Depleted Uranium Survey Report: Kirkcudbright Training Area 2011 Part 1 Terrestrial Environment

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DSTL/TR61850V1
31 May 2012

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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 extent of any radiological impact of the firings on the terrestrial and marine environments and any associated risk to humans.

This report presents the findings of the terrestrial survey undertaken at KTA during 2011; the marine survey is reported separately in Part 2. The survey was undertaken to monitor the levels of any DU in the terrestrial environment resulting from operations on the site and to identify the extent of any environmental transfer processes.

The survey results indicate that past and current safety arrangements are providing adequate protection against the very limited and localised areas of low level DU contamination on site. None of the samples analysed were radioactive within the meaning of the Radioactive Substances Act (as amended) 1993 (RSA93), nor did they exceed the Generalised Derived Limits (GDLs) advised by the Health Protection Agency (formerly the National Radiological Protection Board). In fact, the level of uranium present in the majority of samples was consistent with that expected due to naturally occurring radioactive material.

Based on the findings of this survey – which are consistent with those of previous surveys – potential doses to the representative person, site personnel and members of the public are not significantly different from natural background exposure.

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1 Introduction

1.1 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 extent of any radiological impact of the firings on the terrestrial and marine environments and any associated risk to humans [1 to15].

1.2 This report presents the findings of the terrestrial survey undertaken at KTA during 2011; the marine survey is reported separately in Part 2 [16]. The survey was undertaken to monitor the levels of any uranium in the terrestrial environment resulting from operations on the site and to identify the extent of any environmental transfer processes.

1.3 A review of historic environmental monitoring procedures was undertaken as part of an independent assessment of the DU firing at KTA (and Eskmeals) ranges in July 1995 [17]. During 1996, the environmental monitoring programme for KTA was revised in line with the recommendations of this assessment and the 1996 DU Baseline Survey report was published [18]. Environmental monitoring was undertaken in a consistent manner between 1996 and 2007.

1.4 Due to altered 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 greater emphasis on stream sediment sampling rather than soil sampling. The current terrestrial monitoring programme reflects this agreement and consists principally of the collection and analysis of grass and stream sediment/water samples, along with soil sampling around the active battery-target combination. Animal indicator samples are also collected where available. Further details of the revised sampling protocol are provided in the 2007 terrestrial survey report [11].

2 Background

2.1 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 (DTE).

2.2 DU has been released into the environment at KTA 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.

2.3 Testing of projectiles historically has taken place at five locations on the KTA range. Strength of design trials were initially conducted at the Raeberry range using prototype ammunition. Functionality 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. In 2003, rounds were fired from Challenger tanks placed at the Chapman 1000 metre firing point towards the India Target.

2.4 The current firing policy is to use the Balig Gun and India Target combination. There was no DU firing at KTA between 2003 and 2007, although a total of 20 rounds were

fired in 2008 as part of a routine surveillance programme to ensure the safety and serviceability of the ammunition. No firing has taken place since 2008 (as shown in Figure 5 of Annex B).

2.5 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. Whilst some of these fragments entered the sea, it is known that small quantities of particulate DU were deposited at a few discrete locations in the local terrestrial environment. Most of these locations are now fenced off, although the levels of DU present are below regulatory concern. The recovery of misfired DU penetrators has been attempted, although in most cases, penetrators are suspected to be buried at depth in the soil and therefore it has not been possible to locate or recover them.

2.6 An extensive radiological survey was carried out in 2002 using sensitive large area radiation monitoring equipment. Whilst identifying the expected isolated areas of low level DU contamination, the survey showed levels of radioactivity in most areas to be consistent with natural background levels. Most elevated radiation levels were due to naturally occurring radionuclides found in construction materials such as the granite chippings used on the range roads [17].

3 Depleted Uranium (DU)

3.1 Uranium is a naturally occurring radioactive material which exists mainly as three isotopes: uranium-238 (^{238}U), uranium-235 (^{235}U) and uranium-234 (^{234}U). The typical mass composition of these isotopes is shown in Table 1. In natural uranium, ^{238}U and ^{235}U are in approximate radioactive equilibrium with their daughter products[1]. Together these isotopes emit a range of alpha and beta particles along with gamma radiation. Being a heavy metal, the chemical toxicity of uranium is approximately equal to that of lead.

3.2 Uranium in an 'enriched' form is used as fuel in nuclear reactors. The enrichment process increases the concentration of ^{235}U (above 0.72%) in comparison to the natural form. The by-product of this process is ‘depleted’ uranium (DU), which has a reduced concentration of ^{235}U. Uranium-234 is also removed in the depletion process; meaning that DU is consequently less radioactive than natural uranium (the specific alpha activity of the DU fired at Kirkcudbright being approximately 1.4×10^7 milli becquerels per gram (mBq/g) compared to 2.5×10^7 mBq/g for natural uranium [18]. The mass compositions of DU and natural uranium are presented in Table 1 below.

Form of Uranium	^{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%

Table 1. Typical mass composition of uranium isotopes in natural and depleted uranium.

