Terrestrial Environmental Depleted Uranium Survey Report Kirkcudbright Training Area - 2007

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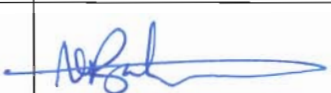
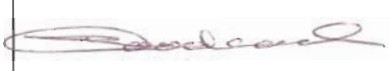
Chief Scientist	Adrian Baker		14/11/08
Project Manager	Nigel Woodcock		12/11/08
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Executive summary

Depleted uranium (DU) ammunition has been test fired at the Kirkcudbright Training Area (KTA) since 1982. 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 presents and interprets the results of the DU Terrestrial Environmental Survey undertaken at the KTA during 2007. The survey was undertaken to measure uranium levels in the terrestrial environment at the KTA and to identify the extent of any dispersion of DU resulting from operations at the site.

None of the samples were radioactive within the meaning of the Radioactive Substances Act 1993. All grass, sediment, water and animal indicators contained total uranium significantly below the Depleted Uranium Firing Environmental Review Committee (DUFERC) action level (set at 10% of the level at which control would be required under the Radioactive Substances Act 1993).

Survey results show evidence of the presence of very low levels of DU in four of the eighty-three grass, soil, water, sediment, animal offal and animal faeces samples that were collected in 2007. These samples consisted of three grass samples and one faeces sample, and originated from three sampling locations, two of which (K3 and K6) lie within fenced off areas. The third location (K5) is not fenced. However, the activity levels associated with these four samples are negligible, and of no health consequences.

Doses to the two critical groups (inspection and maintenance teams, and persons consuming game taken from the range) and members of the public and other site workers, due to DU contamination on the KTA, are assessed to be negligible compared to the local natural background.

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Table of contents

List of figures

List of tables

1 Introduction

This report presents and interprets the results of the Depleted Uranium (DU) Terrestrial Environmental Survey undertaken at the Kirkcudbright Training Area (KTA) during 2007. The survey was undertaken to measure uranium levels in the terrestrial environment at the KTA and to identify the extent of any dispersion of DU resulting from operations at the site.

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.

Due to changed work activities at KTA (with only one battery/target combination now available for use and greatly reduced proof firing of DU munitions) the MOD and the Scottish Environment Protection Agency (SEPA) jointly agreed in 2007 that there should be more emphasis on stream sediment sampling as opposed to soil sampling. This report reflects this agreement. The environmental monitoring programme now consists principally of the collection of grass, stream water, stream sediment and animal offal and 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 coming 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, towards India Target. There was no firing in 2004, 2005, 2006 or 2007.

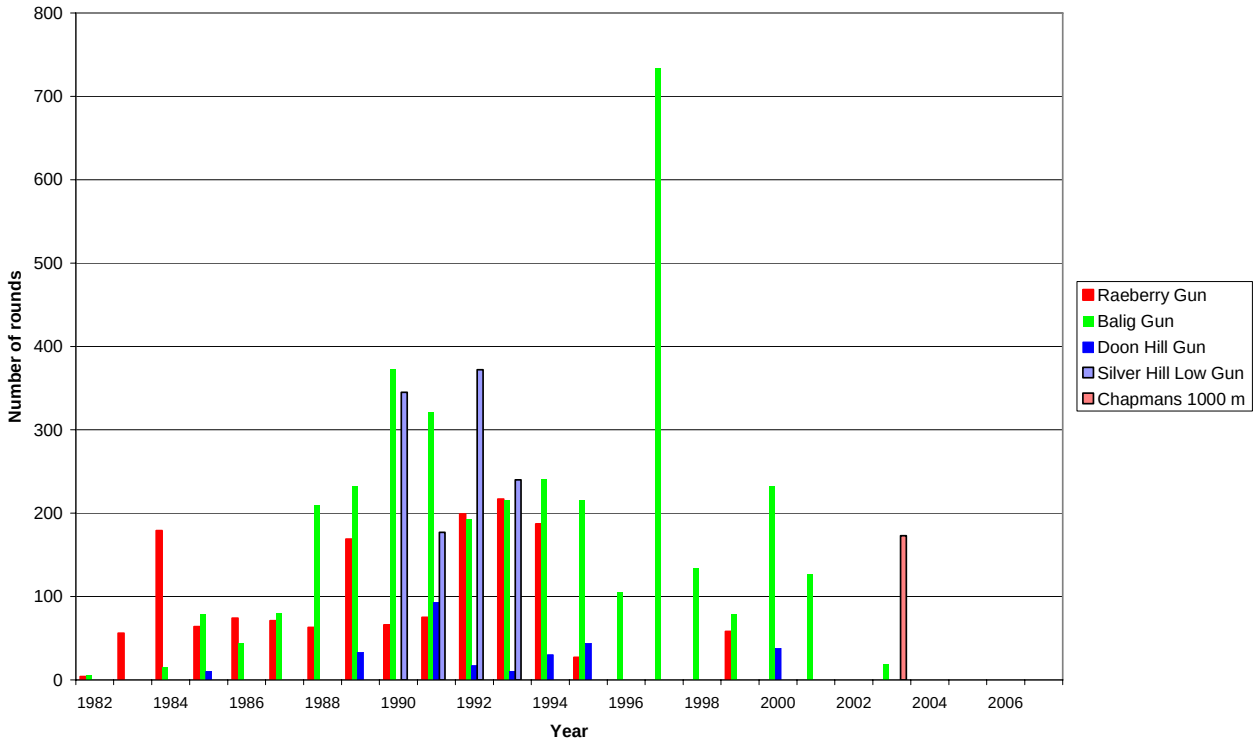

Figure 1: Number of DU projectiles fired from KTA, from 1982 to 2007.

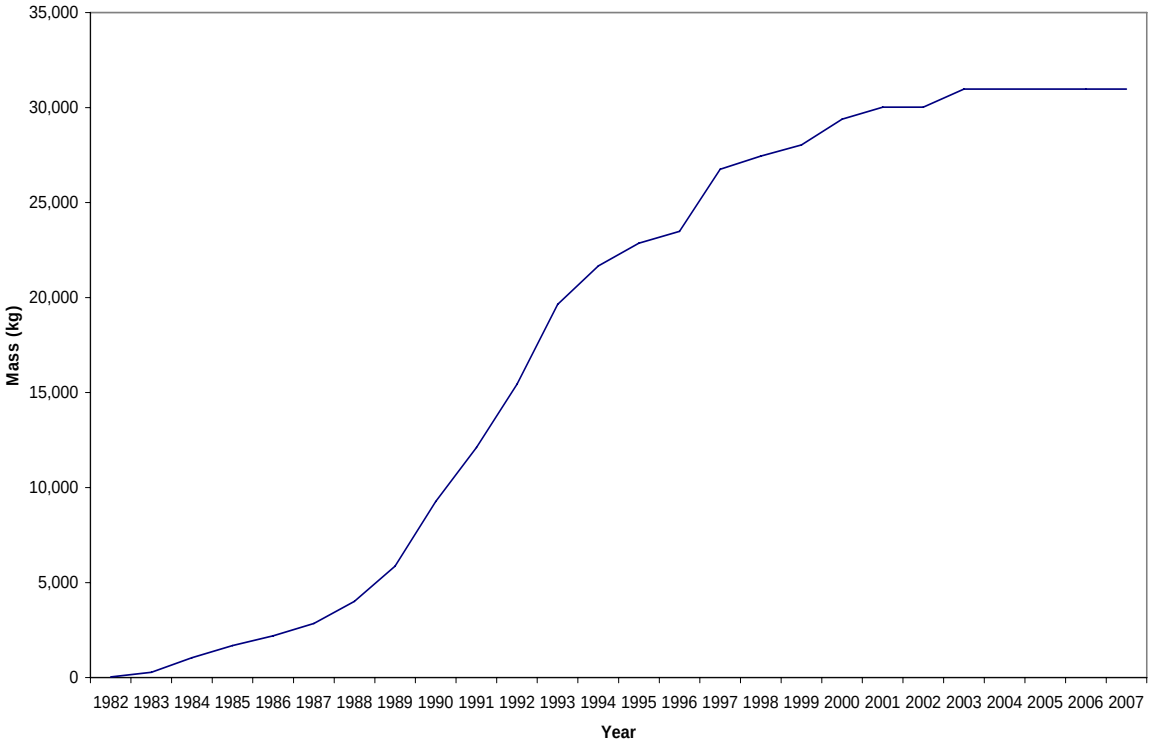

Figure 2: Approximate cumulative mass of DU projectiles fired from KTA, from 1982 to 2007.

