Terrestrial Environmental Depleted Uranium Survey Report Kirkcudbright Training Area - 2005

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Executive summary

Depleted uranium (DU) ammunition has been test fired at the Kirkcudbright Training Area (KTA) since 1981. Routine environmental monitoring has been carried out at KTA since 1980 to assess the environmental impact of the firings on the terrestrial and marine environments. Results of these surveys are published in regular reports.

This report describes and interprets the results of the terrestrial environmental survey undertaken to monitor DU levels in the environment at KTA in 2005. Samples of animal faeces, offal, soil, grass, and water were collected on site as part of the environmental monitoring programme.

The results give reliable indications, using consistent sampling methodologies and UKAS accredited laboratory techniques of the total uranium levels in the terrestrial environment at KTA and of any contribution to this total from the DU used in some munitions trials. Survey results show evidence of the presence of very low levels of DU in twelve out of fifty five environmental samples collected. The levels measured in 2005 were below the investigation levels agreed with agencies with statutory responsibilities for environmental protection, and the samples were not radioactive within the meaning of the Radioactive Substances Act 1993. These positive samples were soils and grass, which came from six sampling locations, four of which lie within fenced off areas. These results are not unexpected, as similar results have been measured at these locations previously. The sampling and analysis programme detects positive soil and grass samples from these locations at intervals, regardless of the amounts and the timing of DU firings. Trace levels of DU of no health significance were measured in some surface water samples during other surveys carried out as part of research into DU corrosion and transport mechanisms and these are also discussed. There is no evidence to indicate that members of the public or site employees are, or have ever been, exposed to a radiological hazard from the terrestrial environment as a result of test firing DU ammunition at the site.

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1 Introduction

This report presents and interprets the results of the Depleted Uranium (DU) terrestrial environmental surveys undertaken at the Kirkcudbright Training Area (KTA) during 2005. The surveys were undertaken to measure total uranium levels in the terrestrial environment at the Kirkcudbright Training Area and to provide information on any DU contamination by the measurement of uranium isotope ratios.

An independent Environmental Assessment of the firing of DU projectiles at the Eskmeals and Kirkcudbright Ranges was published in July 1995 [1]. During 1996, the environmental monitoring programme for the Kirkcudbright site was revised in line with the recommendations of that report and the 1996 DU Baseline Survey report [2] was published. Environmental monitoring has been undertaken in a consistent manner since 1996 to allow direct comparison of the data through time.

The environmental monitoring programme has consisted principally of the collection of soil, grass, water and animal faeces samples and their subsequent analysis in the laboratory.

The monitoring for DU in the marine environment at Kirkcudbright is reported separately [3].

2 Background

The KTA range is located on the coast of Dumfries and Galloway, near Castle Douglas. In April 2006, the range became part of the Defence Training Estate.

DU has been released into the environment at Kirkcudbright as a consequence of the test firing of DU ammunition during design and accuracy assessment trials. DU projectiles are fired through soft vertical targets and continue their trajectory to finally come to rest in the Solway Firth.

Testing of projectiles historically has taken place at five locations on the Kirkcudbright site. Strength of design trials were initially conducted at the Raeberry range using prototype ammunition. Functioning and accuracy trials were conducted until 2001 at the Balig and Doon Hill ranges, whilst confirmatory proving trials were carried out at the Silver Hill Low range. There was no firing in 2002. In February 2003, rounds were fired from Challenger tanks, placed at the Chapman 1000m firing point and on the Balig gun apron, towards India Target. There was no firing in 2004 and 2005.

The number of DU rounds fired each year at Kirkcudbright from the five firing locations and the cumulative mass of DU fired to date, are presented in Figure 1 and Figure 2 respectively.

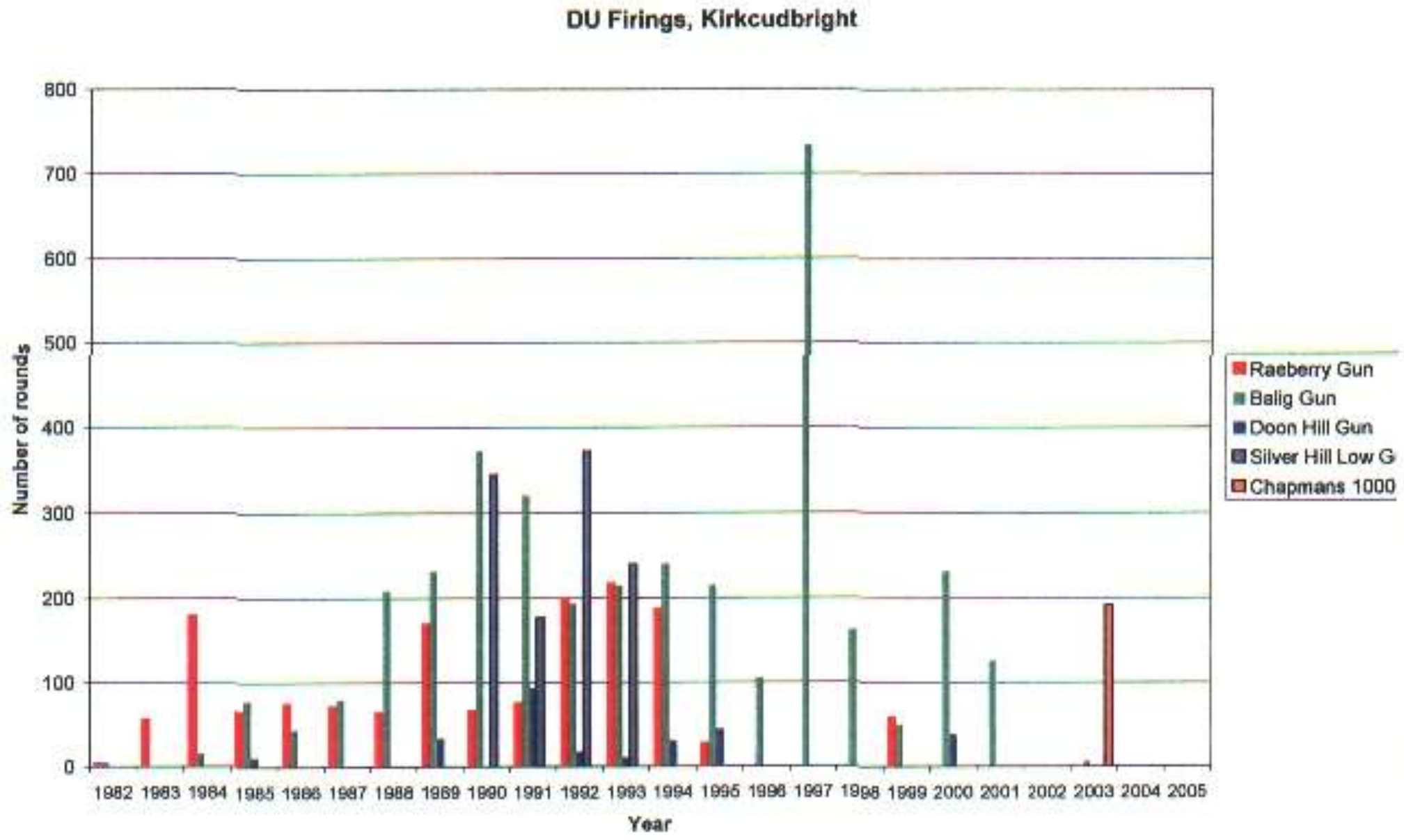

Figure 1: Numbers of DU projectiles fired from KTA, from 1982 to 2005

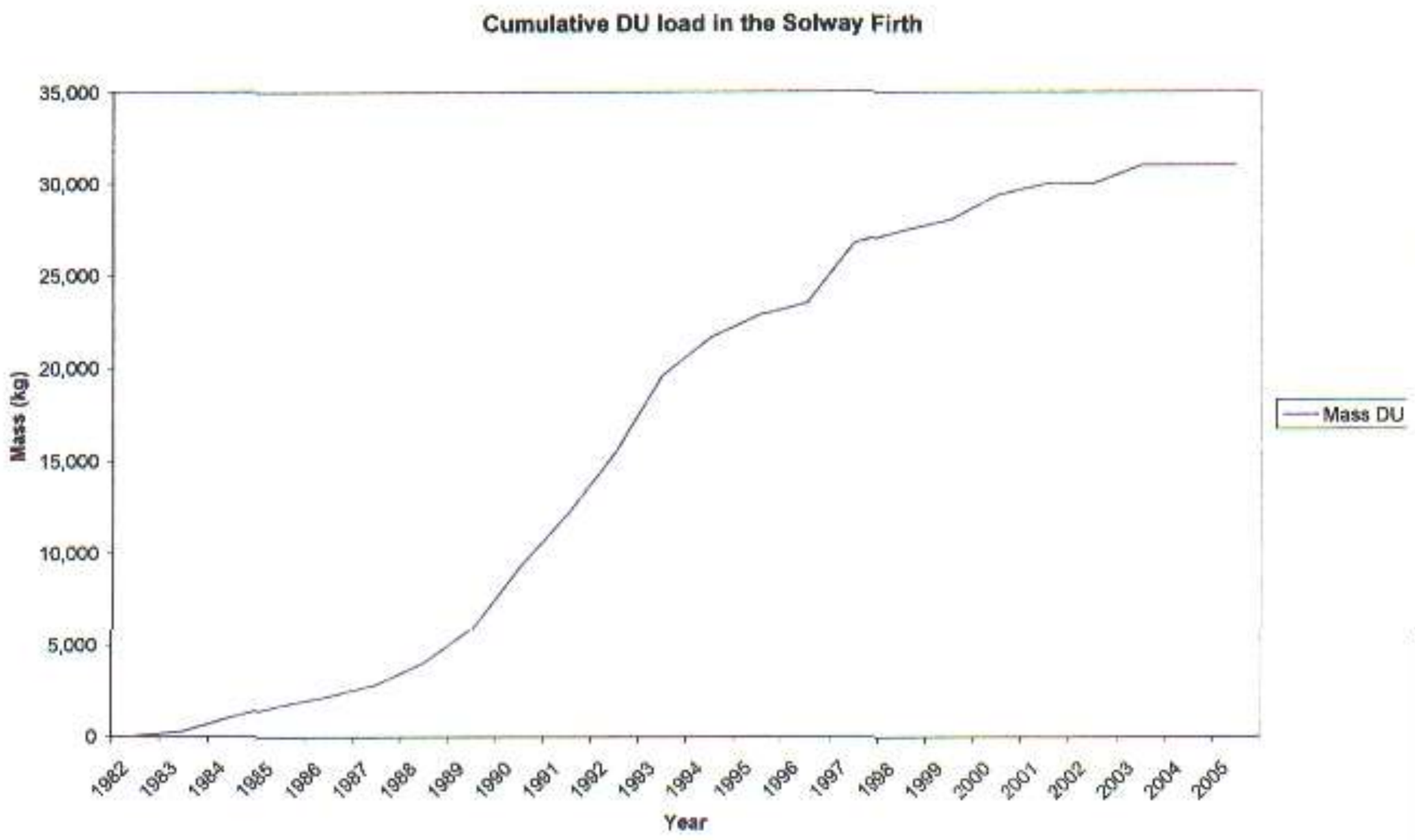

Figure 2: Approximate cumulative mass of DU projectiles fired from KTA, from 1982 to 2005

DU penetrators do not fragment in air under normal circumstances. However, it was inevitable that some malfunctions would occur during the early test firings. Although most malfunctioning penetrators still entered the Solway Firth, a small proportion impacted on land. In addition, some penetrators fragmented on exiting the gun barrel or in flight. The majority of fragments still entered the sea, but it is known that small quantities of particulate DU were deposited at a small number of discrete locations in the local terrestrial environment, when rounds had malfunctioned. Most of these areas are fenced off although the levels of DU present are below regulatory concern. An extensive radiological survey using sensitive large area radiation monitoring equipment in 2002 confirmed the adequacy of the safety and monitoring procedures in place. The survey, whilst identifying the expected isolated areas of low level DU contamination, also proved that only background radiation levels were present in most areas, and that most elevated radiation levels were from naturally occurring radionuclides found in construction materials such as granite chippings on the range roads.[4] The recovery of penetrators that have misfired and landed on the terrestrial part of the Kirkcudbright range has been attempted. However, in most cases where penetrators have been buried at depth in the soil it has not been possible to locate and recover them, despite extensive searching.