[1]A radioactive decay series occurs when a heavy radionuclide decays into successively lighter radionuclides known as daughter products. For example, ^{238}U decays to ^{234}Th, then ^{234m}Pa, then ^{234}U and so on until a stable element is reached (^{206}Pb).

3.3 As discussed in paragraph 3.1, ^{234}U normally exists in approximate equilibrium with ^{238}U in the natural environment. In comparison, DU exhibits a $^{238}U/^{234}U$ activity ratio of between 7:1 and 8:1, dependent on the degree of depletion achievable by different methods of processing. This distinction is important in differentiating DU contamination from naturally occurring uranium in the environment (see Section 4). For the remainder of this report, isotopic ratios will be stated in terms of activity rather than mass and as a single value representing the ratio 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).

4 Differentiating DU From Natural Uranium

4.1 The fundamental requirement of the DU environmental monitoring programme is to quantify the radiological impact of DU firing. This is achieved partly by measuring the amount of total uranium in environmental materials and using this figure as an upper bound of DU contamination levels. However, as uranium is present at detectable levels in most environmental materials, this overestimates the risk. More sophisticated analyses involve the specific measurement of ^{238}U and ^{234}U isotopes (by activity and/or mass). Although isotope measurements are used in this survey, references to total uranium measurements are included for consistency with historic reports. The limitations of using total uranium concentrations are discussed further in Annex C.

4.2 A convenient fingerprint marker for DU contamination 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 in the environment typically has an activity ratio close to unity. 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.

4.3 Samples are considered to contain detectable levels of DU contamination if the $^{238}U/^{234}U$ ratio is above 1.0 following the subtraction of the associated uncertainty (i.e. if there is 95% confidence that the true mean is greater than 1.0). This quantitative calculation can only be made when ^{238}U and ^{234}U are present at levels above the limit of detection for the analytical technique; no ratio can be calculated when both isotopes are below the limits of detection. However, qualitative information can be obtained when ^{238}U is detectable and ^{234}U is not, assuming that ^{234}U is present at a level equal to the limit of detection. Therefore, in some cases where the ratio is shown as “N/A” on the tables, it has been possible to infer rather than definitely prove the presence of DU. This represents a pessimistic interpretation of the data.

4.4 Substantial deposition of DU in the terrestrial environment (in addition to an existing natural uranium background) is required before the $^{238}U/^{234}U$ activity ratio diverges significantly from its natural ratio. An illustration of the impact of DU contamination on the isotopic ratio is given in Annex D. For the ratio to approach 7 in an analytical sample, the mass of DU would have to be approximately 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.

4.5 Isotopic quantification is achieved by techniques such as alpha spectrometry and mass spectrometry. Alpha spectrometry can detect uranium to parts per billion, which is equivalent to mBq per kg, or to lower levels if count times are increased. Mass spectrometry is more sensitive, but the lower levels detectable are of no recognised health significance. Isotopic information can also be yielded from gamma

spectrometry analyses, although limits of detection are not generally sufficient for measurement of environmental levels.

5 Reference Levels

5.1 The Depleted Uranium Firing Environmental Review Committee (DUFERC), on which the MOD is represented, has agreed investigation/action levels for DU in soil[2]. These are currently based on, and represent a small fraction of, the Generalised Derived Limits (GDLs) advised by the Health Protection Agency (formerly the National Radiological Protection Board) [20] and the Schedule 1 activity concentration for uranium laid down in the Radioactive Substances Act 1993 (RSA93) [22]. GDLs for uranium were last updated in 2000 and were referred to by the Royal Society in their studies of the potential health effects of using DU munitions [23]. 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.

5.2 Since April 2011, there have been significant changes to the legislation concerning the control of radioactive substances [22] now include revised regulatory thresholds for material containing uranium[3]. As such, DUFERC investigation/action levels are currently being reviewed in line with these changes. For the purpose of this report, the levels in Table 2 have been used.

Source	Reference Level	Activity concentration (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: ^{238}U in well-mixed soil	20,000
NRPB (2000)	Generalised Derived Limit: ^{238}U in freshwater sediment	400,000

Table 2. Current DUFERC investigation/action levels, RSA93 Schedule 1 activity concentrations and Generalised Derived Limits for uranium in soil and sediment.

5.3 There are no DUFERC agreed investigation/action levels for uranium in water. The alpha spectrometry system deployed by Dstl can detect uranium in water at levels down to about 10% of the World Health Organisation's (WHO) most restrictive recommendation for uranium levels in drinking water (2 μg per litre, which relates to

[2] Soil in areas of contamination above DUFERC investigation/action levels shall be managed in accordance with the KTA Depleted Uranium Management and Remediation Plan [22].

[3] Government guidance [29] on the EPR10 states that radioactive contamination *in situ* falls outside the scope of the regulations which only apply once the material is accumulated or disposed of as radioactive waste. Uranium levels above 5Bq g^{-1} would fall under regulatory control. Notwithstanding this, legislation concerning work with ionising radiation [28] and contaminated land [27] do apply to *in situ* contamination.

approximately 50 mBq/l for natural uranium). This 10% level is commonly used as a 'trigger' in occupational health monitoring.