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.

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 the majority of malfunctioning penetrators still entered the Solway Firth, a small proportion impacted on land and some fragmented on exiting the gun barrel or in the early stage of flight. The majority of fragments still entered the sea, but it is known that small quantities of particulate DU were deposited at a few discrete locations in the local terrestrial environment, when rounds had malfunctioned. Most of these locations 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 the granite chippings used 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 would 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 remainder 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 of uranium per gram of sample (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 (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 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 A.

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 B). 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[1]. Gamma Spectrometry measurements of environmental samples can also yield isotopic information, but the technique is not sensitive enough to reach the limits of detection

[1] 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 in environmental and biological samples.

required for environmental analysis unless relatively large quantities of uranium are present.

5 Investigation/action levels

The Depleted Uranium Firing Environmental Review Committee (DUFERC), on which the MOD is represented, has agreed investigation/action levels with regard to DU environmental monitoring results for soil samples[1]. 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 ^{238}U were last updated in 2000 by the National Radiological Protection Board, which is now part of the Health Protection Agency, and were referred to by the Royal Society in their studies of the potential health effects of using DU munitions [8]. 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, action levels are set to less than 10% of the level at which control would be required under RSA 93.

Table 1: Investigation /action levels, RSA 93 level for uranium and GDL for ^{238}U in soil.

	Limit	**Specific Activity (mBq/g dry weight)**
DUFERC	Investigation Level	300
DUFERC	Action Level	1,110
RSA 93	Level at which regulatory control is required.	11,100
NRPB (2000)	Generalised Derived Limit for ^{238}U in soil	20,000

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 10% level is commonly used as a "trigger" in occupational health monitoring.

6 Sample collection

In accordance with the 1996 Baseline Survey protocol [2], the 2007 survey grass samples were collected from sites where it was considered that DU was most likely to have been deposited during past range operations. In addition, in 2007, stream water and sediment samples were also collected from sites on the range where it was considered that DU was

[1] Soil in areas of contamination above DUFERC action level should be removed and disposed of in accordance with RSA93, and areas of contamination above DUFERC investigation level should be subjected to a walk over survey site to look for any obvious traces of DU.

potentially most likely to have been transported to, by water run-off and soil erosion. The reasons for these changes are described in more detail below.

In the 2005 terrestrial survey report for KTA [17], it was noted that the most significant change in the work activities at Kirkcudbright in recent years had been the marked decrease in the amount and frequency of DU firing. Because of this, the report proposed that initially, the existing survey protocol should be complemented by the monitoring of stream sediments, as implemented in the 2006 survey [9], with a view to possibly substituting some of the soil monitoring with stream sediment monitoring thereafter. It was also recommended that the future sampling strategy should be re-evaluated in conjunction with authorities with statutory responsibilities for environmental protection.

In September 2007, MOD and SEPA jointly agreed that grass sampling and animal indicator sampling should continue as before, but that soil sampling should cease at all locations except at the Gypsy Point background location and the only firing point, mid way point and target combination that will continue to be used for DU firings (Balig Gun to India Target). It was also agreed that, in future surveys, more stream sediment samples and water samples would be collected from fixed locations. The usefulness of collecting offal from culled deer was noted previously [17], and this is now an integral part of the KTA monitoring protocol.

Grass, soil, water, sediment and animal faeces samples were collected in October 2007, following the methodology described in the 1996 Baseline Survey report [2], with the exception that, as in years 2003-6, the numbers of soil samples collected at each sampling site were reduced to three from the six specified in the baseline report. Three deer kidneys were also obtained and analysed in 2007. Dose rates were measured at each site.

Further detail on sample collection methodologies are given below in Section 6.1 to 6.9. A list of the soil, grass and faeces samples collected is given in Table 2. A list of stream sediment and water samples collected is given in Table 3.

6.1 Soil and grass sampling locations

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. Grass samples were taken at each site, whereas soil samples were taken only on Balig gun-India target firing line. To provide background data for comparison purposes, an additional sampling site (for soil and grass) was chosen some distance away from the guns and targets, at Gypsy Point.

The Ordnance Survey of Great Britain grid references for the four soil and thirteen grass sampling sites are given below, and are shown on Figure 3.

Samples were collected at these co-ordinates.

1.	Raeberry Target	270449	543744
2.	Raeberry Bunker	270472	543836
3.	Raeberry Gun	270521	543980
4.	India Target	270631	543658

5.	Balig Gun/Target waypoint	270964	544498
6.	Balig Gun	271238	545452
7.	Zulu Gantry	271848	543548
8.	Mullock Farm	271188	544295
9.	Silver Hill (Low) Gun	270355	544851
10.	Echo Target (Doon Hill)	272291	543807
11.	Doonhill/Target waypoint	272096	545429
12.	Doon Hill Gun	271904	546947
13.	Gypsy Point	268676	543789

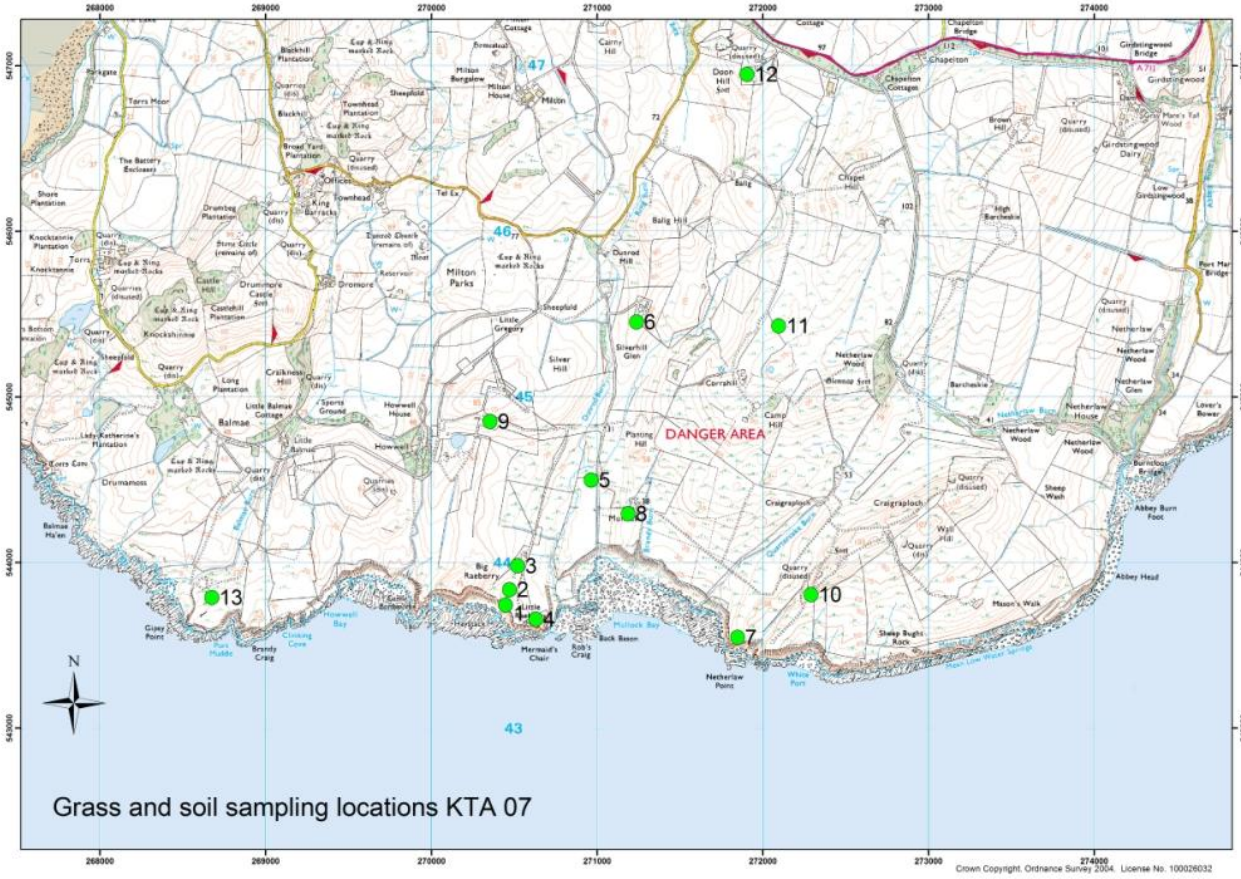

Figure 3: KTA soil and grass sampling locations, 2007 (Note: grass was sampled at all locations, soil was sampled at locations 4, 5, 6 and 13 only. Grid squares are 1 km).