3 Depleted uranium

Uranium is a naturally occurring radioactive material that is found as a mixture of three isotopes: uranium-238 (^{238}U), uranium-235 (^{235}U) and uranium-234 (^{234}U). It emits alpha and beta particles, gamma and X radiation. Uranium, in an 'enriched' form, is used as fuel in nuclear reactors. It is called enriched because, due to processing, it contains a higher concentration (> 0.72%) of ^{235}U than natural uranium. The by-product of the enrichment process is DU, which has a reduced concentration of ^{235}U. Uranium-234 is also removed in the depletion process. The mass compositions of DU and of natural uranium are presented below.

	^{238}U	^{235}U	^{234}U
Natural Uranium	99.274%	0.72%	0.00554%
The DU used at Kirkcudbright	99.8%	0.20%	0.0008%

In natural uranium, ^{234}U is normally in equilibrium, or near equilibrium with ^{238}U, but as a result of depletion, the $^{238}U/^{234}U$ activity ratio changes. The actual $^{238}U/^{234}U$ activity ratio varies per batch of DU according to the degree of depletion achieved during processing, but lies between 7:1 and 8:1. Consequently, DU is slightly less radioactive than natural uranium. The chemical toxicity of DU is about the same as lead. For the rest of this report isotopic ratios will be stated as a single value representing the ratio of a number of becquerels of ^{238}U to 1 becquerel of ^{234}U (i.e. a $^{238}U/^{234}U$ ratio of 7 rather than 7:1).

When converting uranium concentrations reported in micro-grams per gram (μg per g) or parts per million (ppm) to activity concentration, two specific activities have been used as conversion factors, depending on the provenance of the uranium. The specific alpha

activity of the DU alloy used at Kirkcudbright is approximately 14 kBq/g, whereas the specific alpha activity of natural uranium is generally 25 kBq/g [5].

4 Differentiating DU from natural uranium

A fundamental requirement of the DU environmental monitoring programme is to quantify the impact of DU firing. This is achieved partly by measuring the amount of total uranium in environmental materials and using this total uranium level (Figure 1and Figure 2) as an upper bound of DU contamination levels. This is a very cautious approach as natural uranium is present in most natural materials. More sophisticated approaches are emerging, that involve specific measurements of the activities or masses of the ^{238}U and ^{234}U isotopes as described below. Although isotope measurements are used in this work, references to total uranium measurements are included for consistency with previous reports. The limitations of using total uranium concentrations are discussed further in Annex B.

A convenient fingerprint marker for DU is the $^{238}U/^{234}U$ activity ratio. The DU fired at KTA has a $^{238}U/^{234}U$ activity ratio of approximately 7, whereas natural uranium has an activity ratio close to 1. Environmental samples are therefore analysed for isotopes of ^{238}U and ^{234}U to determine activity ratios and hence identify the origin of the uranium.

Substantial deposition of DU, relative to an existing natural uranium inventory, is required before the $^{238}U/^{234}U$ activity ratio in the environment diverges significantly from its natural ratio. (An illustration of the impact of increasing the DU mass in a sample on the sample uranium isotopic ratio is given in Annex C). For the ratio to approach 7 in an analytical sample, the mass of DU would have to be about one hundred times the mass of the uranium that is naturally present. Hence, the lower the natural uranium background, the lower the levels of DU contamination that may be detected by isotopic analysis.

Isotopic quantification is achieved by techniques such as Alpha Spectrometry (AS) or Mass Spectrometry (MS). AS can detect uranium to parts per billion, which is equivalent to mBq per kg, or to lower levels if count times are increased. MS is more sensitive than AS, but the lower levels detectable by MS are of no recognised health significance. Furthermore, because most MS measurements are not UKAS accredited, the technique is not normally used in routine health and safety or environmental monitoring. However, for academic studies, Inductively Coupled Plasma (ICP) MS has become the analytical technique of choice for the measurement of very low uranium content and /or the determination of the isotopic ratio.

5 Investigation/action levels

The MOD's Depleted Uranium Firing Environmental Review Committee (DUFERC) has agreed investigation/action levels with regard to DU environmental monitoring results for soil samples. These are currently based on, and represent a small fraction of, the Generalised Derived Limits (GDLs) (for soil and freshwater) and the Radioactive Substances Act 1993 (RSA 93) [6, 7]. GDLs for uranium were last updated in 2000 by the National Radiological Protection Board, which is now part of the Health Protection

Agency, and were discussed by the Royal Society in their studies of the potential health effects of using DU munitions. [8, 18] The investigation/action levels are set intentionally low to ensure that any DU released into the environment is identified before it can accumulate to significant levels. In particular, investigation and action levels are set to less than 10% of the level at which control would be required under RSA 93.

Investigation /action levels for DU in soil

	Limit	Specific Activity (mBq/g dry weight)
DUFERC	First Investigation Level	300
DUFERC	Action Level	1,100
RSA 93	Level at which regulatory control is required. (For natural uranium)	11,100

There are no DUFERC agreed investigation/action levels for uranium in water samples. Dstl can detect uranium in water at levels down to about 10% of the World Health Organisation's (WHO) most restrictive recommendation ever set for uranium levels in drinking water of 2 μg per litre. This level is commonly used as a "trigger" in occupational health monitoring.

6 Sample collection

The actual Ordnance Survey Grid References (OSGB36) for the grass and soil samples obtained in 2005 are given below, and are shown on Figure 3. Samples are collected from pre-designated areas[1] as defined within the 1996 Baseline Survey protocol [2]. If, however the sampling site is not accessible, or suitable, the nearest area along the trajectory path of fired munitions is sought.

During the 2005 survey, sampling did not coincide with established sampling locations 5, 8, and 11. However, the sample area remained broadly consistent with the trajectory path of the fired munitions for location 8. The sampling area for the locations 5 and 11 were at a distance from the trajectory path due to human error. Sample analysis results for these three sampling locations remain consistent with previous years.

1. Raeberry Target	70448	43757
2. Raeberry Bunker	70473	43833
3. Raeberry Gun	70509	43957
4. India Target	70634	43636
5. Balig Gun/Target waypoint	71044	44180
6. Balig Gun	71251	45467

[1] The 1996 Baseline Survey protocol requires that survey samples be collected from sites where DU is most likely to have been deposited. For each gun-target combination, sampling sites were chosen in the vicinity of the gun position, at the soft target stand and at the mid-point of the range. To provide background data for comparison purposes, an additional sampling site was chosen some distance away from the guns and targets, at Gypsy Point. In total, there are 13 areas that have been identified for the sampling of soil and grass on the range.

7. Zulu Gantry	71838	43560
8. Mullock Farm	71431	43998
9. Silver Hill (Low) Gun	70345	44863
10. Echo Target (Doon Hill)	72270	43811
11. Doonhill/Target waypoint	72250	45603
12. Doon Hill Gun	71950	46963
13. Gypsy Point	68626	43770

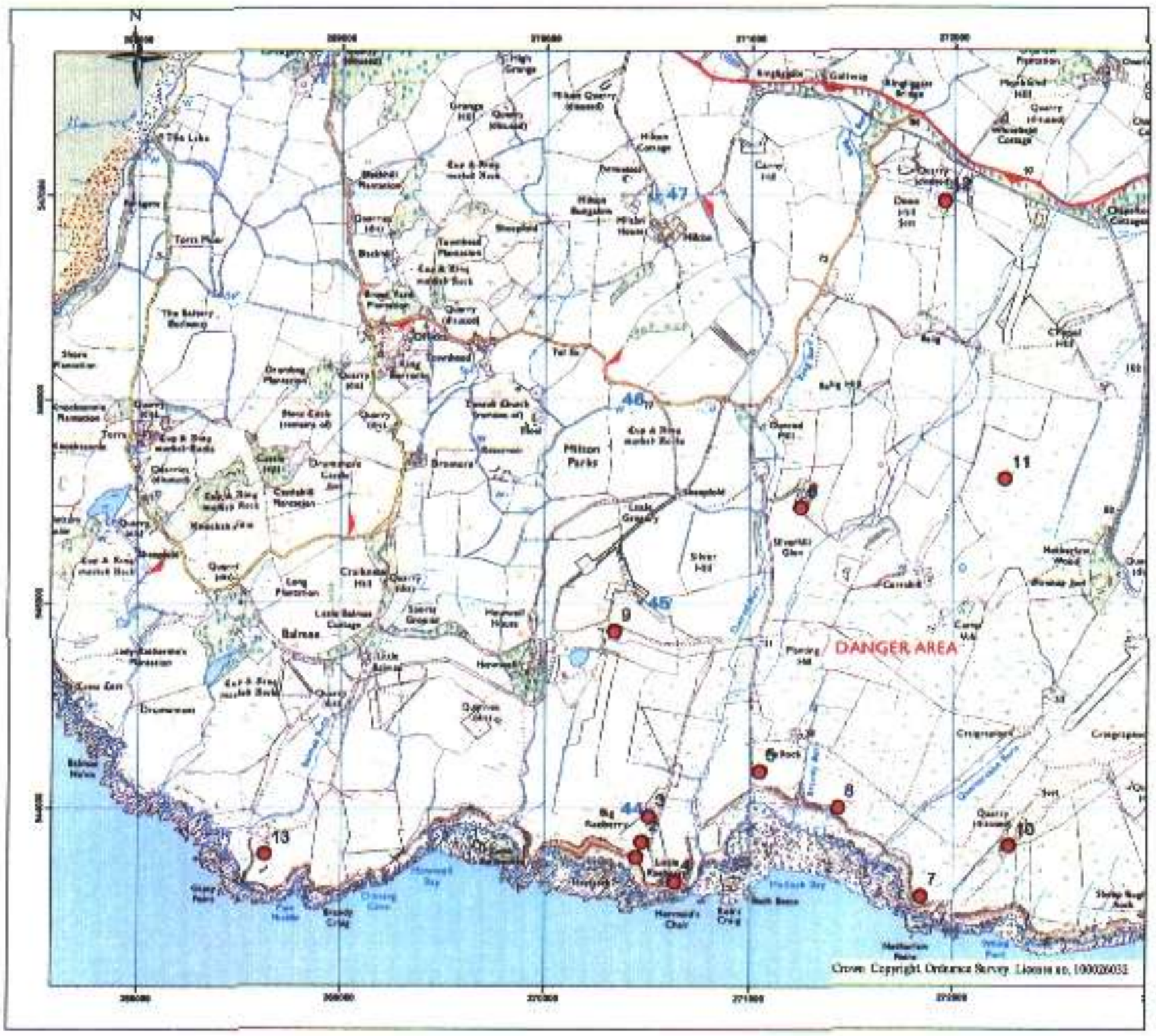

Figure 3: Kirkcudbright Training Area terrestrial sampling locations

Note: Grid squares are 1 km

Grass, soil and animal faeces samples were collected in November 2005, following the methodology described in the 1996 Baseline Survey report [2], with the exception that, as in 2003 and 2004, the numbers of soil samples collected at each sampling site were reduced to three from the six specified in the baseline report. A kidney from each of two female deer was also obtained in January 2006 during deer culling on the range. The timing of the kidney sampling, although it fell in the 2006 calendar year, was closer to the time of the 2005 survey, and accordingly, the results are reported here. Further detail on sample collection methodologies are given below in Section 6.1 to 6.5. Dose rates were also measured at each site.