6 Methodology

6.1 As discussed in Section 1, the current survey methodology consists primarily of the collection and analysis of grass and stream sediment/water samples, together with soil sampling around the active battery-target combination. Animal indicator samples are also collected where available and environmental gamma dose rates are recorded at each sampling location. Stream sediment/water sample points are located at areas where any potential contamination is likely to leach from the surrounding soil.

6.2 Full details of the methodology are provided in the following paragraphs.

Terrestrial sampling sites

6.3 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. In addition, samples collected from the Gypsy Point location were used for the purpose of background comparison. Grass samples were collected from all locations whereas soil samples were only collected from locations 4, 5 and 6 (Balig-India combination) and the background location (K13). The 13 sampling points are shown in Figure 3; the location names and Ordnance Survey of Great Britain grid references are provided below:

1.	Raeberry Target	NX 70449 43744
2.	Raeberry Bunker Midpoint	NX 70472 43836
3.	Raeberry Gun	NX 70521 43980
4.	India Target	NX 70631 43658
5.	Balig Gun/Target waypoint	NX 70964 44498
6.	Balig Gun	NX 71238 45452
7.	Zulu Gantry	NX 71848 43548
8.	Mullock Farm	NX 71188 44295
9.	Silver Hill (Low) Gun	NX 70355 44851
10.	Echo Target (Doon Hill)	NX 72291 43807
11.	Doonhill/Target waypoint	NX 72096 45429
12.	Doon Hill Gun	NX 71904 46947
13.	Gypsy Point	NX 68676 43789

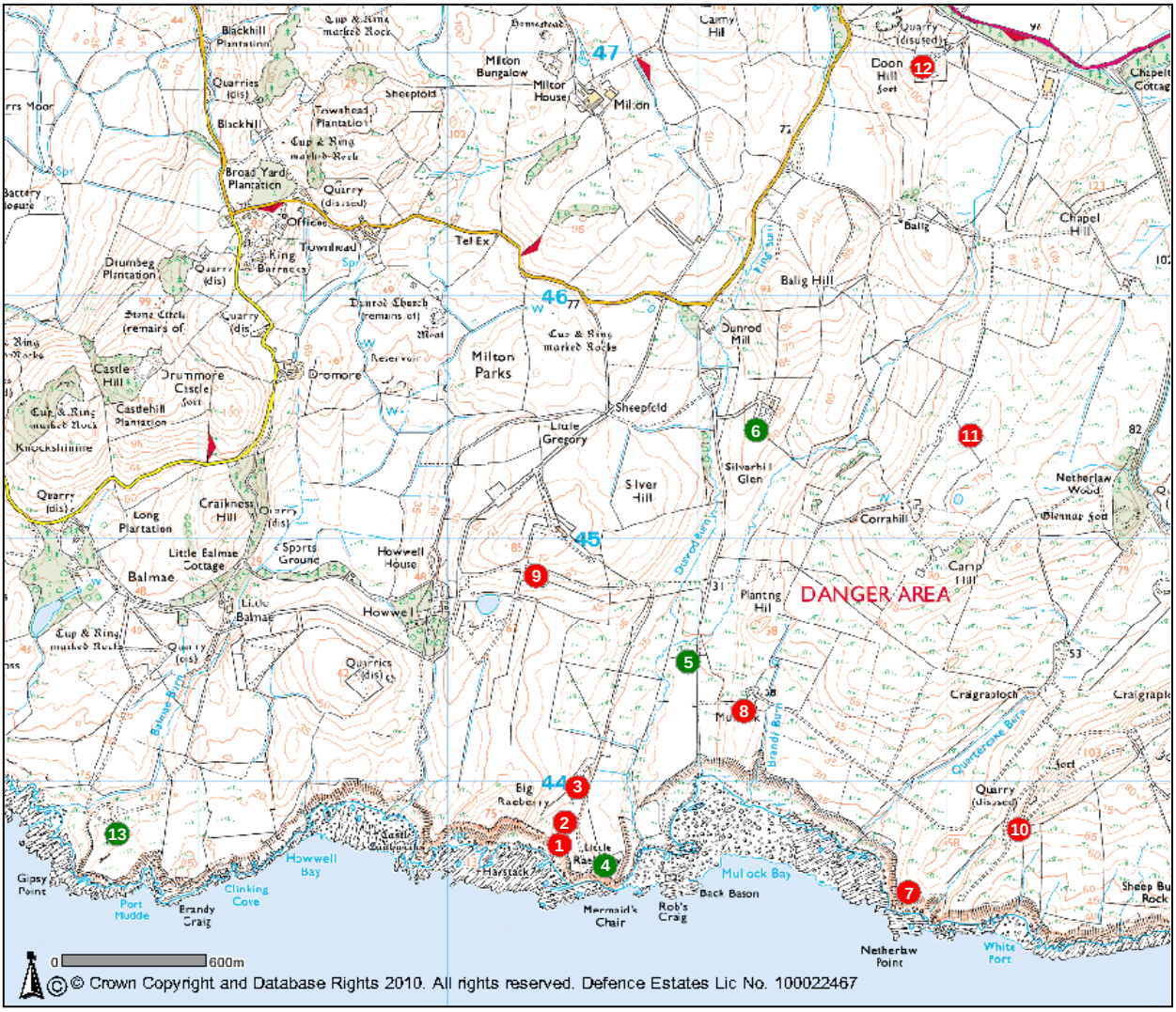

Figure 1. Terrestrial sampling locations at KTA 2011. Note: red markers indicate grass sampling; green markers indicate grass plus soil sampling.