6.2 Animal indicator sampling locations

Animal indicator samples were collected following the methodology described in the 1996 Baseline Survey report [2] as and when they were found during the survey. The Ordnance Survey of Great Britain references for the animal indicator samples are given below.

5	Balig Gun/India Target waypoint	270964	544498
6	Balig Gun	271238	545452
8	Mullock Farm	271188	544295

9	Silverhill Low Gun	270355	544851
11	Mid Point between 10 & 12	272096	545429
12	Doon Hill Gun	271904	546947
13	Gipsy Point	268676	543789

Figure 4: KTA animal indicators sampling locations, 2007.

6.3 Stream sediment and water sampling locations

Stream sediment was collected at fifteen locations from streams that collect run-off water from the soil surface for most of the range. Stream water samples were collected at six locations. The Ordnance Survey of Great Britain grid references for the fifteen stream sediment sampling sites are given below, and are shown on Figure 5 (top). The Ordnance Survey of Great Britain references for the six stream water sampling sites are also given below, and shown in Figure 5 (bottom).

Stream sediments sampling grid references:

S1.	Abbey and Netherlaw Burns	274199	544570
S2.	Netherlaw Burn	274166	544631
S3.	Netherlaw Burn	273438	544779
S4.	Quatercake Burn	272326	544363
S5.	Quatercake Burn	271804	543917
S6.	Brandy Burn	271264	544145

S7.	Dunrod and Overlaw Burns	270820	543732
S8.	Dunrod Burn	270958	544825
S9.	Dunrod Burn	271082	545571
S10.	Ring Burn	271152	545961
S11.	Overlaw Burn	271166	544847
S12.	Overlaw Burn	272120	546277
S13.	Overlaw Burn	272507	546920
S14.	Balmae Burn	269144	546443
S15.	Balmae Burn	268556	543890

Stream water sampling grid references:

W1.	Abbey Burn	274199	544570
W2.	Netherlaw Burn	274202	544594
W3.	Balmae Burn	268556	543890
W4.	Dunrod and Overlaw Burns	270820	543732
W5.	Quartercake Burn	271804	543917
W6.	Dunrod Burn	271082	545571

6.4 Grass collection methodology

Grass samples were obtained from three areas of approximate size $1m^2$ each, located within 5 m 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.

6.5 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 eight composite samples from 4 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.

6.6 Animal faeces collection methodology

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

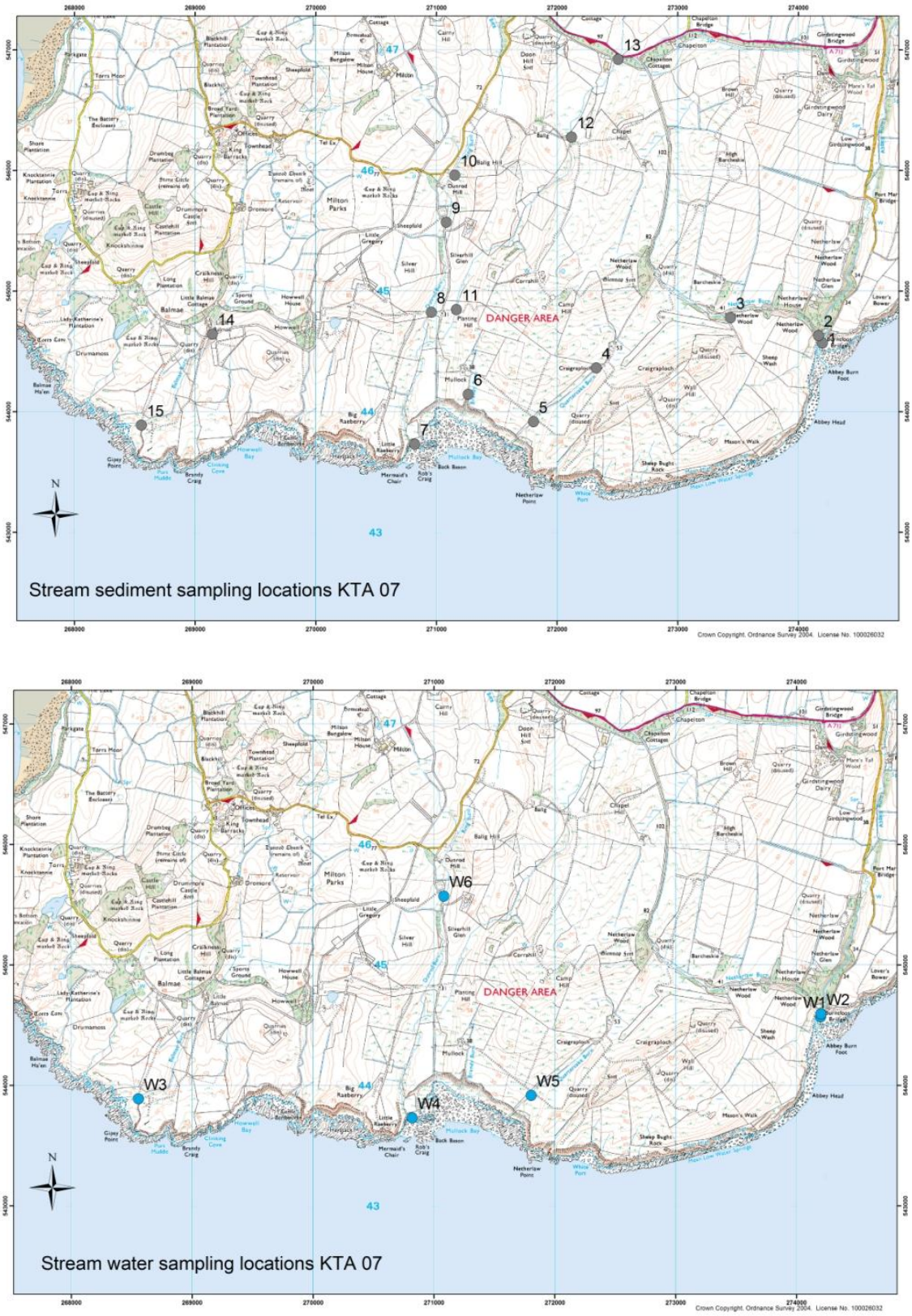

Figure 5: KTA, (top) stream sediment sampling locations, 2007; (bottom) stream water sampling locations, 2007. (Note: Grid squares are 1 km).

taking care to minimise the amount of soil or grass that could inadvertently be sampled at the same time. Rabbit droppings were collected until enough material had been sampled, to make one composite sample for that location.

6.7 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, one kidney each from three female deer were obtained in June 2007. The animals were less than 2 years old.

6.8 Stream sediment collection methodology

Sediment was collected from water courses that drain the range. Sediment was sampled below the water if possible. If there was insufficient sediment below the water, or if the stream flow was too strong to successfully retain the sediment whilst lifting the scoop, sample sediment that was thinly covered by water, or that had recently been covered, by water, was sampled. Where the area had been trampled by cattle, the nearest undisturbed sediments along the stream were sampled. The top layer of the sediment (up to 5 cm depth) was scooped, and large stones were removed, until a volume of sample of at least a quarter of a 0.8 litre sample box was collected.

6.9 Water sample collection methodology

Six water samples (0.5 litre) were collected from watercourses that run through the range (Abbey Burn, Balmae Burn, Dunford Burn, Quartercake Burn, Overlaw Burn and Netherlaw Burn). Samples were collected at accessible locations along the stream, i.e. from bridges and easily reached banks. The water was filtered through a Whatman filter using a funnel previously rinsed in stream water, into a previously rinsed sample bottle.

6.10 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 the letter 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). Letters U for upper and L for lower were added to the descriptor code to identify these different depth intervals.

The grass samples were analysed for each site. Each sample has been given a letter suffix A-C. Two examples of the sample descriptors are given below:

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

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

The biological indicators comprised of twelve species specific composite faecal samples. These samples were collected close to designated 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 were obtained from three deer from a herd that grazes in the area between Raeburry Gun and Dunrod Burn, and were labelled KD1 to KD3.