A list of the soil, grass, offal and faeces samples collected is given in Table 2.

6.1 Grass collection methodology

Grass samples were obtained from three areas of approximate size $1m^2$ each, located within 5m of each other, at each sampling site. However, where the grass was scarce or short, the sampling area was increased accordingly until the samples obtained were of the requisite volume for laboratory analysis. The grass was cut at a height of at least 2 cm from the ground to avoid including soil in the sample. The type of grass collected and the content of other plant species varied from site to site. The grass samples were supplied to the laboratory, and analysed, unwashed, as one composite sample per site.

6.2 Soil collection methodology

Soil samples were collected as undisturbed cores of 4.8 cm diameter and up to 30 cm deep, from the centre of each of the three $1m^2$ areas used for the grass sampling. Each soil core was divided into sub-samples of three depth intervals (0-2 cm, 2-5 cm and over 5 cm) in the laboratory. The top sub-samples of the three cores collected at each sampling site were combined to produce one composite (0-2cm) sample. The 2-5cm depth sub-samples were also combined to make one composite (2-5 cm) sample for each sampling site. The twenty-six composite samples from 13 sampling locations were analysed to give information on the variation in uranium concentration with depth and an indication of the mobility of any surface deposited DU.

6.3 Animal faeces collection methodology

Where available, samples of animal faeces (e.g. deer, rabbit, fox and cattle) were collected close to the sampling sites.

6.4 Animal kidneys collection methodology

Deer culling happens regularly on the range to manage the deer population. Following recommendations to extend the monitoring to biological samples from wild animals that roam on the KTA [9], two female deer's kidneys were obtained in January 2006. The approximate ages of the animals were estimated to be 7 months, and 2 years 7 months. It was felt appropriate that these results should be included in the 2005 survey.

6.5 Water sample collection methodology

Water samples (1 litre) were collected in November 2005, from five watercourses that run through the range (Abbey Burn, Balmae Burn, Dunford Burn, Quartercake Burn and Netherlaw Burn). Samples were collected at locations where access was possible, i.e. from bridges and accessible banks. The Ordnance Survey Grid References for the water sampling locations are given below.

WAT/001	Abbey Burn	74200	44600
WAT/002	Balmae Burn	69048	44468
WAT/003	Quartercake Burn	71799	43931
WAT/004	Netherlaw Burn	73500	44800
WAT/005	Dunford Burn	70958	44824

6.6 Sample descriptor codes

Each sample was given a unique sample descriptor. Samples descriptors were of two basic types. For soils and grasses the descriptor comprised of a location descriptor, followed by a descriptor of sample type.

For soil and grass, the location descriptor code comprised of K (for Kirkcudbright) followed by the location number (1-13) as given above (i.e. K6 for the Balig gun location). The location descriptor was followed by further letters to describe the type of sample:

- G - grass;
- S – soil.

The soil samples that were analysed were composite samples across a depth layer at each sampling site. These samples comprised of an upper soil horizon composite sample (0-2cm) and a lower soil horizon composite sample (2-5cm). U for upper and L for lower were added to the descriptor code to identify these different depth intervals. Two examples of the sample descriptors are given below:

K3/G – for composite grass sample collected from location 3.

K5/S/U – for composite soil sample, upper horizon, collected from location 5.

Water samples and biological indicators were collected from areas outside of the normal sampling locations and so do not have site location codes. The water samples were labelled with WAT, followed by a sample number (i.e. WAT/001, WAT/002).

The biological indicators comprised of one composite faecal sample of mixed animal origins, and eight species specific composite faecal samples. These samples were collected close to standard sampling sites and hence, the sample descriptor is simply the location descriptor followed by the biological indicator type (i.e. rabbit for rabbit faeces).

The kidneys of the two culled female deer were collected from separate locations. The kidneys were labelled as follows:

- KD1: female deer, 7 months old, Chapelhill location
- KD2: female deer, 2 years 7 months old, Balmae location

7 Sample preparation and laboratory analysis

The samples were prepared and analysed by alpha spectrometry in the Dstl UKAS accredited radiochemistry laboratory, following the procedure adopted for the analysis of the terrestrial samples during the 1996 Baseline Survey [2]. An outline of the approach is given below.

The solid samples (soil, grass and animal faeces and kidney samples) were dried to remove moisture and weighed (with results being reported as dry weight). The samples were ashed to remove organic material, and homogenised. During these processes the quantity of uranium in each of the samples remains constant. The ashed samples were boiled in concentrated mineral acid (nitric acid and hydrochloric acid) to remove the 'loose' and leachable uranium from the sample. Recalcitrant matrices such as mineral grains were not broken down by the process and hence natural uranium bound up within them was not removed. The samples were filtered to remove solids.

Water samples of 250 ml were filtered, boiled down to approximately 100 ml and acidified.

Uranium separation was carried out by extraction chromatography. Each eluted sample was electro-deposited onto a stainless steel planchette and the activity of each planchette was counted in a low background, silicon surface barrier, alpha spectrometer.

DU concentrations are given in mBq/g (equivalent to Bq/kg) of dry weight for soils, grass and biological indicators, and mBq/l for water samples.

8 Results and interpretation

A summary of the results for all terrestrial samples collected in 2005 is given below in Table 1. The terrestrial monitoring results are given in Table 3 to Table 6.

It should be noted that the summary at Table 1 is provided to give an overview of the data collected. However, given that the samples were generally selected from specific areas known to be contaminated the mean values should not be taken to be an indicator of average uranium concentrations across the KTA as a whole.

Historical monitoring results for the KTA are presented in Annex A.

8.1 Dose rates

Dose rate measurement results are given in Table 7 for 2005. The maximum recorded dose rate was 110 nGy/h. Dose rates were not reported[1] in 2000, 2001 or 2002. Results compare with dose rate measurements made in 2003 and 2004.

[1] It is thought that dose rates measurements were taken and recorded, but that records were lost during departmental reorganisations before the publication of the yearly reports.

Table 1- Summary of results for terrestrial samples, KTA, 2005

Sample type	Number of Samples	Number of samples containing detectable DU[1]	Total uranium concentration (mBq/g or mBq/l)[2]			
			Mean	Standard deviation of the mean	Minimum	Maximum
Soil upper	13	5	67.4	63.9	26.0	264.6
Soil lower	13	4	65.9	65.2	25.3	258.0
Grass	13	3	1.5	2.5	0.3	9.4
Water	5	0	3.0	1.7	1.8	5.1
Faeces (mixed)	1	0	1.2	Only one sample was collected. Its uranium concentration value is reported here as a mean of one value.		
Faeces (Deer)	1	0	1.4	Only one sample was collected. Its uranium concentration value is reported here as a mean of one value.		
Faeces (Rabbit)	1	0	1.2	Only one sample was collected. Its uranium concentration value is reported here as a mean of one value.		
Faeces (Cow)	6	0	1.9	2.9	0.4	7.7
Kidneys (Deer)	2	0	0.03	0	0.03	0.03

8.2 Biological indicator results

Alpha spectrometry results for biological indicators are presented in Table 3a and 3b. All but one biological indicator sample yielded results similar to those found routinely. One bovine faecal sample had a total uranium activity value higher than reported over the past few years, at 7.7 mBq/g. This is not considered significant, as similar or even higher total uranium values have occasionally been reported, together, as is the case here, with a $^{238}U/^{234}U$ isotopic ratio that denotes natural uranium.

No DU was detected (i.e. was present above the limit of detection of 0.03mBq/g) in the deer kidney samples. This is only a tiny fraction of the GDL for offal (of 1Bq/g) recommended by the National Radiological Protection Board [6] and provides new and further evidence in support of the conclusion about the absence of any effect from the low level DU contamination present in a very few isolated areas.

8.3 Water samples results

Alpha spectrometry results for water samples are presented in Table 4. DU was not detected (i.e. present above the limit of detection) in any of the water samples.

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[1] Samples are reported as containing detectable DU if the ratio of ^{238}U to ^{234}U (after subtraction of the associated uncertainty to give the 95% confidence level) is greater than 1.0 for soil, grass and for biota samples.
[2] Water sample activity results are reported in mBq/l.

8.4 Soils analysis results

Alpha Spectrometry results for soils from the 2005 terrestrial survey are given in Table 5.

No samples contained concentrations of total uranium in excess of the DUFERC investigation level (see Section 5) of 300 mBq/g total uranium. No sample was radioactive within the meaning of the RSA 93 [7].

As mentioned above, total uranium concentrations have also been used to provide an upper bound on DU contamination levels. Previous monitoring reports [10, 11, 12, 13, 14, 15, 16, 17] have highlighted sampling sites where the mean total uranium concentration exceeded that of the Gypsy Point 'background' location by a factor of 2 as areas of possible uranium contamination. They also identified sample results that were at the upper limit of the typical range for UK soils of 50 mBq/g.[1] [18,19, 20]. In 2005, these two identificators of possible uranium contamination were similar. The total uranium results for the Gypsy Point upper and lower soil horizons samples were 31.4 and 25.3 mBq/g respectively. A doubling of these values gives a result that is at the upper limit of the typical range for UK soils.

In 2005, seven soil samples contained total uranium in excess of twice that at Gypsy Point, and one other contained total uranium over 50 mBq/g. The distribution of these samples is as follows:

- Raeberry Gun (K3) – upper and lower horizons – 264.6 and 258.0 mBq/g respectively;
- Mullock Farm (K8) – upper horizon only – 105.4 mBq/g;
- India Target (K4) - upper and lower horizons – 87.3 and 173.5 mBq/g respectively;
- Echo Target (K10) – upper and lower horizons – 73.5 and 56.5 mBq/g respectively;
- Doon Hill (K12) – upper horizon only – 57.6 mBq/g.