6.4 At each sampling site, grass samples were collected from three areas of approximately 1 m^2 in size located within 5 metres of each other. Where the grass was scarce or short, the sampling area was increased until the samples obtained were of the requisite mass for laboratory analysis (greater than 200 g). The grass was cut at a height of at least 2 cm above 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 3 unwashed grass samples from each site were combined into one composite sample and analysed by alpha spectrometry.

6.5 Soil samples were collected as undisturbed cores of 4.8 cm diameter and up to 30 cm in depth from the centre of each of the three 1m^2 grass sampling areas. Each soil core was divided into sub-samples of two depth intervals (0-2 cm and 2-5 cm) in the laboratory and portions of the three sub-samples from each point combined to create one composite sample for each depth interval (0-2 cm and 2-5 cm). This system yielded a total of 8 composite samples from the 4 soil sample locations.

These were analysed by alpha spectrometry to provide an indication of distribution with depth.

6.6 At each grass sampling area, gamma dose rates were derived from measurements taken using a Mini-Instruments 6-80/81 and a compensated MC71 Geiger-Muller tube set up at 1 m above the ground and allowed to record over a period of 300 seconds. A mean gamma dose rate was calculated from three replicate measurements using the methodology described in Reference [23].

6.7 Where available, samples of animal faeces (e.g. rabbit, fox, sheep and cattle) were collected close to the sampling sites. Only fresh samples were collected, 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, making one composite sample for that location. These samples were analysed by alpha spectrometry.

6.8 Deer culling takes place on the range to manage the deer population and biological samples (liver and/or kidneys) are routinely collected from the culled deer on an opportunistic basis. No biological samples were available for analysis in 2011 as no deer cull was conducted by site management. However, historical sample analysis has shown that levels of total uranium are very low and do not indicate any DU contamination.

Stream sediment and water sampling

6.9 Stream sediment was collected at fifteen locations from streams that collect run-off water from the soil surface of the range. Stream water samples were collected at five locations. The Ordnance Survey of Great Britain grid references for the fifteen stream sediment and water sampling sites used in 2011 are given below. The exact position of the sampling sites changes slightly from year to year due to changing stream conditions and access. The current locations are shown on a map of the site in Figure 2.

Stream sediments sampling grid references:

S1.	Burnfoot Bridge	NX 74199 44570
S2.	Netherlaw Wood	NX 74166 44631
S3.	Netherlaw Burn,	NX 73438 44779
S4.	Quatercake Burn	NX 72326 44363
S5.	Quatercake Burn	NX 71804 43917
S6.	Brandy Burn	NX 71264 44145
S7.	Dunrod & Overlaw Burns	NX 70820 43732
S8.	Dunrod Burn	NX 70958 44825
S9.	Dunrod Burn	NX 71082 45571
S10.	Ring Burn	NX 71152 45961
S11.	Overlaw Burn	NX 71166 44847
S12.	Overlaw Burn	NX 72120 46277
S13.	Overlaw Burn	NX 72507 46920
S14.	Balmae Burn	NX 69144 44643
S15.	Balmae Burn	NX 68556 43890

Stream water sampling grid references:

W1.	Abbey Burn	NX 74199 44570
W2.	Netherlaw Burn	NX 74202 44594
W3.	Balmae Burn(Gypsy Point)	NX 68556 43890