Water samples and stream sediment samples were collected from areas outside the designated sampling locations and so do not have site location codes such as K1 to K13. The water samples were labelled with the letter W, followed by a sample number (i.e. W1, W2). The sediments samples were labelled with the letter S, followed by a sample number (ie. S1, S2).

6.11 Dose rate measurement methodology

Gamma radiation measurements were made using three Mini Instruments Type 6-80/81 rate meters fitted with compensated Geiger Muller tubes. The instruments were deployed so that the centres of the Geiger Muller tubes were at one metre above ground, at each grass sampling location. Three 100 second counts were taken at distance intervals of 1m. The average of the three counts was used to calculate the dose rate.

7 Sample preparation and laboratory analysis

The samples were prepared and analysed by Alpha Spectrometry (AS) 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, 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 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.

8 Results and interpretation

A summary of the results for all terrestrial samples collected in 2007 is given below. 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. The terrestrial monitoring results are given in Table 4 to Table 10. Historical monitoring results for the KTA for the years 1996 to 2007 are presented in APPENDIX A.

It should be noted that the summary below 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.

Sample type	Number of Samples	Number of samples containing detectable DU[1]	Total uranium concentration (mBq/g or mBq/l)			
			Mean	Standard deviation of the mean	Minimum	Maximum
Soil upper	4	0	42.6	4.6	36.0	46.2
Soil lower	4	0	41.7	2.1	39.3	44.2
Grass	39	3	0.7	0.2	0.0	0.9
Water	6	0	4.1	3.2	2.0	7.5
Stream sediment	15	0	24.4	4.7	24.0	35.2
Faeces (Sheep)	2	0	7.8	9.4	1.4	14.5
Faeces (Badger)	2	0	0.8	1.1	0.1	1.2
Faeces (Rabbit)	3	1	5.7	6.6	1.1	13.2
Faeces (Cow)	5	0	1.5	0.7	1.0	2.6
Kidneys (Deer)	3	0	0.1	0.0	0.1	0.1

[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.

8.1 Dose rates

Dose rate measurement results for 2007 are given in Table 10. The maximum recorded dose rate was 118 nGy/h. Dose rates were not reported1 in 2000, 2001 or 2002. Results compare with dose rate measurements made in 2003-2006.

8.2 Animal indicator results

AS results for biological indicators are presented in Table 4 and Table 5 One rabbit faecal sample collected at Balig Gun (K6) had a uranium isotopic ratio above 1.0 after the associated uncertainty has been deducted (2.3 ± 0.5), and a total uranium activity of 13.2 ± 1.4 mBq/g. A similar concentration of natural uranium was found in a sheep faecal sample. All other faecal samples yielded results that denoted uranium of natural origin, at levels that were similar to those found routinely.

No DU was detected (i.e. was present above the limit of detection of 0.1 mBq/g) in the deer kidney samples.

8.3 Water analysis results

AS results for water samples are presented in Table 6. Total uranium concentrations ranged 2.0 ± 1.6 mBq/l to 7.5 ± 3.1 mBq/l. All were below the WHO limits of 2 μg/l for uranium, which equals about 30 mBq/l. Isotopic U concentrations were so low that the isotopic ratio could not be determined.

8.4 Stream sediment results

AS results for stream sediment samples are presented in Table 7. Uranium activity ranged from 24.0 ± 2.9 to 35.2 ± 3.8 mBq/g. This represents less than 0.01% of the GDL for ^{238}U in freshwater sediments [6]. No sample was radioactive within the meaning of the RSA 93 [7]. All isotopic ratios were indicative of natural uranium.

8.5 Soils analysis results

AS results for soils from the 2007 terrestrial survey are given in Table 8.

As mentioned above, total uranium concentrations have also been used to provide an upper bound on DU contamination levels. Previous monitoring reports [2, 9, 10 to 18] 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[2] [8,19, 20]. In 2007, all soil samples

[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.

[2] 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

contained total uranium below a level of 50 mBq/g and results from the gun position were very similar to the background levels. No sample exceeded 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]. All soil samples had isotopic ratios indicative of natural uranium.

8.6 Grass analysis results

AS results for grass from the terrestrial survey for 2007 are given in Table 9.

The results for 2007 range in value from 0.0 ± 0.0 mBq/g to 0.9 ± 0.2 mBq/g, and so compare with the range of literature values reported for UK grass of 0.2 to 3.8 mBq/g [21].

In 2007, the average total uranium level at Gipsy Point (K13) was 0.3 ± 0.1. Two grass samples contained total uranium in excess of, or equal to twice that at Gypsy Point, but had isotopic ratios indicative of natural uranium. These were grass samples from:

- Balig Gun/India Target way point (K5) – 0.9 ± 0.2 mBq/g;
- Doon Hill Gun /Target way point (K11) – 0.6 ± 0.1 mBq/g.

9 Interpretation of the soil and grass isotopic ratios

In this section the $^{238}U/^{234}U$ isotopic ratios are examined 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 B.

9.1 Isotopic ratios in soil

A summary of the measured ratios for the individual soil samples analysed in 2007 is shown in Figure 6. In 2007, all the soil samples were found to contain only natural uranium. The individual $^{238}U/^{234}U$ soil sample activity ratios range from 0.9 ± 0.2 to 1.3 ± 0.3. (Typical $^{238}U/^{234}U$ isotopic ratios in soils vary from 0.83-1.43 [8].)

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.

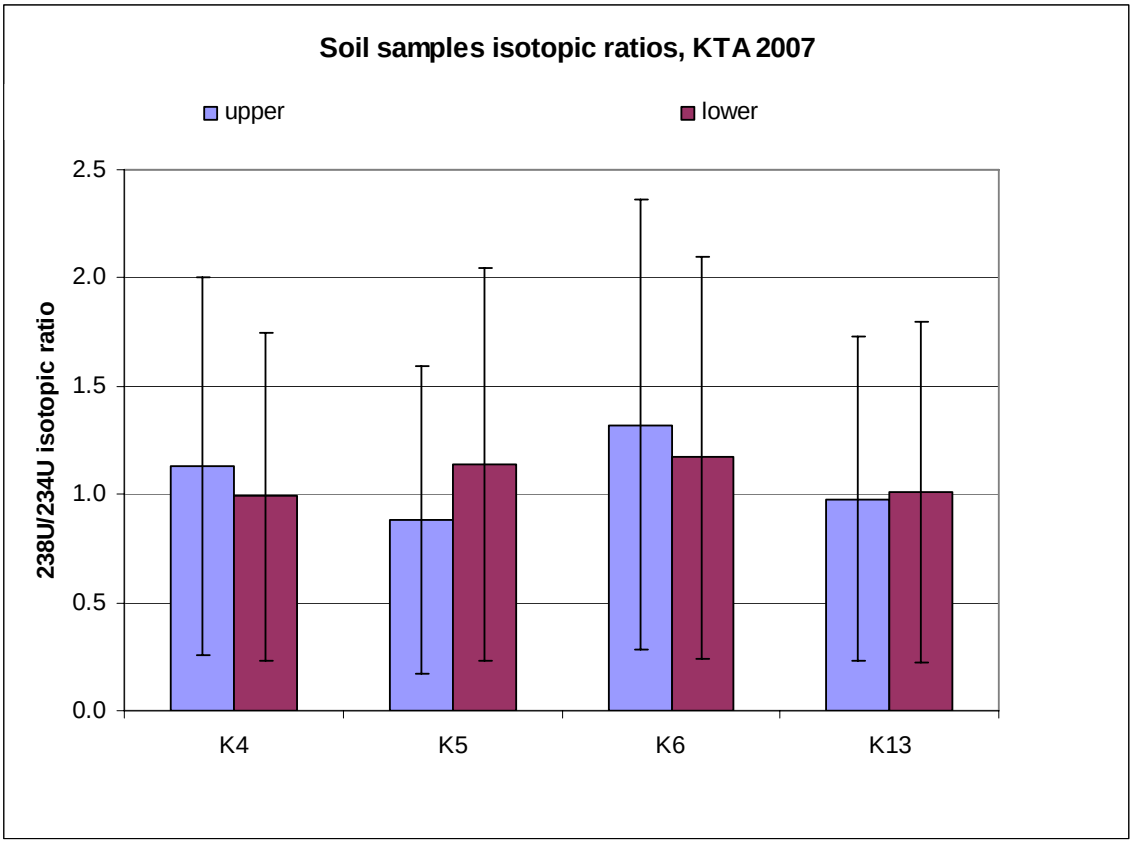

Figure 6: The isotopic ratios of the soil samples, 2007.