These 8 results exceed the 'typical' range [8, 19, 20] with the highest total uranium concentration found at any point being 265mBq/g. However, even if all of this uranium had resulted from DU munitions firings, its presence is of no health significance as it is less than 1.5% of the GDL recommended by the Health Protection Agency

The Raeberry Gun (K3SU & K3SL), Mullock Farm (K8SU) and India Target (K4SL) sample results give rise to a large distribution of results and thus large standard deviations of the means in Table 1. The mean total uranium concentration for the twenty remaining composite soil samples collected in 2005 (excluding the two composite samples collected from the background location Gypsy Hill) was 69.9 mBq/g, with a

[1] Soil minerals containing uranium are widely distributed on the surface of the earth's crust and the concentration of natural uranium in the terrestrial environment therefore varies between locations. Consequently there is no single, definitive, reference level for natural uranium in soils, but there is broad agreement in the range of values published in literature. Typical values in the UK range from 2 to 50 mBq/g wet weight, but values of up to 100 times the typical range can be found locally.

range from 26.0 ± 3.3 to 264.6 ± 27.2 mBq/g. This is comparable with the mean total uranium concentrations from previous years[1].

One interesting aspect of the India Target 2005 results is the discovery of a slightly greater concentration of uranium in the lower horizon result, compared to the upper horizon value. Although the levels are not of regulatory concern, this may be an indication that a DU fragment on the soil surface has corroded away, and that the corrosion products are migrating down the soil profile. An alternate suggestion could be that a small fragment of DU embedded itself to a depth greater than 2 cm on impact.

As DU has not been fired at Raeberry Gun since 1999, towards Echo Target since 2000, or towards India Target since 2003, the slightly elevated concentrations in this year's samples are considered to be purely a function of the heterogeneity of existing, past soil contamination and the nature of the yearly sampling protocol mentioned in Section 6. They do not relate to any increase in DU loadings in the soil over the past year.

8.5 Grass analysis results

Alpha Spectrometry results for grass from the terrestrial survey for 2005 are given in Table 6.

In 2005, total uranium levels at Gipsy Point (K13) were 0.3 ± 0.1. Five grass samples contained total uranium in excess of twice that at Gypsy Point. These were grass samples from:

- India Target (K4) – 9.4 ± 1.1 mBq/g;
- Balig Gun/India Target waypoint (K5) – 3.0 ± 0.4 mBq/g;
- Balig Gun (K6) – 1.5 ± 0.3 mBq/g;
- SilverHill (Low) Gun (K9) – 1.1 ± 0.3 mBq/g;
- Raeberry Gun (K3) – 0.7 ± 0.1 mBq/g.

With the exception of one sample (the composite sample from India Target (K4G – 9.4 mBq/g)), the results for 2005 range in value from 0.3 mBq/g to 3.0 mBq/g, and so compare with the range of literature values reported for UK grass of 0.2 to 3.8 mBq/g [21].

The average total uranium concentration for the grass samples collected in 2005 was 1.5 mBq/g. This compares with the averages for previous years (but see footnote 1 in Section 8.4).

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[1] This comparison provides a "broad-brush" indication of environmental conditions but it needs to be borne in mind that variability can arise from the heterogeneous distribution of uranium in the environment and the variability in sampling location mentioned in Section 6, rather than time dependent effects. In addition, as mentioned earlier in Section 8, Para 8.4, samples were generally selected from specific areas known to be contaminated and the mean value cannot therefore be taken to be an indicator of average uranium concentration across the KTA as a whole.

9 Interpretation of the soil and grass isotopic ratios

In this section the $^{238}U/^{234}U$ isotopic ratios are discussed, the aim being to assess the degree of depletion of the uranium within a sample and hence the extent of DU contamination.

The value of the ratio of $^{238}U/^{234}U$ indicates the relative proportion of DU mixed with the natural uranium present in a sample. An illustration of the impact of increasing the DU mass in a sample on the sample uranium isotopic ratio is given in Annex C.

9.1 Isotopic ratios in soil

Typical $^{238}U/^{234}U$ isotopic ratios in soils vary from 0.83-1.43 [8]. A summary of the measured ratios for the individual soil samples analysed in 2005 is shown in Figure 4. The individual $^{238}U/^{234}U$ soil sample activity ratios range from 0.9 ± 0.2 to 5.2 ± 0.9. Although the majority of samples (including the Mullock Farm samples) were found to contain only natural uranium, in a number of samples (five upper soil and four lower soil samples), there was clearly some degree of depletion. These samples came from locations K3 (Raeberry Gun), K4 (India target), K10 (Echo target), K11 (waypoint between Doon Hill and Echo target) and K12 (Doon Hill Gun). The highest activity ratio of 5.2, for a sample from the Raeberry Gun location, indicates that the mass of DU present in that sample is approximately twelve times the mass of natural uranium. However, the Raeberry Gun location, the India Target and Echo Target locations are all known to have very low levels of DU contamination and are therefore subject to restricted access. It is therefore very unlikely that either public or staff would sustain exposure as a result of the uranium concentrations at these sites.

The $^{238}U/^{234}U$ activity ratio for the soil samples collected at Gypsy Point was close to 1 in 2005, indicating as expected, that at this location all uranium present is of natural isotopic ratio.

Based on the isotopic ratios, four of the five sites identified in Section 8.3 as having total uranium concentrations in excess of twice the background values, and/or in excess of the 'typical' UK range also had evidence of DU in the soil in 2005. In addition, there was evidence of depletion in the upper horizon of a sample with otherwise low total uranium activity (at K11).

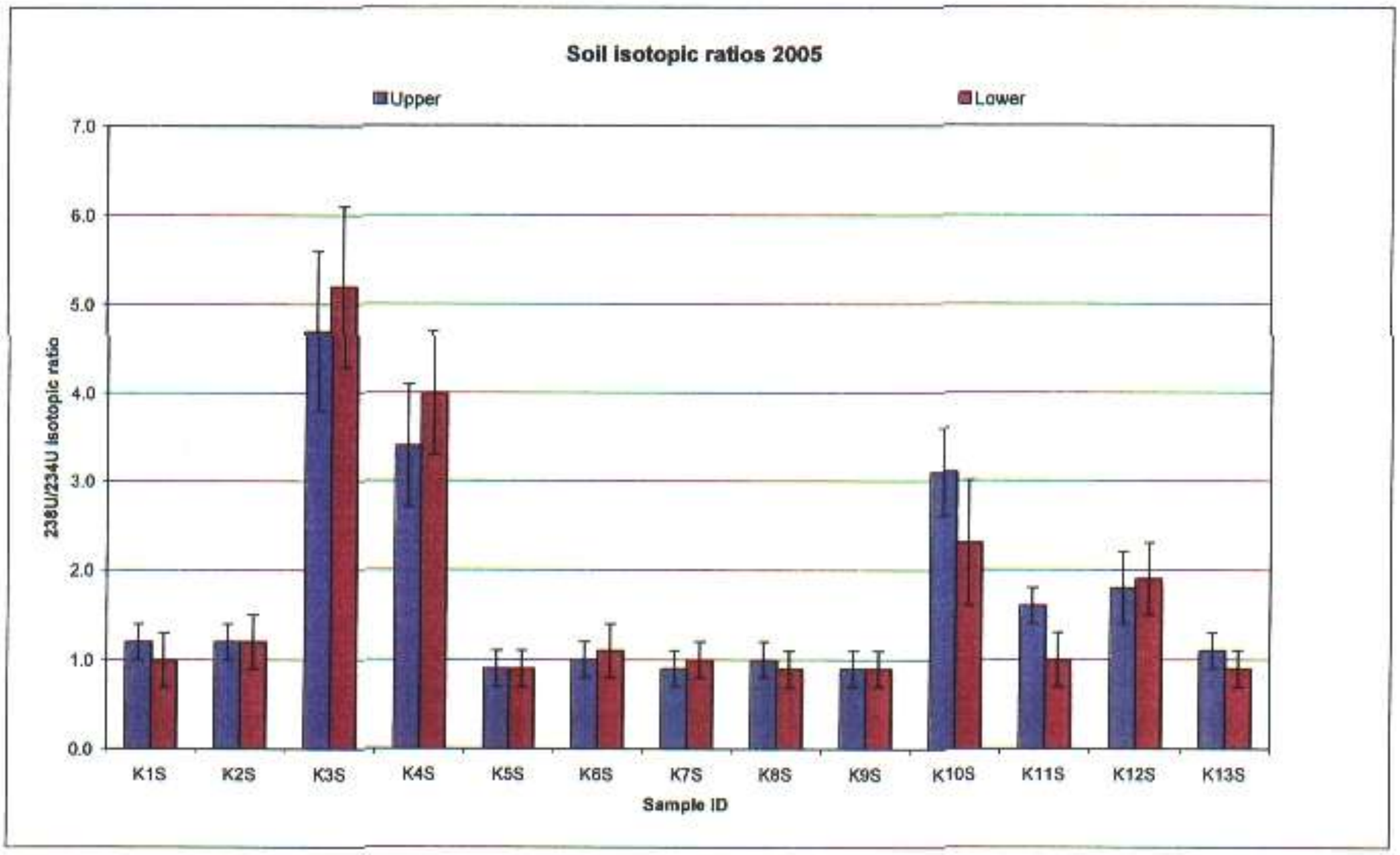

Figure 4: The isotopic ratios of the soil samples, 2005

9.2 Isotopic ratios in grass

A summary of the isotopic ratios for the grass samples collected during summer 2005 is plotted in Figure 5. The individual ratios ranged from 0.4 ± 0.2 and 4.2 ± 1.7.

In 2005, grass sample $^{238}U/^{234}U$ isotopic ratios of value greater than 1 (within the analytical limits of uncertainty) were found at Raeberry Bunker (K2), Raeberry Gun (K3), India Target (K4) and Doon Hill Gun (K12).

Only Raeberry Gun (K3) and India Target (K4) were identified in Sections 8.4 as having total uranium concentrations in excess of twice the background values and/or in excess of the 'typical' UK range, also had evidence of DU in the grass in 2005. In addition, there was evidence of depletion in one grass sample with an otherwise low total uranium activity. These results are not unexpected, as similar results have been measured at these locations previously. The sampling and analysis programme detects positive soil and grass samples from these locations at intervals, regardless of the amounts and the timings of the DU firings. The sites, all of which lie within fenced areas, are subject to restricted access. It is therefore unlikely that either public or staff would sustain exposure as a result of the uranium concentrations at these sites.

- Raeberry Bunker (K2);
- Raeberry Gun (K3);
- India Target (K4).