W4. Dunrod & Overlaw Burns NX 70820 43732
W5. Quartercake Burn NX 71804 43917

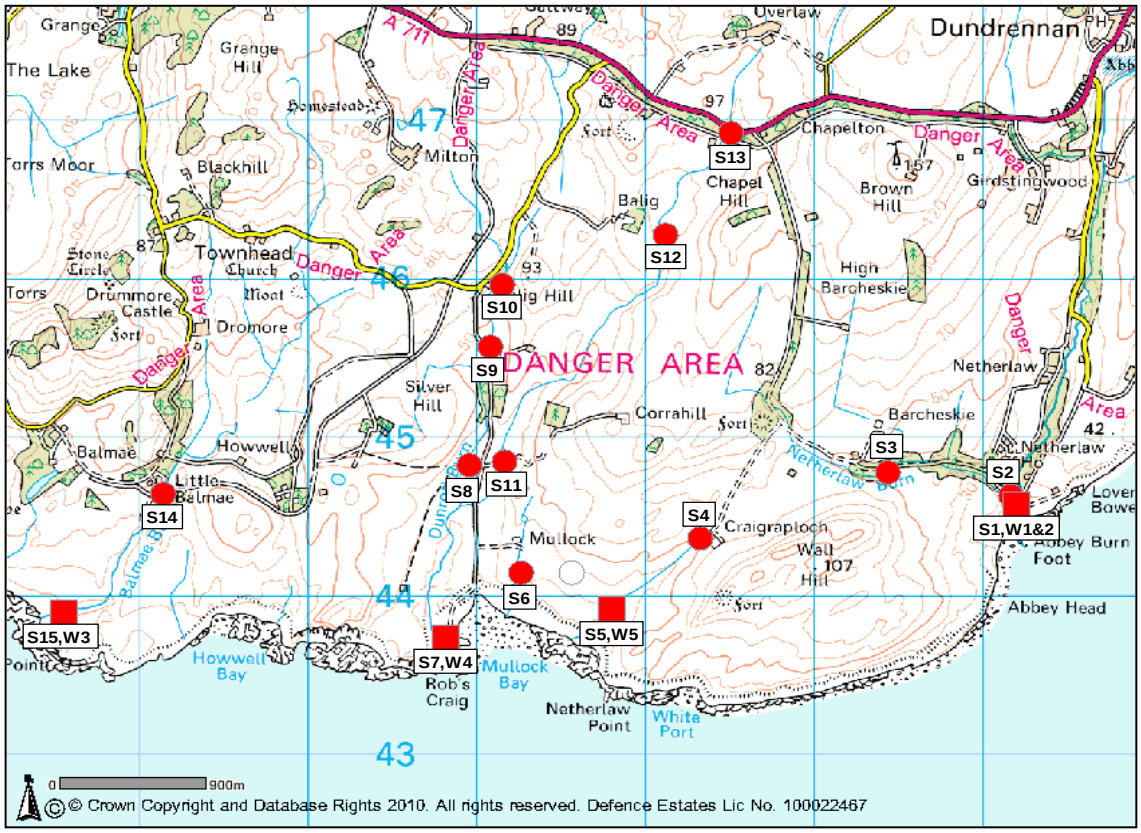

Figure 2. Stream sampling locations - KTA 2011. Note: circular markings denote sediment sampling; square markings denote both sediment *and* water sampling.

6.10 Stream sediment was collected from below the water where possible. Care was taken to sample undisturbed sediments which had not been disturbed by cattle, for example. The top layer of the sediment (up to 5 cm depth) was collected and any large stones were removed. Sample sizes ranged from 0.4 to 0.8 litres. The sediment samples were analysed by alpha spectrometry.

6.11 Five water samples (0.5 litre) were collected from watercourses that run through the range. Samples were collected at accessible locations along the stream (e.g. from bridges and easily accessible banks). To remove any suspended sediment, the water was filtered through a Whatman filter paper using a funnel previously rinsed in stream water into a rinsed sample bottle. Both the water and the filter paper were analysed by alpha spectrometry.

Sample Descriptors

6.12 Each sample was given a unique sample descriptor. Those samples collected from specific sites (e.g. grass samples) were given a prefix such as K5 ('K' for Kirkcudbright followed by the location number). This prefix was followed by 'S' for soil sample; a 'G' for grass samples or the type of faecal sample. Soil samples were also denoted with a 'U' or a 'L' for the upper and lower soil horizon composite samples respectively. Water/sediment samples were given descriptors such as W3 and S13 respectively. Some examples of sample descriptors are provided below:

K5/SU : Composite soil sample, upper horizon, collected from location 5

K8/G : Composite grass sample collected from location 8

K3 rabbit : Rabbit faecal samples collected from location 3

W2 : Water sample collected from water sample location 2

S12 : Stream sediment sample collected from stream location 12

Sample preparation and laboratory analysis

6.13 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 [18]. An outline of the approach is given below.

6.14 The solid samples (soil, grass and biological indicators) 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 loss of uranium from the sample is deemed to be insignificant. 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.

6.15 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 alpha spectrometer with a silicon surface barrier.

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

7 Results and Interpretation

7.1 A summary of the results for all terrestrial samples collected in 2011 is given below in Table 3. The full terrestrial monitoring results are provided in Annex A. Historical monitoring results for the KTA for the years 1996 to 2011 are presented in Historical Data section.

7.2 It should be noted that the summary below is provided as an overview of the data collected. Given that some samples were collected from specific areas of known contamination, the mean values should not be viewed as an indicator of average uranium concentrations across KTA as a whole.

Sample type	Number of samples	Number of samples containing detectable DU[4]	Total uranium concentration (mBq/g or mBq/l)			
			Mean	Standard deviation of the mean	Minimum	Maximum
Soil upper	4	1	44.61	14.82	26.68	66.66
Soil lower	4	2	45.08	15.26	30.47	58.79
Grass	13	2	0.27	0.71	0.02	2.62
Water	5	0	2.19	0.83	1.63	3.61
Stream sediment	12	0	27.45	4.60	22.76	35.91
Faeces (Cow)	2	1	2.15	2.64	0.28	4.02
Faeces (Sheep)	1	0	0.56	0	0.56	0.56
Faeces (Rabbit)	1	0	5.15	0	5.15	5.15
Faeces (Fox)	1	1	7.40	0	7.40	7.40

Table 3. Summary of sample analyses.

