04	11512	138.0	Potable
W/SIP/03/16/08/02	<0.3	0.41	5.E-03	2.E-04	11655	138.1	Potable
W/SIP/03/16/08/02 (DUP)		0.40	5.E-03	2.E-04	11581	137.9	Potable
W/SIP/04/16/08/02	<0.5	0.42	5.E-03	2.E-04	11425	137.3	Potable
W/SIP/05/17/08/02	<0.4	0.46	6.E-03	3.E-04	11470	137.4	Potable

AIR

Sample I.D.	Alpha spectroscopy			
	U-238 Bqm ⁻³	U-235 Bqm ⁻³	U-234 Bqm ⁻³	238/234 ratio (by activity)
A/SIP/01/15/08/02	1.4E-04	<2.5E-05	1.4E-04	1.0+/-0.4

Table 17 – Summary of Analysis by Site - Soil

Mean values for each site quoted in table

SITE CODE	No of samples	g Spect.		Env. Dose rate nSvh ⁻¹	XRF				
		Cs-137 Bqkg ⁻¹	GDL %		Total U ppm	Equiv. U-238 Bqkg ⁻¹	GDL %	Equiv.U-235 Bqkg ⁻¹	GDL %
BGR	12	10	1.0	65	3	31	0.2	1.5	0.02
BLM	38	11	1.1	62	2	30	0.1	1.4	0.02
GLA	8	78	7.8	65	2	30	0.2	1.4	0.02
KNE	10	34	3.4	63	3	33	0.2	1.5	0.02
KVA	10	31	3.1	46	2	24	0.1	1.1	0.02
LIS	12	17	1.7	51	1	12	0.1	0.6	0.01
MAN	10	19	1.9	81	3	40	0.2	1.9	0.03
MGB	12	34	3.4	63	2	23	0.1	1.1	0.02
MGS	10	26	2.6	89	3	40	0.2	1.9	0.03
PRI	10	26	2.6	76	3	38	0.2	1.8	0.03
PRN	12	10	1.0	57	3	35	0.2	1.7	0.02
RAD	10	73	7.3	68	3	37	0.2	1.7	0.02
SIP	42	24	2.4	80	2	30	0.2	1.4	0.02

Note: Relevant GDLs' used in calculations are: Cs-137 - 1000, U-238 -20,000, U-235 - 7000 (all Bqkg⁻¹)

Table 18 – Summary of Analysis by Site - Water

Where more than one sample collected at a site, the maximum value is quoted in the table

Potable

SITE CODE	No of samples	g Spect.		ICP-MS				
		Cs-137 Bqkg ⁻¹	GDL %	Total U mg l ⁻¹	Equiv. U-238 Bq l ⁻¹	GDL %	Equiv.U-235 Bq l ⁻¹	GDL %
BGR	1	<0.6	0.6	0.75	9.E-03	3.E-02	4.E-04	1.E-03
BLM	1	<0.3	0.3	0.44	5.E-03	2.E-02	3.E-04	9.E-04
GLA	1	2.4	2.4	0.46	6.E-03	2.E-02	3.E-04	9.E-04
KNE	1	<0.5	0.5	0.01	1.E-04	4.E-04	6.E-06	2.E-05
KVA	1	<0.4	0.4	0.46	6.E-03	2.E-02	3.E-04	9.E-04
LIS	1	<0.4	0.4	0.46	6.E-03	2.E-02	3.E-04	9.E-04
MAN	0							
MGB	1	<0.4	0.4	2.04	3.E-02	8.E-02	1.E-03	4.E-03
MGS	1	<0.3	0.3	0.64	8.E-03	3.E-02	4.E-04	1.E-03
PRI	1	<3.0	3.0	0.28	3.E-03	1.E-02	2.E-04	5.E-04
PRN	1	0.8	0.8	0.49	6.E-03	2.E-02	3.E-04	9.E-04
RAD	1	<0.3	0.3	0.42	5.E-03	2.E-02	2.E-04	8.E-04
SIP	4	2.1	2.1	0.46	6.E-03	2.E-02	3.E-04	9.E-04

Note: Relevant GDLs' used in calculations are: Cs-137 - 100, U-238 -30, U-235 - 30 (all Bq l⁻¹)

Non-potable

SITE CODE	No of samples	g Spect.		ICP-MS				
		Cs-137 Bqkg ⁻¹	GDL %	Total U mg l ⁻¹	Equiv. U-238 Bq l ⁻¹	GDL %	Equiv.U-235 Bq l ⁻¹	GDL %
BGR	1	<0.4	0.4	1.69	2.E-02	7.E-02	1.E-03	3.E-03
BLM	2	<0.5	0.5	1.99	2.E-02	8.E-02	1.E-03	4.E-03
GLA	0							
KNE	1	<0.2	0.2	0.20	2.E-03	8.E-03	1.E-04	4.E-04
KVA	1	<0.4	0.4	2.41	3.E-02	1.E-01	1.E-03	5.E-03
LIS	0							
MAN	0							
MGB	1	<0.4	0.4	0.51	6.E-03	2.E-02	3.E-04	1.E-03
MGS	0							
PRI	1	<0.4	0.4	0.64	8.E-03	3.E-02	4.E-04	1.E-03
PRN	1	<0.7	0.7	0.30	4.E-03	1.E-02	2.E-04	6.E-04
RAD	0							
SIP	1	<0.4	0.4	2.23	3.E-02	9.E-02	1.E-03	4.E-03