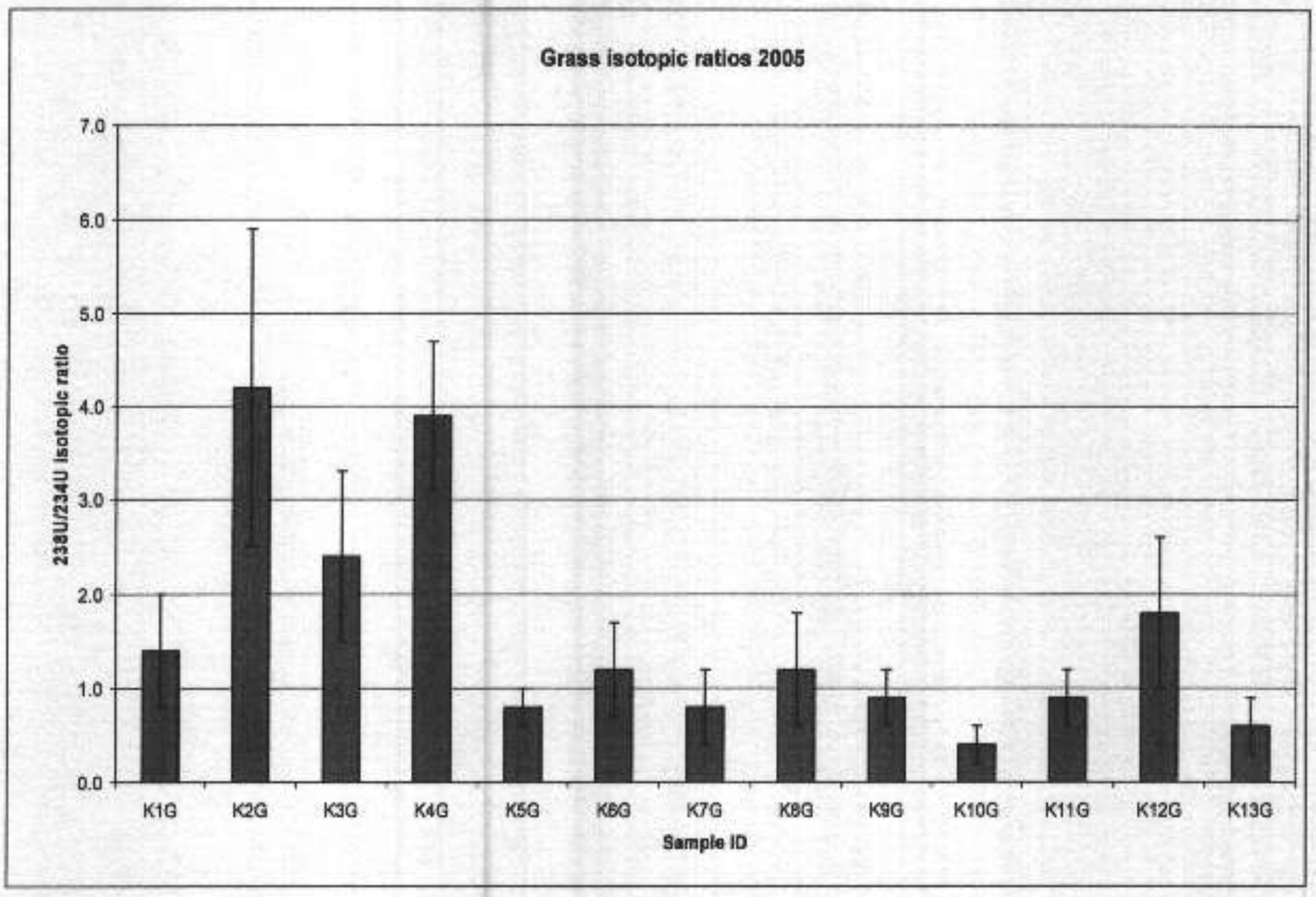

Figure 5: The isotopic ratios in grass samples, 2005

10 Evaluation of potential exposure pathways.

The contamination of the terrestrial environment with DU results in five potential exposure pathways for humans. These are:

- external radiation exposure from contaminated vegetation and soil or from DU fragments;
- inhalation of DU contamination released into the air or re-suspended from vegetation, soil or sediment;
- ingestion of crops or animal products from DU contaminated pasture or soil;
- ingestion of DU contaminated water from streams;
- Ingestion of contaminated soil.

10.1 External radiation exposure

Gamma dose rate levels on the range are essentially indistinguishable from natural background levels. This demonstrates that there is no risk from external radiation exposure related to DU at KTA.

10.2 Inhalation of re-suspended DU.

DU that has been deposited on soil and vegetation may be re-suspended into the air and subsequently inhaled. As contamination levels in grass at KTA are low in comparison to the GDL of 20 Bq/g for dry sea-washed pasture [6], and the small and widely separated areas of contamination are within fenced areas, any possible committed effective dose to a member of the public walking over the range is insignificant. This is supported by the following additional considerations.

In order to estimate the inhalation dose that may be accrued, first the amount of uranium that may be inhaled during a specific inhalation exposure scenario is calculated. This is derived from the total grass activity per surface area[1]. The highest total uranium concentration measured in a sample of grass during 2005 was 9.4 ± 1.1 mBq total uranium per gram of dry grass. This was measured in a grass sample from the India Target area. The mass of the composite grass sample from the India target, which was collected in an area of 1 m^2 surface, was 486.7 g when dried. The total uranium for this area of grass was therefore 4,575 mBq.

The critical group for that exposure must be identified: India target is a location with controlled access, and therefore not likely to be visited by a member of the public. However, the location is visited by range staff on a few occasions each year, during which the boundary fence is checked, and faulty parts replaced if necessary. There is the potential for a member of staff to inhale some dust whilst walking through the grass or working at the site.

Finally, the potential inhalation dose for this event is calculated below, using the activity per unit area and the details of the exposure scenario of the critical group, and a number of assumptions. The calculation depends on the Re-suspension Factor (RF) used. This can vary from 10^{-3} to 10^{-6} for scenarios concerned with the natural weathering of soil, depending on the use of the land and the radioactivity. A very pessimistic RF of 1 (i.e. all adhered DU is re-suspended) is used for a scenario where an adult occupies the land for 8 hours per year [22]. It is also assumed that all of the uranium is in a respirable form and that the re-suspended DU fills a one cubic metre volume of air, which this adult is breathing at a rate of 1.5 m^3/h [23] (light work). Even using these unrealistically pessimistic values as the basis for assessment, the dose received from inhalation would be less than about 40 microsievert per year, based on standard data for radionuclide intake and an adult dose conversion factor appropriate to 'medium' rate absorption in the lungs [24].

10.3 Ingestion of DU contaminated foodstuffs

No crops intended for human consumption are grown on the range [1], so the potential exposure route involving the ingestion of contaminated crops needs not be considered.

As limited numbers of cattle and sheep graze on the range, consideration must be given to the exposure pathway of ingestion of animal products derived from contaminated soil

[1] Grass coverage is extensive at the location and the amount of soil dust that may be re-suspended from the bare soil is thought to be minimal. Hence re-suspension from grass is the only scenario considered here.

or pasture. Because contamination levels are low in relation to the GDL's and because the areas of contamination are relatively small and widely separated, the maximum potential dose to any person ingesting beef, mutton or milk derived from range animals is assessed as insignificant.

Wild rabbit, pheasants and deer feed and graze on the range, may be caught and eaten, resulting in a radiological exposure to DU. The sampling of faeces has been used as a means of monitoring potential exposures by this route and the finding of this survey are consistent with those of previous years in which it was concluded that any potential exposures would be insignificant. However additional and more direct evidence of the absence of any effect is now available through the analysis of the deer kidneys in which it was shown that even total uranium concentrations were well below the applicable GDL of 1 Bq per gram of fresh offal. [6]

10.4 Ingestion of DU contaminated water from streams

The surface water samples collected in this survey contained no detectable DU contamination. However the British Geological Survey (BGS) announced in March 2006 that trace levels of DU had been detected in some surface water samples collected at KTA as part of the MOD DU research programme. As discussed above, this is not unexpected, as mass spectrometry analysis was used in the BGS research work and this has a lower limit of detection than the techniques used in most routine monitoring programmes. The DU was found in three samples from the Dunrod Burn downstream of the Balig Gun site [25]. In two of the samples, 1 – 2% of the uranium was depleted and the third sample had an uranium content that was 20% depleted.

The findings of the BGS work are of academic interest only, and not of health significance. In all cases the total uranium concentration was towards the lower end of what is found naturally and about ten times less than the WHO lowest recommendation for uranium levels in drinking water (See Section 5). So the contribution from the DU was negligible. Furthermore, even this assessment is unrealistically pessimistic as the burn is not a drinking water source and regular consumption by a single individual or group is not plausible. It is concluded that any radiation doses from DU contamination of surface water are therefore insignificant.

10.5 Radiation exposure to critical group

Using local knowledge of the Range, it is considered that two types of people may constitute critical groups for DU released into the KTA terrestrial environment.

Workers employed to inspect and maintain the boundary fence on the firing ranges are likely to form a critical group. This group of people is likely to inhale more re-suspended DU contamination from vegetation than any other group. Their potential dose is calculated in section 10.2, using extremely pessimistic assumptions, and is considered to be minor, at 40 microsievert per year. This is a 1.4 % of the average yearly dose likely to be received by a member of the UK public, which is estimated at 2.8 mSv per year.

Local inhabitants that have access to venison or meat from the wild animals that roam on the range may constitute the other critical group. The results of this year's survey are consistent with those of other years, and additional supporting evidence for the lack of any health effect has been provided by the analysis of the kidneys of two deer.

11 Conclusions

All grass, water or animal/ vegetal indicators contained total uranium significantly below the DUFERC investigation level (set at 10% of the level at which control would be required under the Radioactive Substances Act 1993).

Five sites (Raeberry Gun – K3, India Target – K4, Echo Target – K10, Waypoint Doonhill/Echo target – K11 and Doon Hill Gun – K12) contained total soil uranium concentrations above those expected for typical UK soils, and isotopic analysis of the soils demonstrated that these five sites had detectable DU contamination.

Most grass samples contained total uranium concentrations within the typical range expected for UK grasses, with the exception of one sample from the India target (K4) which had an activity more than twice this. Isotopic analysis indicated that grass samples from three locations (Raeberry Bunker – K2, Raeberry Gun – K3, India Target – K4) contained uranium with some degree of depletion.

These findings are not unexpected. The locations lie in isolated areas that have been identified in gamma surface surveys and recorded as having low levels DU contamination. Similar results have been measured at these locations previously, regardless of the amounts and timings of DU firings at the range.

Doses to the critical groups (i.e. inspection and maintenance teams, and persons ingesting contaminated meat from wild animals from the range), members of the public and site workers, due to DU contamination on the KTA, are assessed to be negligible compared to natural background.

12 Recommendations

The monitoring strategy for KTA is kept constantly under review, to ensure it is consistent with the most up to date scientific findings and practices, as well as changing activities at KTA. The most recent development has been the sampling of wild animal offal, and the usefulness of collecting offal from culled deer has been noted earlier. It is recommended that the sampling of this and similar samples from other animals should continue to be integrated into the monitoring protocol for KTA.

As demonstrated in Figure 1, the most significant change in the work activities at Kirkcudbright has been the marked decrease in the amount and frequency of DU firing at the range in recent years. It is therefore recommended that there should be less focus on the detection of any possible long-term build-up of surface or near surface soil contamination (as was done in the past, while firings were being carried out on a regular basis). Instead, the focus should now be on detecting any migration of the low level

contamination known to exist in a small number of discrete locations and of corrosion products from the small number of penetrators which malfunctioned and have not been recovered. It is therefore recommended that some of the soil sampling should be replaced by the sampling of stream sediments (as well as water). The finding of trace quantities of DU in Dunrod Burn (Para 10.4) is considered to provide support for this. It is intended that the existing sampling programme will continue for a further year and that additional sediment samples will be collected for comparison purposes. It is proposed that the future sampling strategy should then be re-evaluated in conjunction with the local Council and other authorities with statutory responsibilities for environmental protection.