Grass sample analysis

7.3 Alpha spectrometry results for grass samples are shown in Table 7. The total uranium levels ranged from 0.02 ± 0.02 to 2.62 ± 0.32 mBq/g; the highest result originating from the enclosed Raeberry Gun area (K03). The background level at Gypsy Point (K13) was found to be 0.04 ± 0.03 mBq/g.

7.4 Whilst no sample was radioactive within the meaning of RSA93, the ^{238}U:^{234}U ratio of two samples (K03 and K04) is indicative of depleted uranium (maximum 6.97 ± 1.84). This may also be the case for samples K01 and K02 wherein ^{238}U was detected.

[4] 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 biota samples.

However, the total uranium levels are consistent with the typical range for grasses in the UK (0.2 to 3.8 mBq/g [24]) and are of no radiological concern.

7.5 A graphical summary of the isotopic ratios for the grass samples collected in 2011 is provided in Figure 3. Where no isotopic value is shown, ^{238}U and/or ^{234}U have not been detected.

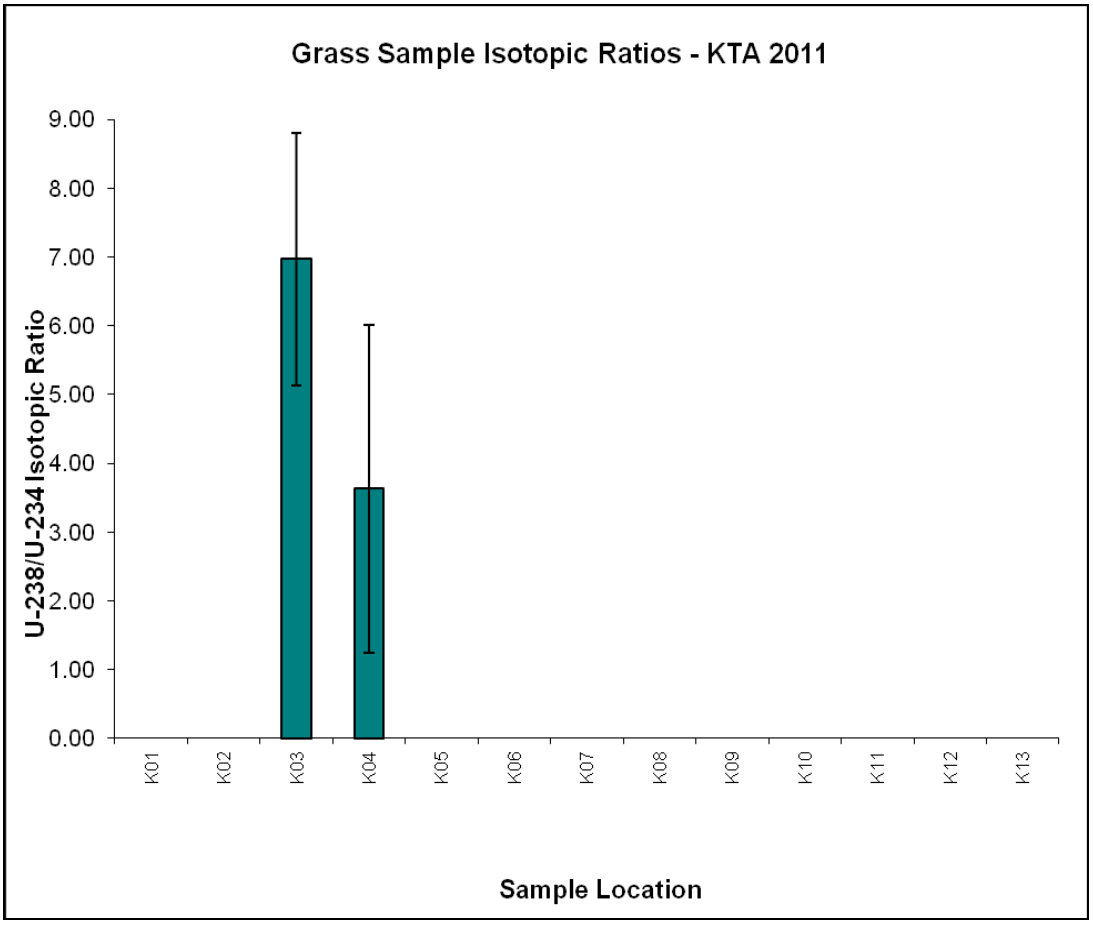

Figure 3. Grass samples: isotopic ratios from alpha spectrometry analysis

Soil sample analysis

7.6 Alpha spectrometry results for soil samples are shown in Table 8. No sample was radioactive within the meaning of RSA93. For the majority of samples the ^{238}U:^{234}U ratio indicates that the uranium is of natural origin.

7.7 The ^{238}U:^{234}U ratio of soil samples K04 (SU+SL) India Target, and K06 (SL) Balig Gun are slightly higher than unity but are of no radiological concern as all samples had uranium concentrations significantly below the GDL for well mixed soil (20,000 mBq/g) [21][5]. Furthermore, evidence of some minor depletion at these areas is consistent with the findings of previous surveys [1 to 15].