Table 19 – Summary of Analysis by Site - Air

Where more than one sample collected at a site, the maximum value is quoted in the table

SITE CODE	No of samples	Alpha spectroscopy					
		U-238 Bqm-3	GDL %	U-235 Bqm-3	GDL %	U-234 Bqm-3	GDL %
BLM	1	3.3E-04	0.7	<5.0E-05	<0.1	3.0E-04	0.8
SIP	3	3.1E-04	0.6	<8.3E-05	<0.2	2.8E-04	0.7

Note: Relevant GDLs' used in calculations are: Cs-137 - n/a, U-238 - 5E-2, U-235 - 4E-2, U-234 - 4E-2 (all Bq m⁻³)

Table 20 – Summary of Analysis by Site – Dust

Mean values for each site quoted in table

SITE CODE	No of samples	g Spect.		XRF				
		Cs-137 Bqkg ⁻¹	GDL %	Total U ppm	Equiv. U-238 Bqkg ⁻¹	GDL %	Equiv.U-235 Bqkg ⁻¹	GDL %
BGR	2	7	0.7	1	12	0.1	0.6	0.01
BLM	6	4	0.4	<1	<12.4	<0.1	<0.6	<0.01
GLA	2	15	1.5	2	24	0.1	1	0.02
KNE	1	<5	<0.5	<1	<12.4	<0.1	<0.6	<0.01
KVA	2	<3	<0.3	<1	<12.4	<0.1	<0.6	<0.01
LIS	2	22	2.2	<1	<12.4	<0.1	<0.6	<0.01
MAN	2	<2	<0.2	<1	<12.4	<0.1	<0.6	<0.01
MGB	1	19	1.9	<1	<12.4	<0.1	<0.6	<0.01
MGS	1	17	1.7	2	25	0.1	1.2	0.02
PRI	2	<4	<0.4	1	12.4	0.1	0.6	0.01
PRN	2	1.0	0.1	<1	<12.4	<0.1	<0.6	<0.01
RAD	1	<1	<0.1	2	25	0.1	1	0.02
SIP	6	15	1.5	1	12	0.1	1	0.01

Note 1: GDLs' used in calculations are: Cs-137 - 1000, U-238 -20,000, U-235 - 7000 (all Bqkg⁻¹)

Note 2: no NRPB GDL for dust - GDL for soil used.

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3. Report Protective Markings and any other markings e.g. Caveats, Descriptors, Privacy markings UNCLASSIFIED		
4. Title of Report UK Ministry of Defence Environmental Monitoring in Bosnia August 2002 Survey Report		
5. Title Protective Markings including any Caveats UNCLASSIFIED		
6. Authors Dr David Smith		
7. Originators Name and Address Dr David Smith Dstl Radiological Protection Services Environmental Sciences Department Crescent Road Gosport, Hants PO12 2DL	8. MOD Sponsor Name and Address Mr F Dawson Head of Health Physics Directorate of Safety, Environment and Fire Policy, St Giles Court 1-13 St Giles High Street London WC2H 8LD	
9. MOD contract number and period covered 529133 14U May 2002 – November 2003		
10. Applied Research Package No. N/A	11. Corporate Research Package No. N/A	12. Other report Nos. N/A
13. Date of Issue 28 November 2003	14. Pagination 49	15. No. of References 11
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19. Abstract (A brief (approx. 200 words) factual summary of the report)

The report is concerned with an enhanced environmental monitoring survey carried out in Bosnia to assess the concerns about the peacetime radiological hazards and risks associated with the use of depleted uranium (DU) munitions during the Balkans conflict. The survey also addressed issues arising from caesium in the environment originating from the Chernobyl accident.

The report covers the methodology and results of an extensive environmental survey in the UK-led area of responsibility in Bosnia in August 2002. It also contains an analysis of the results, advice and recommendations to MOD.

There are no significant risks to UK forces in Bosnia arising as a result of exposure to uranium in the environment in and around UK bases. All mean values of uranium in the environment are well below 10% of the relevant advisory limits. Levels of uranium in soils and waters are typical of those associated with natural uranium in the environment.

Whilst there is evidence of caesium originating from Chernobyl in the environment in Bosnia, the resultant risk to UK forces based at existing UK locations is not significant.

It is recommended that any prospective new locations for a UK base is subject to a risk assessment for caesium prior to being selected and developed.

20. Abstract Protective Marking including any Caveats

UNCLASSIFIED

21. Keywords/Descriptors (Authors may provide terms or short phrases which identify concisely the technical concepts, platforms, systems etc. covered in the report).

depleted uranium; DU; caesium; Bosnia; Balkans; environmental survey

22. Authorisation (Complete as applicable)

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