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Sample station number	Sample type and number of samples			
	Soil	Grass	Animal indicators[1]	Environmental dose rates
1	1	1	1	✓
2	1	1		✓
3	1	1		✓
4	1	1	1	✓
5	1	1		✓
6	1	1	1	✓
7	1	1	1	✓
8	1	1	1	✓
9	1	1	1	✓
10	1	1	1	✓
11	1	1	1	✓
12	1	1		✓
13	1	1	1	✓
Chapel Hill	×	×	1	×
Balmae	×	×	1	×

Table 2 - Summary of samples collected, 2005
Note: × sample not collected

Sample descriptor	Fresh weight (g)	Dry weight (g)	Ashed weight (g)	Measured activity of dry sample (mBq/g)												$^{238}U/^{234}U$ ratio		
				^{238}U			^{235}U			^{234}U			Total U					
K1/sample[2]	87.2	21.4	2.3	0.6	±	0.2		<	0.1	0.5	±	0.2	1.2	±	0.2	1.2	±	0.5
K4/Rabbit	46.5	14.3	2.0	0.6	±	0.2		<	0.2	0.7	±	0.2	1.2	±	0.3	0.9	±	0.4
K6/Cow	201.4	67.6	3.3	0.2	±	0.1		<	0.1	0.2	±	0.1	0.4	±	0.1	1.4	±	0.6
K7/Cow	133.1	23.3	3.3	3.8	±	0.6	0.2	±	0.1	3.8	±	0.6	7.7	±	0.9	1.0	±	0.2
K8/Cow	133.4	13.8	1.8	0.5	±	0.2		<	0.1	0.3	±	0.1	0.8	±	0.2	1.5	±	0.7
K9/Cow	145.1	21.0	3.0	0.5	±	0.2		<	0.2	0.6	±	0.2	1.1	±	0.3	0.7	±	0.4
K10/Deer	47.7	6.8	0.6	0.7	±	0.2		<	0.2	0.7	±	0.2	1.4	±	0.1	1.0	±	0.4
K11/Cow	218.7	27.0	3.6	0.3	±	0.1		<	0.1	0.3	±	0.1	0.7	±	0.2	1.0	±	0.6
K13/Cow	204.5	42.9	3.3	0.2	±	0.1		<	0.1	0.2	±	0.1	0.4	±	0.1	0.8	±	0.5

Table 3a - Biological indicators, faeces, total uranium and isotopic ratio results – November 2005

Note: Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq/kg has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula[3] at 95%. The total activity is calculated from the sum of the actual activities for each isotope, regardless of the LOD quoted for that isotope, hence in Table 3a, where activities are reported as less than LOD for any of the uranium isotopes, the total uranium value may not be equal to the sum of the individual isotopic values.

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[1] Animal indicators samples include faecal samples and offal.
[2] Faecal sample of undetermined origin.
[3] Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000).

Sample descriptor	Fresh weight (g)	Dry weight (g)	Ashed weight (g)	Measured activity of dry sample (mBq/g)														$^{238}U/^{234}U$ ratio		
				^{238}U			^{235}U			^{234}U			Total U							
KD1	76.9	25.5	0.8		<	0.1		<	0.1		<	0.1	0.0	±	0.0		N/A	
KD2	71.2	24.4	0.9		<	0.1		<	0.1		<	0.1	0.0	±	0.0		N/A	

Table 3b - Biological indicators, deer kidneys, total uranium and isotopic ratio results – January 2006

Note: Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq/kg has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula[1] at 95%. The total activity is calculated from the sum of the actual activities for each isotope, regardless of the LOD quoted for that isotope, hence in Table 3b, where activities are reported as less than LOD for any of the uranium isotopes, the total uranium value may not be equal to the sum of the individual isotopic values. Where the isotopic activities are below the LOD for more than one isotope, the total activity and the isotopic ratios could not be calculated and are reported as N/A.

Sample descriptor	Location	Measured activity of dry sample (mBq/l)												$^{238}U/^{234}U$ ratio		
		^{238}U			^{235}U			^{234}U			Total U					
WAT/001	Abbey Burn		<	4.2		<	4.2		<	4.2	5.1	±	2.7		N/A	
WAT/002	Balmae Burn		<	3.5		<	3.5		<	3.5	4.6	±	2.4		N/A	
WAT/003	Quartercake Burn		<	3.6		<	3.6		<	3.6	1.9	±	1.5		N/A	
WAT/004	Netherlaw Burn		<	3.4		<	3.4		<	3.4	1.8	±	1.4		N/A	
WAT/005	Dunford Burn		<	3.5		<	3.5		<	3.5	1.9	±	1.5		N/A	

Table 4 - Water samples, total uranium and isotopic ratio results – November 2005

Note:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq/kg has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula[3] at 95%. The total activity is calculated from the sum of the actual activities for each isotope, regardless of the LOD quoted for that isotope, hence in Table 4, where activities are reported as less than LOD for any of the uranium isotopes, the total uranium value may not be equal to the sum of the individual isotopic values. Where the isotopic activities are below the LOD for more than one isotope, the total activity and the isotopic ratios could not be calculated and are reported as N/A.

[1] Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)

Sample descriptor	Measured activity of dry sample (mBq/g)												$^{238}U/^{234}U$ ratio		
	^{238}U			^{235}U			^{234}U			Total					
K1/S/U	17.4	±	2.5	0.9	±	0.3	14.1	±	2.1	32.4	±	3.3	1.2	±	0.3
K1/S/L	16.9	±	2.6	0.7	±	0.3	16.2	±	2.5	33.7	±	3.6	1.0	±	0.2
K2/S/U	22.7	±	3.5		<	0.5	19.5	±	3.1	42.7	±	4.7	1.2	±	0.3
K2/S/L	23.5	±	3.3	0.8	±	0.4	20.0	±	2.9	44.3	±	4.4	1.2	±	0.2
K3/S/U	215.8	±	26.5	3.2	±	0.8	45.6	±	6.0	264.6	±	27.2	4.7	±	0.9
K3/S/L	213.3	±	26.0	3.5	±	0.8	41.2	±	5.4	258.0	±	26.6	5.2	±	0.9
K4/S/U	65.9	±	8.6	1.7	±	0.5	19.6	±	2.9	87.3	±	9.1	3.4	±	0.7
K4/S/L	136.7	±	16.9	2.7	±	0.7	34.1	±	4.7	173.5	±	17.6	4.0	±	0.7
K5/S/U	17.7	±	2.6	0.5	±	0.3	19.9	±	2.9	38.1	±	3.9	0.9	±	0.2
K5/S/L	16.9	±	2.6	0.9	±	0.4	18.4	±	2.7	36.1	±	3.8	0.9	±	0.2
K6/S/U	13.1	±	2.3		<	0.6	12.5	±	2.3	26.0	±	3.3	1.0	±	0.3
K6/S/L	18.0	±	2.9	0.8	±	0.4	16.7	±	2.7	35.5	±	4.0	1.1	±	0.2
K7/S/U	15.4	±	2.3	0.7	±	0.3	17.3	±	2.6	33.3	±	3.5	0.9	±	0.2
K7/S/L	16.3	±	2.4	0.7	±	0.3	16.9	±	2.5	33.9	±	3.5	1.0	±	0.2
K8/S/U	51.5	±	6.8	2.1	±	0.6	51.8	±	6.9	105.4	±	9.7	1.0	±	0.2
K8/S/L	17.0	±	2.5		<	0.5	18.2	±	2.7	35.6	±	3.7	0.9	±	0.2
K9/S/U	17.3	±	2.8		<	0.6	19.3	±	3.1	37.2	±	4.2	0.9	±	0.2
K9/S/L	16.7	±	2.7		<	0.7	18.5	±	3.0	35.8	±	4.0	0.9	±	0.2
K10/S/U	54.3	±	7.8	1.4	±	0.5	17.8	±	2.9	73.5	±	8.3	3.1	±	0.7
K10/S/L	38.6	±	5.3	0.7	±	0.3	16.7	±	2.6	56.5	±	5.9	2.3	±	0.5
K11/S/U	28.2	±	4.2	1.2	±	0.5	17.6	±	2.8	47.0	±	5.1	1.6	±	0.3
K11/S/L	19.1	±	3.0	0.6	±	0.3	20.1	±	3.1	39.7	±	4.3	1.0	±	0.2
K12/S/U	36.2	±	5.3	1.1	±	0.4	20.4	±	3.2	57.6	±	6.3	1.8	±	0.4
K12/S/L	31.4	±	4.5	0.8	±	0.4	16.9	±	2.7	49.1	±	5.3	1.9	±	0.4
K13/S/U	16.1	±	2.6		<	0.6	15.0	±	2.4	31.4	±	3.5	1.1	±	0.2
K13/S/L	1.8	±	1.9		<	0.6	13.1	±	2.1	25.3	±	2.8	0.9	±	0.2

Table 5 - Soil samples, total uranium and isotopic ratio results – November 2005

Note:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq/kg has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula[1] at 95%. The total activity is calculated from the sum of the actual activities for each isotope, regardless of the LOD quoted for that isotope, hence in Table 5, where activities are reported as less than LOD for any of the uranium isotopes, the total uranium value may not be equal to the sum of the individual isotopic values

[1] Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)

Sample descriptor	Fresh weight (g)	Dry weight (g)	Ashed weight (g)	Measured activity of dry sample (mBq/g)												$^{238}U/^{234}U$ ratio		
				^{238}U			^{235}U			^{234}U			Total U					
K1/G	961.6	502.5	21.5	0.2	±	0.1		<	0.0	0.2	±	0.1	0.4	±	0.1	1.4	±	0.6
K2/G	674.0	409.9	17.4	0.5	±	0.1		<	0.0	0.1	±	0.0	0.6	±	0.1	4.2	±	1.7
K3/G	881.5	454.8	26.3	0.5	±	0.1		<	0.0	0.2	±	0.1	0.7	±	0.1	2.4	±	0.9
K4/G	1241.3	486.7	40.7	7.4	±	1.0	0.2	±	0.1	1.9	±	0.3	9.4	±	1.1	3.9	±	0.8
K5/G	1681.8	356.0	75.1	1.3	±	0.3	0.1	±	0.1	1.6	±	0.3	3.0	±	0.4	0.8	±	0.2
K6/G	1375.9	268.9	48.5	0.8	±	0.2		<	0.1	0.6	±	0.2	1.5	±	0.3	1.2	±	0.5
K7/G	1238.7	317.0	29.8	0.2	±	0.1		<	0.1	0.3	±	0.1	0.5	±	0.1	0.8	±	0.4
K8/G	1811.8	379.4	33.9	0.3	±	0.1		<	0.1	0.3	±	0.1	0.6	±	0.2	1.2	±	0.6
K9/G	1107.4	382.0	46.6	1.0	±	0.2		<	0.1	1.1	±	0.3	1.1	±	0.3	0.9	±	0.3
K10/G	1615.6	346.2	17.8	0.1	±	0.0		<	0.0	0.2	±	0.1	0.3	±	0.1	0.4	±	0.2
K11/G	1322.8	432.3	22.4	0.3	±	0.1		<	0.0	0.3	±	0.1	0.5	±	0.1	0.9	±	0.3
K12/G	1334.9	567.9	34.2	0.3	±	0.1		<	0.1	0.2	±	0.1	0.5	±	0.1	1.8	±	0.8
K13/G	1022.3	350.1	22.5	0.1	±	0.0		<	0.1	0.2	±	0.1	0.3	±	0.1	0.6	±	0.3

Table 6 - Grass samples, total uranium and isotopic ratio results – November 2005

Notes:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq/kg has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula[1] at 95%. The total activity is calculated from the sum of the actual activities for each isotope, regardless of the LOD quoted for that isotope, hence in Table 6, where activities are reported as less than LOD for any of the uranium isotopes, the total uranium value may not be equal to the sum of the individual isotopic values. Where the isotopic activities are below the LOD for more than one isotope, the total activity and the isotopic ratios could not be calculated and are reported as N.