7.8 A graphical summary of the isotopic ratios for the soil samples is shown in Figure 4.

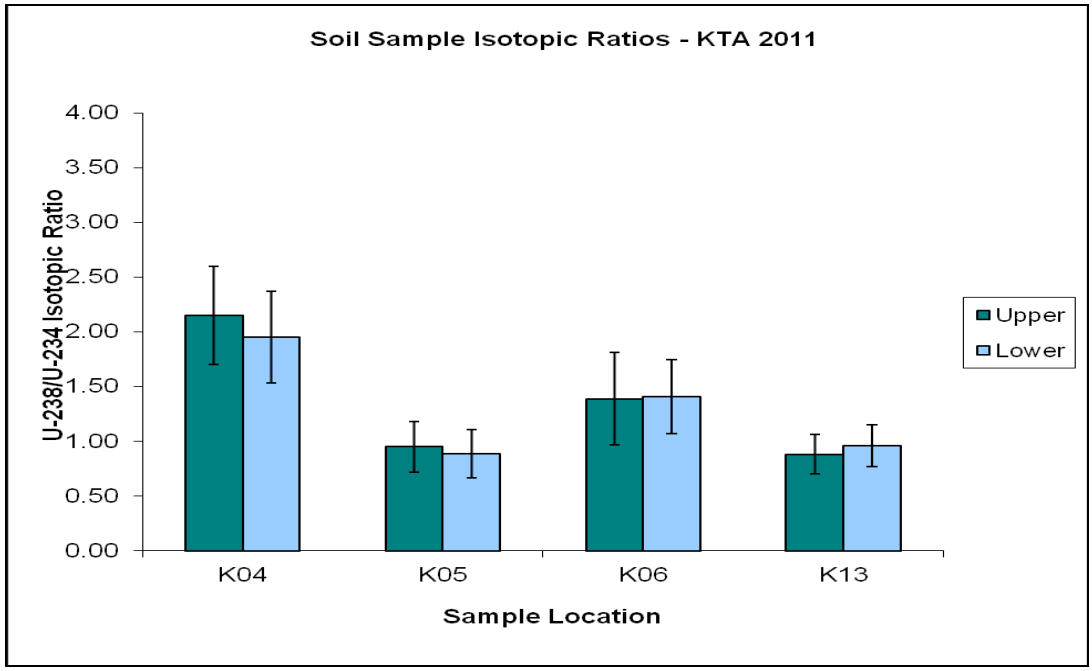

Figure 4. Soil samples: isotopic ratios from alpha spectrometry analysis

Animal indicator sample analysis

7.9 Alpha spectrometry results for animal faeces samples are shown in Table 9. The levels of total uranium in faecal samples ranged from 0.28 ± 0.09 to 7.40 ± 0.83 mBq/g. The background level recorded at Gypsy Point was 0.28 ± 0.09 mBq/g. Similar levels of uranium have been found in faecal samples in the past (see Annex B) and it is emphasised that isotopic ratios in the majority of samples indicate that the uranium is natural in origin. The isotopic ratio in the fox and a cow sample

[5] Soil minerals containing uranium are widely distributed on the surface of the Earth's crust and the concentrations of natural uranium in the terrestrial environment can vary significantly between locations. Consequently, there is no single definitive reference level for natural uranium in soils. However, there is broad agreement in the range of values published in the literature: typical values in the UK range from 2 to 50 mBq/g wet weight [21], but concentrations of up to 100 times the typical range have been found in some locations.

show evidence of depletion but are consistent with the findings of previous surveys and were taken from areas where there is known to be low level contamination (K3 Raeberry Gun).

Stream water sample analysis

7.10 Alpha spectrometry results for stream water and filter paper samples are presented in Table 9 and 10 respectively. Total uranium in water samples ranged from 1.63 ± 1.31 to 3.61 ± 2.02 mBq/l. Analysis of filter paper samples, which represent the suspended particulates in the water, showed that total uranium levels ranged from 0.37 ± 0.30 to 0.74 ± 0.46 mBq/l. All sample results were well below the WHO drinking water limit of 2 µg/l, which is equivalent to approximately 50 mBq/l (natural uranium).

Stream sediment sample analysis

7.11 Alpha spectrometry results for stream sediment samples are presented in Table 10. The levels of total uranium present ranged from 22.76 ± 2.96 to 35.91 ± 4.15 mBq/g, with isotopic ratios indicating that the uranium present was natural in origin. No sample was radioactive within the meaning of RSA93 and all samples were well below the GDL for freshwater sediments (400,000 mBq/g).

Environmental dose rate measurements

7.12 Environmental gamma dose rate measurements recorded during 2011 are shown in Table 4 and range from 0.069 to 0.112 micro grays per hour (µGy/h). The background measurement at Gypsy Point was recorded at 0.112 µGy/h. These measurements are consistent with those found during previous surveys [1 to 15].