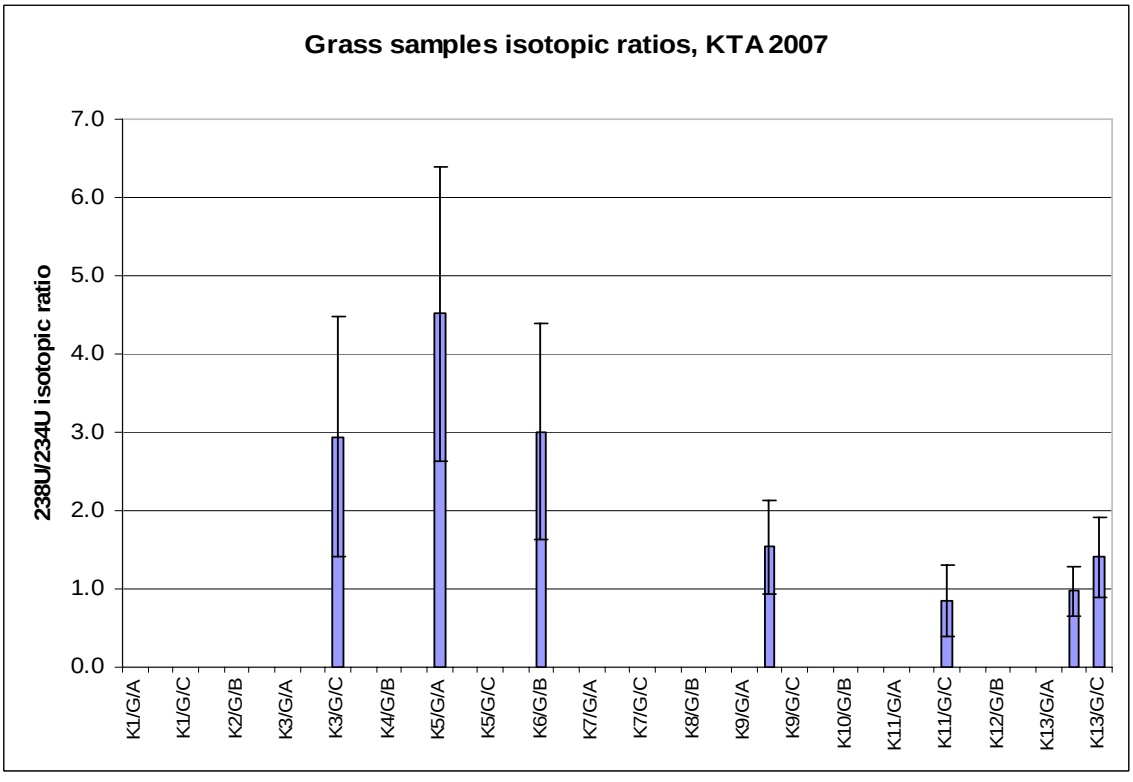

Figure 7: The isotopic ratios in grass samples, 2007.

9.2 Isotopic ratios in grass

A summary of the isotopic ratios for the grass samples collected during October 2007 is plotted in Figure 7. Only seven samples had isotopic activities above the limits of detection, meaning that isotopic ratios could only be determined for seven out of 39 grass samples. The individual ratios that were determined ranged from 0.9 ± 0.4 and 4.5 ± 2.6. The isotopic ratio for the grass samples from Doon Hill Gun /Target way point (K11) denoted uranium of natural origin.

In 2007, grass samples with $^{238}U/^{234}U$ isotopic ratios of value greater than 1 (within the analytical limits of uncertainty) were found at Raeberry Gun (K3), at the way point between Balig Gun and India Target (K5), and at Balig Gun (K6). Compared to the background grass value of Gipsy Point, only one of these samples (from Balig Gun (K6)) had an activity that may be considered slightly elevated, whilst the other two samples had total U concentrations that were consistent with background.

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 DU contaminated soil or sediment.

As mentioned in Section 8, the total uranium activity results for all samples represented a fraction of the GDL for uranium in soil, freshwater sediment or sea washed pasture, and of the WHO limit for drinking water. For the sake of completeness, the potential doses from the uranium level found in one grass sample and in one rabbit faecal sample from Balig Gun (K6) are considered below, within a more general dose assessment for the range at large.

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, including the locations of Raeberry Gun and India Target.

10.2 Inhalation of re-suspended DU

DU that has been deposited on soil, river sediment and vegetation may be re-suspended into the air and subsequently inhaled. As contamination levels in soil surface samples, freshwater sediment and in grass at KTA overall are very low in comparison to the GDL of 20,000 Bq/g for soil, 400,000 Bq/g for freshwater sediment and 20 Bq/g for dry sea-washed pasture grass [6], any possible committed effective dose to a member of the public or range staff outside the restricted access areas is insignificant.

Contamination levels measured in one grass sample from Balig Gun (K6) (0.9 ± 0.2 mBq/g) were very low and at the lower end of the range of total uranium for UK grass samples. As this area has restricted access, and members of the range staff do not spend long lengths of time at these sites, it is considered that any possible Committed Effective Dose to a member of the public or range staff is insignificant.

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, sheep and deer graze on the range, consideration must be given to the exposure pathway of ingestion of animal products derived from contaminated soil or pasture. As contamination levels are low in relation to the GDL of 20 Bq/g, and because the areas of contamination are relatively small and widely separated, the maximum potential dose to any person ingesting beef, mutton, venison or milk derived from range animals is assessed as insignificant.

Wild rabbits, pheasants and deer that feed and graze on the range, may be caught and eaten, potentially resulting in a radiological exposure to DU. No DU was present above the limit of detection of 0.1 mBq/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 the very few isolated areas.

The sampling of faeces has been used as a means of monitoring the potential contamination of these animals over the years. However, this can only be approximate as the DU may have been transferred from soil or grass on the surface on the faeces rather than be a constituent of the faecal material. The findings of this survey are consistent with those of previous years in which it was concluded that any potential exposures would be insignificant.

10.4 Ingestion of DU contaminated water from streams

The surface water samples collected in this survey contained no detectable DU contamination. In all cases the total uranium concentration was towards the lower end of what is found naturally and between 3 to 30 times less than the WHO lowest recommendation for uranium levels in drinking water (See Section 5). In addition, the burns are 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 one 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 considered to be minor. 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 in which it was concluded that any potential exposures would be insignificant.

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).

Contamination levels in all samples from KTA were very low in comparison to the GDL of 20,000 Bg/g for soil, 400,000 Bq/g for freshwater sediment and 20 Bq/g for dry sea-washed pasture grass [6]. All soil samples contained total uranium within the typical range expected for UK soils. All grass samples contained total uranium concentrations within the typical range expected for UK grasses. Isotopic analysis indicated that grass samples from three locations contained uranium with some degree of depletion (Raeberry Gun (K3), the way point between Balig Gun and India Target (K5), and at Balig Gun (K6)). 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 of DU contamination. Similar results have been measured at these locations previously, regardless of the amounts and timings of DU firings at the range. The total uranium activity results are so low that potential exposure scenarios will result in insignificant doses to range staff or members of the public

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

12 List of references

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13 KTA Terrestrial survey results (Pages 31 to 38)

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

Table 2: Summary of soil, grass and animal indicator samples collected - KTA 2007.
Note: × sample not collected

Table 3: Summary of stream sediment and water samples collected - KTA 2007.

Stream	Sediment	Water
Abbey Burn	×	1
Netherlaw Burn	2	1
Abbey and Netherlaw Burns	1	×
Brandy Burn	1	×
Ring Burn	1	×
Dunrod Burn	2	1
Overlaw Burn	3	×
Dunrod and Overlaw Burns	1	1
Quartercake Burn	2	1
Balmae Burn	2	1

[1] Animal indicator samples consist of faecal samples.