[1] Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)

Station number	Location	Average dose rate (nGy/h)
1	Raeberry Target	85
2	Raeberry Bunker	102
3	Raeberry Gun	100
4	India Target	85
5	Balig Gun/Target waypoint	98
6	Balig Gun	110
7	Zulu Gantry	100
8	Mullock Farm	103
9	Silver Hill (Low) Gun	97
10	Echo Target (Doon Hill)	103
11	Doonhill/Target waypoint	85
12	Doon Hill Gun	107
13	Gypsy Point	93

Table 7 - Dose rates measurements at the terrestrial sampling locations in November 2005

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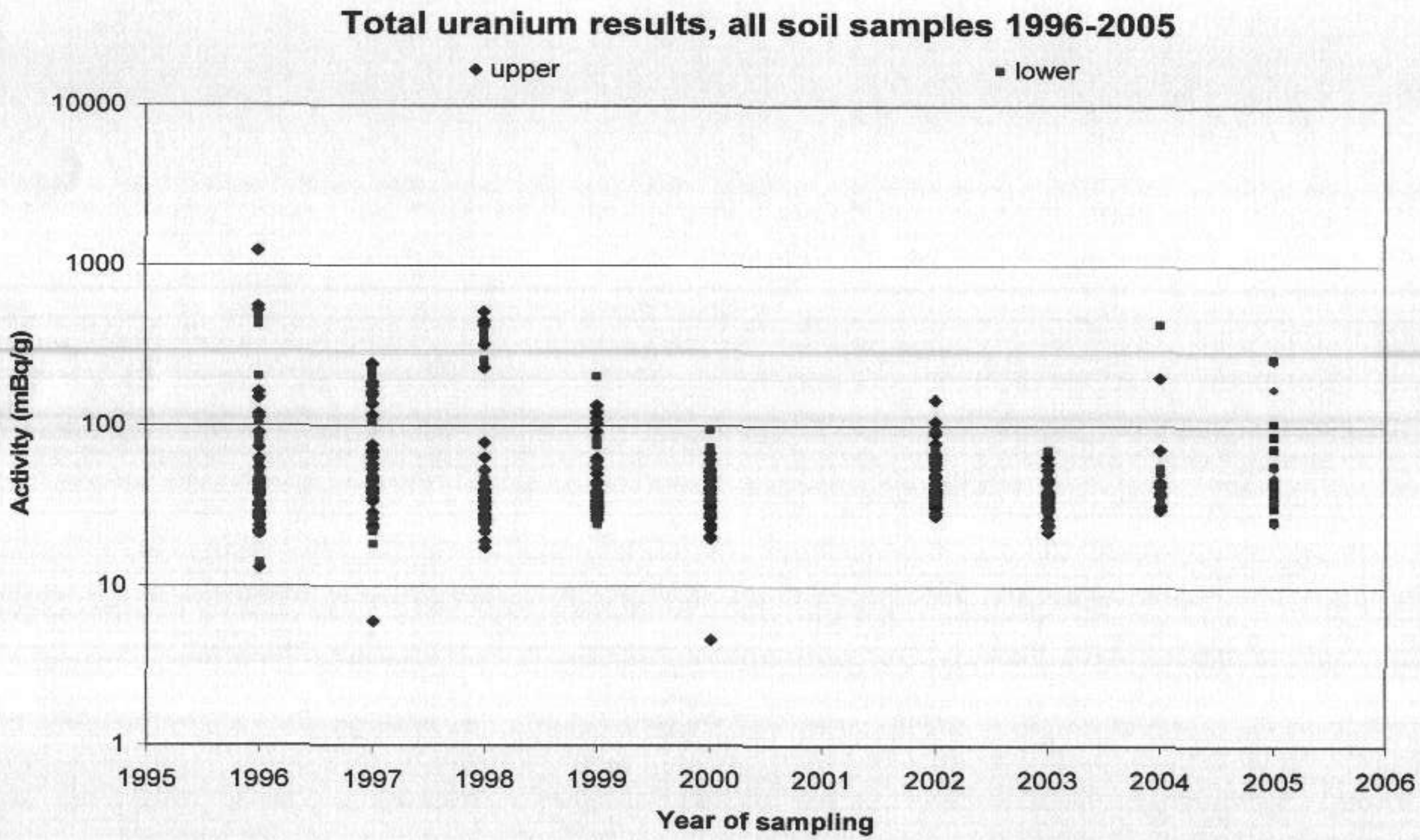
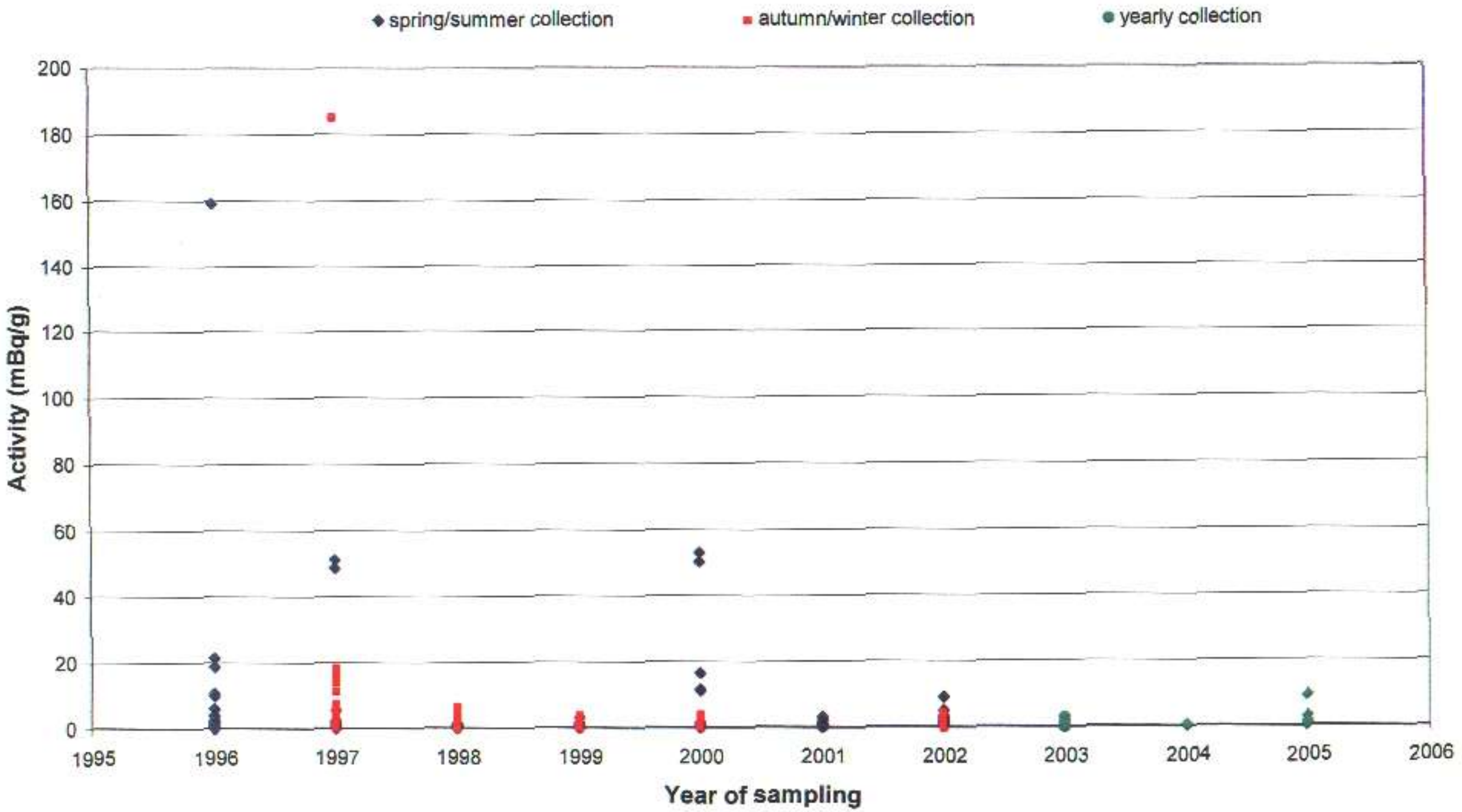
ANNEX A Historical data

To allow year on year comparison, data from the environmental monitoring surveys from 1995 to date is presented in the following tables.


Total uranium results, all soil samples 1996-2005
◆ upper
▪ lower
10000
1000
100
10
1
Activity (mBq/g)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year of sampling

Total uranium results, all grass samples, 1996-2005



Total uranium results for all terrestrial biological and vegetal indicator samples (mBq/g of dry weight), and water samples (in mBq/l) reported for 1996-2005.