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					
K5/Sheep	45.3	13.1	5.1	6.1	±	1.0	0.3	±	0.2	8.1	±	1.3	14.5	±	1.6	0.8	±	0.2
K6/Rabbit	103.2	10.3	2.6	9.0	±	1.3	0.2	±	0.1	4.0	±	0.7	13.2	±	1.4	2.3	±	0.5
K6/Cow	199.7	34.3	6.4	1.3	±	0.3		<	0.1	1.3	±	0.3	2.6	±	0.4	1.0	±	0.3
K8/Cow	158.3	13.4	2.0	0.5	±	0.2		<	0.1	0.8	±	0.2	1.3	±	0.3	0.7	±	0.3
K8/Cow	173.8	10.4	1.3	0.4	±	0.1		<	0.1	0.5	±	0.2	1.0	±	0.2	0.8	±	0.4
K9/Badger	39.3	11.3	0.8		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	
K11/Sheep	176.5	35.7	5.6	0.7	±	0.2		<	0.2	0.7	±	0.2	1.4	±	0.3	1.0	±	0.4
K11/Cow	171.4	33.5	4.2	0.5	±	0.1		<	0.1	0.6	±	0.2	1.2	±	0.2	0.9	±	0.3
K12/Badger	64.4	12.5	1.0	0.7	±	0.2		<	0.1	0.5	±	0.1	1.2	±	0.2	1.3	±	0.5
K12/Rabbit	46.2	13.5	1.7	0.7	±	0.2		<	0.1	0.9	±	0.2	1.6	±	0.3	0.8	±	0.3
K13/Rabbit	85.9	10.7	1.8	0.6	±	0.2		<	0.2	0.5	±	0.2	1.1	±	0.3	1.2	±	0.6
K13/Cow	47.1	10.8	1.7	1.3	±	0.3		<	0.1	1.3	±	0.3	2.6	±	0.4	1.1	±	0.3

Table 4: Animal indicators (faeces), total uranium and isotopic ratio results – KTA 2007.

Note: Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq.kg^{-1} 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 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.

Table 5: Animal indicators (deer kidneys), total uranium and isotopic ratio results – KTA 2007.

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	201.3	29.9	1.6		<	0.2		<	0.1		<	0.1	0.1	±	0.0		n/a	
KD2	218.3	20.9	1.0		<	0.2		<	0.1		<	0.1	0.1	±	0.0		n/a	
KD3	213.1	27.6	1.4		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	

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. 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.

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Sample descriptor	Location	Measured activity of dry sample (mBq/l)												$^{238}U/^{234}U$ ratio		
		^{238}U			^{235}U			^{234}U			Total U					
W1	Abbey Burn		<	3.7		<	3.7		<	3.7	2.0	±	1.6		n/a	
W2	Netherlaw Burn	3.9	±	2.2		<	3.7		<	3.7	7.5	±	3.1		n/a	
W3	Balmae Burn	4.3	±	2.1		<	2.9		<	2.9	7.4	±	2.7		n/a	
W4	Dunford & Overlaw Burn		<	4.5		<	4.5		<	4.5	4.5	±	2.6		n/a	
W5	Quartercake Burn		<	3.8		<	3.8		<	3.8	5.5	±	2.6		n/a	
W6	Dunrod Burn		<	3.9		<	3.9		<	3.9	2.6	±	1.8		n/a	

Table 6: Water samples, total uranium and isotopic ratio results – KTA 2007.

Note:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 $MBq.kg^{-1}$ 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/a.

Sample descriptor	Location	Measured activity of dry sample (mBq/g)												$^{238}U/^{234}U$ ratio		
		^{238}U			^{235}U			^{234}U			Total U					
S1	Abbey Burn	16.9	±	2.6	0.6	±	0.3	16.6	±	2.6	34.1	±	3.7	1.0	±	0.2
S2	Netherlaw Burn	13.4	±	2.1		<	0.5	14.5	±	2.2	28.3	±	3.1	0.9	±	0.2
S3	Netherlaw Burn	17.6	±	2.7	0.7	±	0.4	17.0	±	2.6	35.2	±	3.8	1.0	±	0.2
S4	Quartercake Burn	13.1	±	2.1	0.6	±	0.3	15.4	±	2.4	29.1	±	3.2	0.9	±	0.2
S5	Quartercake Burn	11.9	±	2.0	0.5	±	0.3	12.6	±	2.1	25.1	±	2.9	1.0	±	0.2
S6	Brandy Burn	14.4	±	2.2	0.9	±	0.4	10.8	±	1.7	26.1	±	2.8	1.3	±	0.3
S7	Dunrod & Overlaw Burn	13.7	±	2.5		<	0.8	15.7	±	2.8	29.9	±	3.8	0.9	±	0.2
S8	Dunrod Burn	13.3	±	2.3	0.8	±	0.4	13.5	±	2.4	27.5	±	3.3	1.0	±	0.2
S9	Dunrod Burn	12.4	±	2.3	0.9	±	0.5	15.2	±	2.7	28.5	±	3.6	0.8	±	0.2
S10	Ring Burn	13.6	±	2.4		<	0.7	14.7	±	2.5	28.4	±	3.5	0.9	±	0.2
S11	Overlaw Burn	14.5	±	2.4	0.7	±	0.4	15.9	±	2.6	31.2	±	3.6	0.9	±	0.2
S12	Overlaw Burn	11.3	±	2.0	0.6	±	0.3	12.1	±	2.1	24.0	±	2.9	0.9	±	0.2
S13	Overlaw Burn	13.7	±	2.2	0.8	±	0.4	15.3	±	2.4	29.8	±	3.3	0.9	±	0.2
S14	Balmae Burn	14.8	±	2.3	0.6	±	0.3	16.4	±	2.4	31.7	±	3.3	0.9	±	0.2
S15	Balmae Burn	12.4	±	2.1		<	0.6	13.3	±	2.2	26.0	±	3.0	0.9	±	0.2

Table 7: Stream sediments, total uranium and isotopic ratio results – KTA 2007.

Note:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq.kg-1 has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' 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 7, 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.

Sample descriptor	Measured activity of dry sample (mBq/g)												$^{238}U/^{234}U$ ratio		
	^{238}U			^{235}U			^{234}U			Total					
K4/S/U	18.8	±	3.0		<	0.6	16.7	±	2.7	36.0	±	4.1	1.1	±	0.3
K4/S/L	19.2	±	3.1	0.8	±	0.4	19.4	±	3.1	39.3	±	4.5	1.0	±	0.2
K5/S/U	20.5	±	2.8	1.0	±	0.4	23.3	±	3.1	44.8	±	4.3	0.9	±	0.2
K5/S/L	21.4	±	3.1	0.8	±	0.4	18.8	±	2.7	41.0	±	4.1	1.1	±	0.2
K6/S/U	25.9	±	3.7	0.7	±	0.4	19.6	±	3.0	46.2	±	4.8	1.3	±	0.3
K6/S/L	23.4	±	3.4	0.8	±	0.4	19.9	±	3.0	44.2	±	4.5	1.2	±	0.2
K13/S/U	21.0	±	3.5	0.8	±	0.5	21.5	±	3.6	43.3	±	5.0	1.0	±	0.2
K13/S/L	20.8	±	3.2	0.8	±	0.4	20.5	±	3.2	42.2	±	4.5	1.0	±	0.2

Table 8: Soil samples, total uranium and isotopic ratio results – KTA 2007.

Note:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 MBq.kg-1 has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' 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 8, 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.

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/A	207.5	74.1	5.7		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	
K1/G/B	158.7	62.8	5.0		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K1/G/C	192.0	66.8	4.9		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K2/G/A	263.9	92.2	6.7		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K2/G/B	348.7	123.5	8.4		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K2/G/C	245.0	105.5	7.8	0.1	±	0.0		<	0.1		<	0.1	0.1	±	0.1		n/a	
K3/G/A	221.7	73.1	4.9	0.2	±	0.1		<	0.1		<	0.1	0.2	±	0.1		n/a	
K3/G/B	264.4	68.3	5.3	0.3	±	0.1		<	0.1		<	0.1	0.3	±	0.1		n/a	
K3/G/C	204.8	79.0	4.9	0.4	±	0.1		<	0.1	0.1	±	0.1	0.5	±	0.1	2.9	±	1.4
K4/G/A	320.9	135.2	9.3	0.2	±	0.1		<	0.1		<	0.1	0.2	±	0.1		n/a	
K4/G/B	496.0	174.0	12.4		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K4/G/C	377.7	116.4	9.5		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	
K5/G/A	338.5	101.1	6.7	0.7	±	0.2		<	0.1	0.2	±	0.1	0.9	±	0.2	4.5	±	2.6
K5/G/B	307.7	90.6	5.5	0.4	±	0.1		<	0.1		<	0.1	0.5	±	0.1		n/a	
K5/G/C	495.2	182.7	9.3	0.1	±	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K6/G/A	420.6	63.9	6.3	0.4	±	0.2		<	0.1		<	0.1	0.5	±	0.2		n/a	
K6/G/B	622.2	104.2	9.9	0.4	±	0.1		<	0.1	0.1	±	0.1	0.5	±	0.1	3.0	±	1.6
K6/G/C	544.8	78.9	8.9	0.3	±	0.1		<	0.1		<	0.1	0.4	±	0.1		n/a	
K7/G/A	223.8	57.2	4.5	0.1	±	0.1		<	0.1		<	0.1	0.2	±	0.1		n/a	
K7/G/B	289.6	68.3	5.5	0.1	±	0.0		<	0.1		<	0.1	0.1	±	0.0		n/a	
K7/G/C	263.7	84.8	5.1	0.1	±	0.1		<	0.1		<	0.1	0.2	±	0.1		n/a	
K8/G/A	175.7	59.5	4.1		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K8/G/B	194.7	66.2	5.0		<	0.1		<	0.1	0.1	±	0.1	0.2	±	0.1		n/a	
K8/G/C	191.1	72.1	5.0	0.2	±	0.1		<	0.1		<	0.1	0.3	±	0.1		n/a	
K9/G/A	215.6	83.6	4.0	0.1	±	0.0		<	0.0		<	0.0	0.1	±	0.0		n/a	
K9/G/B	336.8	119.0	7.2	0.1	±	0.1		<	0.1	0.1	±	0.0	0.2	±	0.1	1.5	±	0.9

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					
K9/G/C	207.8	92.6	5.0		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	
K10/G/A	354.7	112.8	7.4		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	
K10/G/B	396.5	120.4	7.4		<	0.1		<	0.1		<	0.1	0.1	±	0.0		n/a	
K10/G/C	340.3	109.0	7.7		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K11/G/A	847.9	183.2	8.8		<	0.1		<	0.1		<	0.1	0.0	±	0.0		n/a	
K11/G/B	697.6	138.3	7.7		<	0.1		<	0.1		<	0.1	0.0	±	0.0		n/a	
K11/G/C	585.4	135.5	8.7	0.3	±	0.1		<	0.1	0.3	±	0.1	0.6	±	0.1	0.9	±	0.4
K12/G/A	567.7	176.9	7.6		<	0.0		<	0.0		<	0.0	0.0	±	0.0		n/a	
K12/G/B	425.8	137.9	7.3		<	0.1		<	0.1		<	0.1	0.1	±	0.1		n/a	
K12/G/C	506.4	169.9	7.4		<	0.0		<	0.0		<	0.0	0.0	±	0.0		n/a	
K13/G/A	407.2	64.5	7.0	0.2	±	0.1		<	0.1		<	0.1	0.3	±	0.1		n/a	
K13/G/B	442.4	82.8	7.3	0.1	±	0.1		<	0.1	0.2	±	0.1	0.3	±	0.1	1.0	±	0.7
K13/G/C	305.9	56.4	6.4	0.2	±	0.1		<	0.1	0.2	±	0.1	0.4	±	0.1	1.4	±	0.9

Table 9: Grass samples, total uranium and isotopic ratio results – KTA 2007.

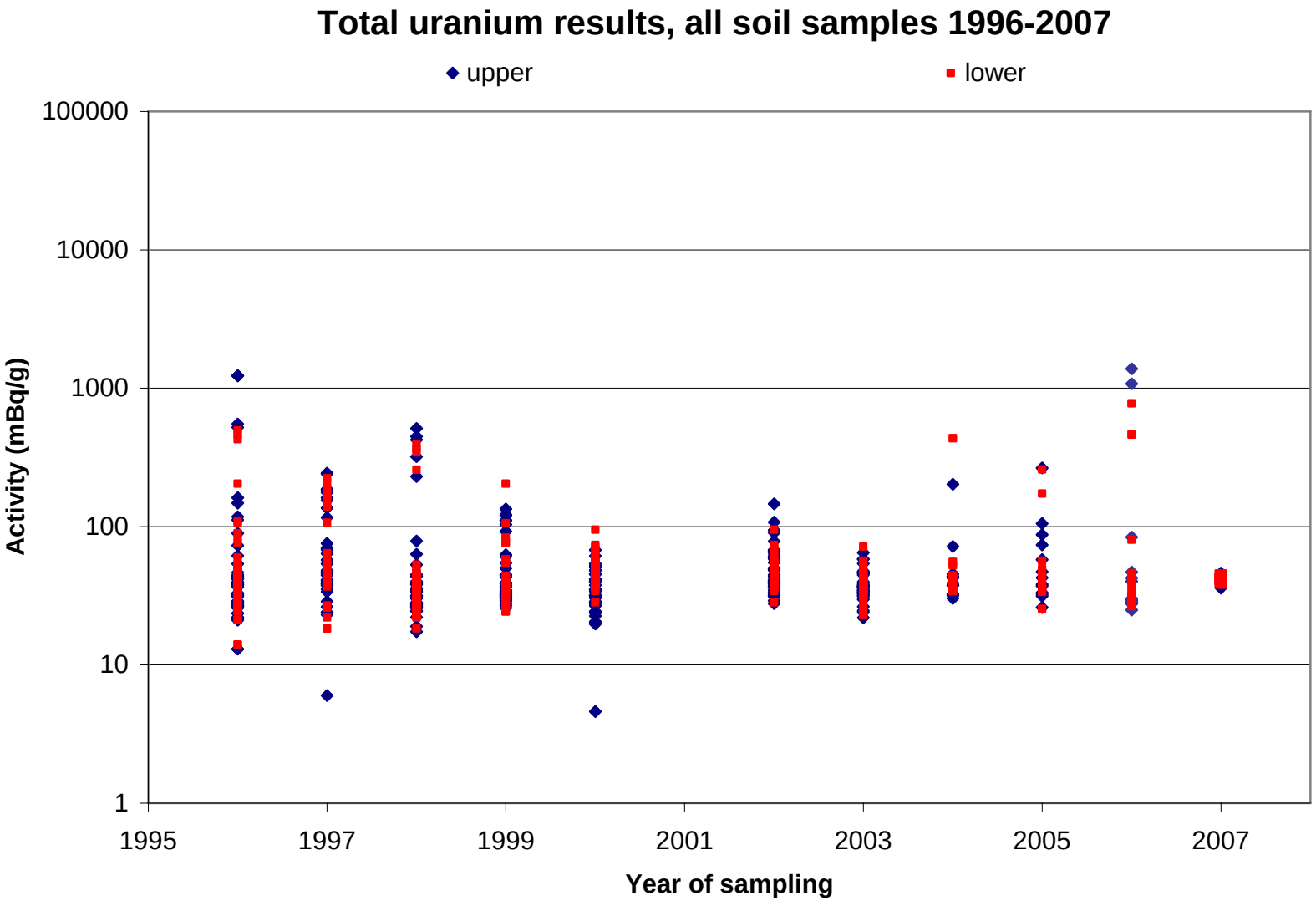
Notes:
Activity results have been rounded to 1 decimal place. A specific activity for DU of 14.0 $MBq.kg^{-1}$ has been used. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula [1] at 95%. The total activity is calculated from the sum of the actual activities for each isotope, regardless of the LOD quoted for that isotope, hence in Table 9, 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.