Sample Type	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Cow	2.1-5.6 **(4)**[a] *(0.8-1.3)*	0.8-1.3 **(2)**[a] *(0.8-1.0)*	1.4 ± 0.3 *(0.9 ± 0.3)*	0.8 ± 0.2 *(0.7 ± 0.4)*	31.5 ± 2.7 *(1.1 ± 0.2)*	There was no sampling in 2001	0.2 ± 0.1 *(0.8 ± 0.5)*	1.6 ± 0.3 *(0.5 ± 0.2)*	0.5-1.5 **(2)** *(0.6-0.8)*	0.4-7.7 **(5)**[a, e, f, h, i] *(0.7-1.5)*
Sheep	<0.3	1.1 ± 0.3[a] *(1.1 ± 0.6)*	3.1 ± 0.6[g] *(0.6 ± 0.2)*	0.7-7.8 **(2)** *(0.9-1.7)*	3.9 ± 0.5 *(1.3 ± 0.3)*		5.2 ± 0.8[e] *(0.7 ± 0.2)*	0.9 ± 0.3 *(1.5 ± 0.9)*	0.5 ± 0.1[c] *(1.5 ± 0.8)*	x
Fox	x	x	11.4 ± 1.5 *(0.7 ± 0.2)*	6.0 ± 0.5 *(0.8 ± 0.2)*	46.7 ± 6.3 *(6.7 ± 1.9)*		8.7 ± 1.8[c] *(0.6 ± 0.3)*	5.2 ± 1.1 *(2.2 ± 1.0)*	x	x
Deer	x	2.1 ± 0.5[a] *(N)*	7.8 ± 0.8[c] *(2.7 ± 0.6*	0.4-0.6 **(2)** *(1.7 ± 1.5)* **(1)** *(N)* **(1)**	x		1.0 ± 0.3[c] *(0.7 ± 0.4)*	0.5 ± 0.1 *(0.7 ± 0.3)*	x	1.4 ± 0.1[b] *(1.0 ± 0.4)*
Rabbit /Hare	x	x	0.3 ± 0.1[c] *(0.9 ± 0.8)*	x	3.9 ± 0.5 *(2.0 ± 0.5)*		42.6 ± 4.7[b] *(7.2 ± 1.4)*	0.5 ± 0.1 *(1.0 ± 0.5)*	0.5 ± 0.1[b] *(1.5 ± 0.8)*	1.2 ± 0.3[d] *(0.9 ± 0.4)*
Mushroom	x	x	x	x	x		x	0.5 ± 0.4 *(N)*	x	x
Berries[oo]	x	x	x	x	x		x	x	x	x
Water samples	4.4-8.1 **(2)** *(1.0-1.1)*	<9.4 **(3)** *(N)*	3.8-16.6 **(3)** *(1.1-1.4)*	9.0-14.6 **(2)** *(N)*	12.3-13.0 **(3)** *(N)*		2.7-7.1 **(2)** *(N)*	1.7-4.7 **(5)** *(N)*	<11 **(1)** N/D **(4)** *(N)*	1.8-5.1 **(5)** *(N)*

Notes: × denotes that no sample of this type was collected.

° blackberries

For simplicity, results for both the total uranium activity and the isotopic $^{238}U/^{234}U$ ratio are reported as follows:

- The activity is reported first, and followed by the ratio in italics in bracket.
- N not applicable. Where the isotopic activities are below the Limit of Detection (LOD) for more than one isotope, the isotopic ratios could not be calculated and are reported as N.
- N/D not detectable. For water samples, where the isotopic activity is below the LOD for more than one isotope for a sample, the activity is reported as N/D. This was true of four water samples in 2004.
- When only one result is reported for a sample type, the result is reported together with its uncertainty. When there are more than one result for a sample type, the range (min – max) is reported. The analytical error for these results, which is not reported here, is typically below 20%. The number of samples is indicated in bold in brackets.
- The approximate location of sample (if known) is identified by a superscript letter in the table as follows: a - Mullock Farm (K8); b - Doon Hill 1/ Echo Target (K10); c - Raeberry Gun (K3); d - India Target (K4); e - Balig Gun (K6); f - Zulu Target (K7); g - location between Balig Gun and India Target (K5); h – Silver Hill (Low) Gun (K9); i – Doonhill/Target waypoint (K11). In years 1999, 2000 and 2003, the sampling location was not reported, and results in this table may include samples from the background location Gypsy point. For all other years, samples from Gypsy Point have been excluded from the table.

ANNEX B Issues to be considered when interpreting or comparing uranium data

There are a number of issues that may give rise to uncertainties, when interpreting or comparing uranium data. These include:

- analytical technique;
- statistical variation;
- spatial variability;
- temporal variability; and
- species variation (for plant and animal samples).

Analytical approaches

Soil sample results may be reported as either dry weight or wet weight depending on whether the masses of the samples were obtained prior to or after drying. This will have implications for comparison of results between the surveys at Kirkcudbright, which are reported as dry weight and other UK uranium in soil data, which may be reported as wet weight. Samples reported as dry weight will appear to have concentrations of uranium approximately 20% higher than those reported as wet weight (although this will depend on the moisture content).

For analysis techniques such as ICP-MS or alpha spectrometry samples uranium may be extracted into solution by either leaching the soil samples or totally dissolving them. Total dissolution will give rise to higher uranium results, because the analysis will include all uranium, including that which is contained within the mineral grains, whereas leached samples will only contain uranium that is either easily dissolved or is sorbed to the surfaces of mineral grains. Total sample analysis techniques such as gamma spectrometry will give results similar to those for total dissolution. Given the differences between the results for total analysis and leached analysis care should be taken when comparing sets of data to ensure that either the same approach has been used or that differences are appropriately discussed.

Uranium concentrations in plants may be affected by contamination of foliage or roots with dust or soil particles. Preparation of plants for analysis may or may not involve a washing stage. Hence, it is important to be aware of the preparation approaches that have been applied when comparing the results of different plant analyses.

Statistical variations

There will be minor variations between the true uranium content of a sample and that reported by an analytical technique. This variation is highlighted in the counting statistics for the technique. The statistical uncertainties of laboratory results are likely to be small in comparison with the true variation in activity between samples.

Spatial variations

DU contamination will not be uniformly distributed within a sampling area. Any DU firing malfunctions will probably result in small fragments distributed over an area. Within that area, sampling at some locations would indicate contamination, whereas at others the soil would appear to be clean. Hence, the repeat sampling and analysis of soils from within an area may give rise to a significant degree of variation.

In addition to DU contamination due to firing at the range, there may be variations in uranium concentrations due to local anthropogenic or natural discharges. For example, natural uranium concentrations may be enhanced by the local application of phosphate *based fertilise to agricultural land. Most of the phosphate fertilise applied to clay loam* soils in England in the last 100 years can be still be found retained in the top 23 cm layer of soils, with no increase at greater depths [B26]. Veins rich in uranium minerals occur naturally along the coast of the Solway Firth, such as uraninite found at Needle's Eye on the north coast of the estuary. These features are thought to be present on a more regional basis, although this has not been studied [B27, B28].

Temporal variations

There will be natural temporal variations in the uranium concentration and abundance of the various isotopes in the samples, for example due to seasonal variations in rainfall. Rainfall can impact on dust re-suspension and deposition on grass and on the dissolution and migration of surface uranium down the soil profile. Some concentrations may be slightly elevated at the time of sampling, whilst others may be slightly below expected background levels.

The activities of samples from any particular sampling site may vary from year to year. This may relate to temporal changes in uranium concentration, but will also be affected by spatial variation (see above).

Plant uptake of radionuclides is affected by the period in the plant growing cycle. This is also mirrored in the animal uptake of radionuclides within their life cycle.

Species variations

Plant uptake of radionuclides is affected by the soil characteristics (uranium concentration and speciation as well as other soil physico-chemical characteristics) and varies with plant species. In general leafy vegetables take up higher concentrations than fruit and grain crops. Uranium tends to be preferentially distributed in the leaves and stems than in the roots, fruits or seeds [B26].

Animal uptake of uranium is affected by their life habits, feeding patterns, physiology and the uranium concentration in their foodstuffs and the environment. Because it is clearly impractical to consider all species in a particular environment, the current approach in radiological dose assessments to non-human species is to advocate the use of reference organisms. For the terrestrial environment, animals that live both above and below ground have been selected (earthworms, mice and foxes), as well as animals that live strictly above ground (deer and cattle) [B29]. Although this environmental survey does not aim at compiling a dose assessment for non-human species, wherever possible, the faeces of some of these animals have been collected and analysed.

Annex B references

[B26] Mortvedt, JJ. Plant and Soil Relationships of Uranium and Thorium Decay Series radionuclides – A review, Journal of Environmental quality, 23, 643, (1992).

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[B29] Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA), EC 6th Framework Programme (Contract FI6R-CT-2003-508847, http:\\ www.erica-project.org.

ANNEX C Change in the $^{238}U/^{234}U$ activity ratio of a medium containing natural uranium with the addition of depleted uranium

Mass of DU added [1]	Soil activity [2] ($mBqkg^{-1}$)			Ratio of total activity natural uranium to total activity	$^{238}U/^{234}U$ activity ratio
	U-238	U-235	U-234		
0	$3.7 x10^4$	$1.7 x10^3$	$3.8 x10^4$	1.0	1.0
1	$7.4 x10^4$	$2.2 x10^3$	$4.3 x10^4$	1.6	1.7
2	$1.1 x10^5$	$2.7 x10^3$	$4.8 x10^4$	2.1	2.3
3	$1.5 x10^5$	$3.2 x10^3$	$5.3 x10^4$	2.6	2.8
4	$1.9 x10^5$	$3.7 x10^3$	$5.8 x10^4$	3.2	3.2
5	$2.2 x10^5$	$4.1 x10^3$	$6.3 x10^4$	3.8	3.6
6	$2.6 x10^5$	$4.6 x10^3$	$6.8 x10^4$	4.3	3.9
7	$3.0 x10^5$	$5.1 x10^3$	$7.2 x10^4$	4.9	4.1
8	$3.4 x10^5$	$5.6 x10^3$	$7.7 x10^4$	5.4	4.3
9	$3.7 x10^5$	$6.0 x10^3$	$8.2 x10^4$	6.0	4.5
10	$4.1 x10^5$	$6.5 x10^3$	$8.7 x10^4$	6.5	4.7
20	$7.8 x10^5$	$1.1 x10^4$	$1.4 x10^5$	12.0	5.8
60	$2.3 x10^6$	$3.1 x10^4$	$3.3 x10^5$	34.1	6.9
80	$3.0 x10^6$	$4.0 x10^4$	$4.3 x10^5$	45.1	7.1
100	$3.8 x10^6$	$5.0 x10^4$	$5.2 x10^5$	56.1	7.2
200	$7.5 x10^6$	$9.8 x10^4$	$1.0 x10^6$	111.0	7.4
600	$2.2 x10^7$	$2.9 x10^5$	$3.0 x10^6$	332.0	7.6
800	$3.0 x10^7$	$3..9 x10^5$	$3.9 x10^6$	442.0	7.6
1000	$3.73\ 10^7$	$4.8 x10^5$	$4.9 x10^6$	552.0	7.6

Table from Volume 2 - Appendices, WS Atkins Environmental Assessment on DU Firings

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1. The value represents the additional mass of depleted uranium added (all radionuclides) relative to the original mass of natural uranium present (3 mg U kg^{-1} soil).

2. Table assumes 3 mg U kg^{-1} of natural uranium present in soil in following proportion: ^{238}U (2.978 mg U kg^{-1}); ^{235}U (0.022 mg U kg^{-1}); ^{234}U (2e-04 mg U kg^{-1}), prior to addition of DU.

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11 June 2007	46	29

13. Abstract (A brief (approximately 150 words) factual summary of the report)

This report describes and interprets the results of the terrestrial environmental survey undertaken to monitor Depleted Uranium (DU) levels in the environment at KTA in 2005. Samples of animal faeces, offal, soil, grass, and water were collected on site as part of the environmental monitoring programme. Survey results show evidence of the presence of DU in 12 out of 55 environmental samples collected. However, the levels were below the investigation levels agreed with agencies with statutory responsibilities for environmental protection, and the samples were not radioactive within the meaning of the Radioactive Substances Act 1993. The positive samples were soils and grass, which came from 6 sampling locations, four of which lie within fenced off areas. These results are consistent with those obtained throughout the DU munitions testing programme. The finding of trace quantities of DU reported separately by the British Geological Survey is discussed. It is concluded that there is no evidence to indicate that members of the public or site employee are, or have ever been, exposed to a radiological hazard from the terrestrial environment as a result of test firing DU ammunition at the site.

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