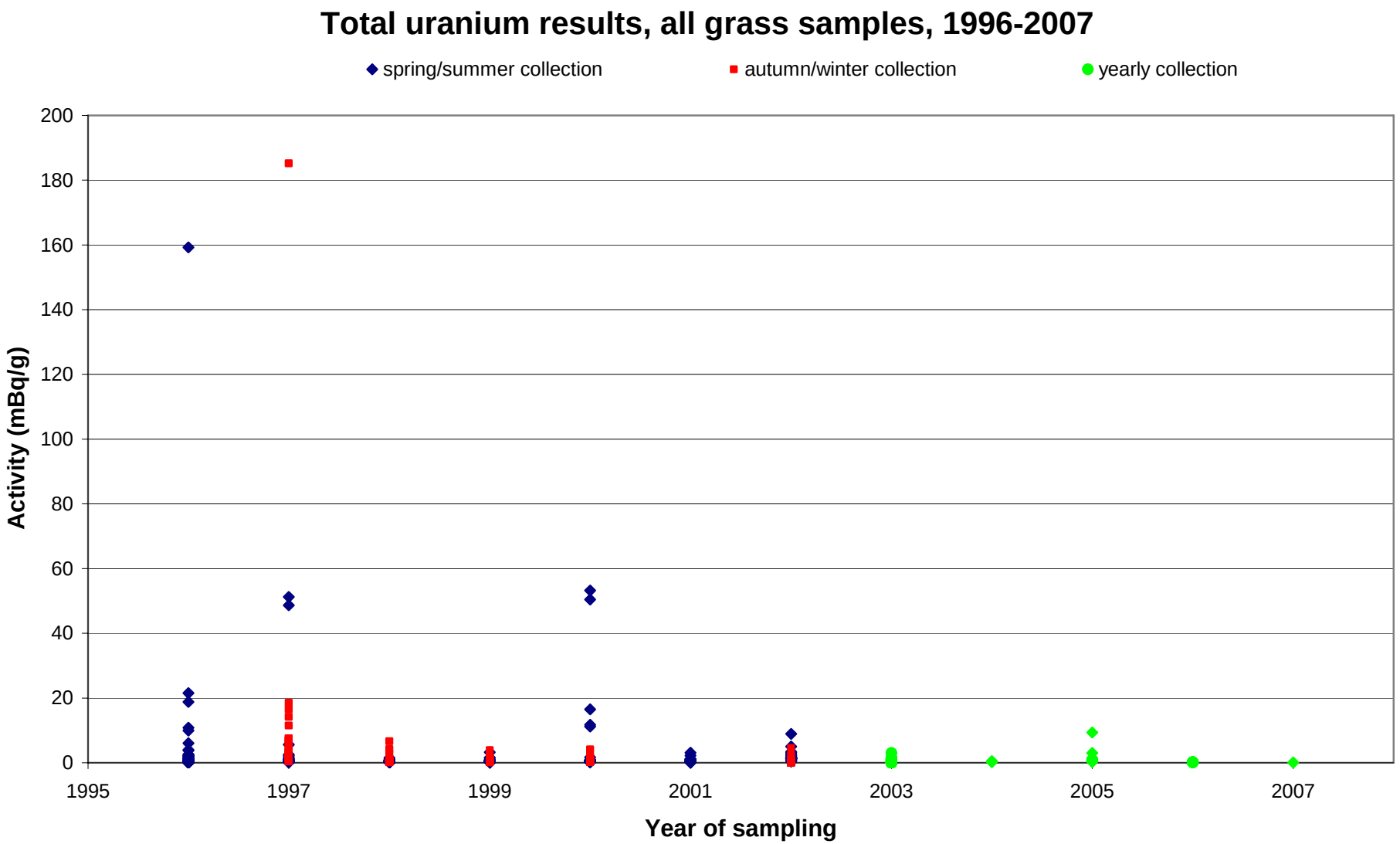
Station number	Location	Average dose rate (nGy/h)
1	Raeberry Target	105
2	Raeberry Bunker	118
3	Raeberry Gun	110
4	India Target	89
5	Balig Gun/Target waypoint	91
6	Balig Gun	87
7	Zulu Gantry	94
8	Mullock Farm	87
9	Silver Hill (Low) Gun	93
10	Echo Target (Doon Hill)	95
11	Doonhill/Target waypoint	90
12	Doon Hill Gun	92
13	Gypsy Point	102

Table 10: Dose rates measurements - KTA October 2007.

APPENDIX A Historical data

To allow year-to-year comparison, data from KTA environmental surveys from 1996 to 2007 is presented in the following tables.


Total uranium results, all soil samples 1996-2007
upper
lower
100000
10000
1000
100
10
1
Activity (mBq/g)
1995
1997
1999
2001
2003
2005
2007
Year of sampling


Total uranium results, all grass samples, 1996-2007
spring/summer collection
autumn/winter collection
yearly collection
Activity (mBq/g)
200
180
160
140
120
100
80
60
40
20
0
1995
1997
1999
2001
2003
2005
2007
Year of sampling

Total uranium results for all terrestrial biological and vegetal indicator samples (mBq/g of dry weight), and water samples (in mBq/l) reported for 1996-2007.

Sample Type	1996	1997	1998	1999	2000		2002	2003	2004	2005	2006	2007
Cow Faeces	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)*	1.1-1.5(**2**) a, e *(0.9-1.0)*	1.0-2.6 (**5**) g, e, a, i *(0.7-1.2)*
Sheep Faeces	<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)*	×	0.3 ± 0.1[a] *(1.0 ± 0.4)*	1.2-14.5 (**2**) i *(0.8-0.9)*
Fox Faeces	×	×	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)*	×	×	12.4 ± 1.2[k] *(1.8 ± 0.4)*	×
Deer Faeces	×	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)**	×		1.0 ± 0.3[c] *(0.7 ± 0.4)*	0.5 ± 0.1 *(0.7 ± 0.3)*	×	1.4 ± 0.1[b] *(1.0 ± 0.4)*	0.5 ± 0.1[b] *(2.7 ± 1.4)*	×
Rabbit /Hare Faeces	×	×	0.3 ± 0.1[e] *(0.9 ± 0.8)*	×	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)*	1.3 - 5.8 **(2)**[c, j] *(1.2 – 1.4)*	1.2-13.2 (**3**) e, j *(1.1-2.3)*
Badger Faeces	×	×	×	×	×		×	×	×	×	×	0.1-1.2 **(2)** h, j *(1.3 ± 0.5)*
Deer Kidneys	×	×	×	×	×		×	×	×	0.0 ± 0.0 **(2)** (N)	×	0.0-0.1(**3**) (N)
Mushroom	×	×	×	×	×		×	0.5 ± 0.4 *(N)*	×	×	×	×
Berries°	×	×	×	×	×		0.2 ± 0.1 (N)	×	×	×	×	×
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) (**4**)	1.8-5.1 (**5**) (N)	1.8-9.1 (**5**) (N)	2.0-7.5 (**6**) (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.
- 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) ; j – Doonhill Gun (K12); k – Raeberry Target (K1) . 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 (other than water samples) have been excluded from the table.

ANNEX A 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 AS the uranium present in a sample 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. This limitation is acceptable as the primary purpose of the environmental survey is to assess the impact of DU firing. However, this limitation causes a conservative bias on the $^{238}U/^{234}U$ isotopic ratios for mineral samples and other recalcitrant matrices. 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 difference 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 results produced by analysis. 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 fertiliser 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 [22]. Veins rich in uranium minerals occur naturally along the coast of the Solway Firth, such as uraninite found at Needle's Eye, approximately 24 km away from KTA on the north coast of the estuary. These features are thought to be present across the region, although this has not been studied [23, 24].

Temporal variations

There will be natural temporal variations in the uranium concentration and the abundance of the various isotopes in the samples, 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 rather than in the roots, fruits or seeds [22].

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) [25]. 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 A references

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

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

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 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); ^{235}U (0.022 mg U/kg); ^{234}U (2e-04 mg U/kg), prior to addition of DU.

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

This report presents and interprets the results of the Depleted Uranium (DU) terrestrial environmental surveys undertaken at the Kirkcudbright Training Area (KTA) during 2007. Survey results show evidence of the presence of very low levels of DU in four of the eighty-three grass, soil, water, sediment, animal offal and animal faeces samples that were collected in 2007. These samples consisted of three grass samples and one faeces sample, and originated from three sampling locations, two of which (K3 and K6) lie within fenced off areas. The third location (K5) is not fenced. However, the activity levels associated with these four samples are negligible, and of no health consequences. None of the samples were radioactive within the meaning of the Radioactive Substances Act 1993. All grass, sediment, water and animal indicators contained total uranium significantly below the DUFERC action level (set at 10% of the level at which control would be required under the Radioactive Substances Act 1993). Doses to the two critical groups (inspection and maintenance teams, and also persons consuming game taken 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.

14. Abstract Protective Marking including any Caveats

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Kirkcudbright Training Area, Environmental Survey, Depleted Uranium, DU, Terrestrial Environment, 2007

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