Station number	Location	Average dose rate (µGy/h) (n = 3)
1	Raeberry Target	0.088
2	Raeberry Bunker	0.096
3	Raeberry Gun	0.100
4	India Target	0.087
5	Balig Gun/Target waypoint	0.086
6	Balig Gun	0.075
7	Zulu Gantry	0.083
8	Mullock Farm	0.078
9	Silver Hill (Low) Gun	0.100
10	Echo Target (Doon Hill)	0.090
11	Doonhill/Target waypoint	0.069
12	Doon Hill Gun	0.081
13	Gypsy Point	0.112

Table 4. Environmental gamma dose rates 2011

8 Evaluation of Potential Exposure Pathways

8.1 Any contamination of the terrestrial environment with DU results in five potential exposure pathways for humans, as described below:

- External exposure from contaminated vegetation/soil or from DU fragments;
- Inhalation of re-suspended DU contamination;
- Ingestion of crops or animal products from DU contaminated pasture or soil;
- Ingestion of DU contaminated water from streams; and
- (Inadvertent) ingestion of DU contaminated soil or sediment.

8.2 As discussed in Section 7, the total uranium activity results for all samples represented a small fraction of the relevant GDLs and WHO limit for drinking water. Therefore, any associated radiation doses are deemed to be insignificant. For completeness, however, the potential doses from the highest level of uranium found in grass and soil samples are discussed below, together with a more general discussion of potential doses on the range as a whole.

External radiation exposure

8.3 Environmental gamma dose rates recorded across KTA during 2011 were consistent with natural background radiation levels. This is also the case where low levels of DU contamination have been found historically (e.g. Raeberry Target) and indicates that there is no increased risk from external exposure related to DU at KTA.

Inhalation of re-suspended DU

8.4 Any DU which has been deposited on soil, river sediment and vegetation may be re-suspended into the air and subsequently inhaled by range staff or members of the public. The risk associated with re-suspended DU would be greatest during maintenance work on site such as fence maintenance and strimming of vegetation. However, the levels of DU found in soil during 2011 are well below the GDL for well-mixed soil (20,000 mBq/g) which itself relates to a Committed Effective Dose of 1 mSv per annum (the current UK dose limit for members of the public). The maximum level of uranium found in soil during 2011 was at sample location K5, where total uranium levels were 66.66 ± 6.60 mBq/g (at 0 to 2 cm depth). Although this is slightly higher than the expected natural background levels reported in the literature (up to approximately 50 mBq/g), any radiological dose due to inhalation would be indistinguishable from natural background exposure.

Ingestion of DU contaminated foodstuffs

8.5 No agricultural crops intended for human consumption are grown on the range so the potential exposure route involving the ingestion of contaminated crops need not be considered further. However, as a small number 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. It should be noted, however, that most areas of contamination on site are enclosed within fenced areas

and represent a small fraction of the total range area; any potential dose estimates therefore represent a worst case scenario.

8.6 No deer kidney or liver samples could be collected in 2011 as no deer cull took place. However, uranium levels in kidney and liver samples analysed during previous surveys have been very low. Any potential doses through this exposure pathway are therefore deemed to be indistinguishable from natural background exposure.

(Inadvertent) ingestion of DU contaminated soil or stream sediment

8.7 While there is a possibility that trace amounts of soil or stream sediment could be inadvertently ingested by those who come into contact with the material, the levels detected during 2011 are consistent with previous year's results and do not indicate any risk through this exposure pathway (they are well below the relevant GDLs). Furthermore, it should be noted that most areas of contamination on site are situated within fenced areas and access is strictly controlled.

Radiation exposure of representative person

8.8 The 'representative person' is a hypothetical individual who is deemed to receive the greatest radiation exposure from DU due to the critical pathway (e.g. external exposure and inhalation of re-suspended material). Two representative individuals have been identified for the terrestrial environment at KTA, as discussed below.

8.9 Workers employed to inspect and maintain the boundary fence around the contaminated areas are likely to be at most risk due to their occasional presence and proximity to the contaminated areas. A representative person from this group of people may receive a radiation dose via external exposure and the inhalation of re-suspended DU contamination from soil or vegetation. They may also receive further exposure through the inadvertent ingestion of trace amounts of contaminated soil. However, since the findings of the 2011 survey indicate that total uranium levels are consistent with typical background levels, the dose implications are considered to be indistinguishable from natural background exposure.

8.10 For information, using the methodology provided in the HPA document W36 (Reference 25), the potential dose to a full time park worker exposed to disturbed patchy contamination at 1,100 mBq/g (the DUFERC Action Level) is estimated to be 1.4 μSv per annum. This represents just 0.1 % of the UK dose limit for members of the public.

8.11 The second representative person is a local individual who consumes meat from the wild animals that roam on the range. Although no deer samples could be obtained in 2011, the results of previous surveys indicate that the dose from this pathway would be indistinguishable from natural background exposure.

9 Conclusions

9.1 The 2011 Kirkcudbright terrestrial monitoring programme was undertaken to assess the levels of DU in the environment resulting from the firing of DU munitions. The monitoring programme consisted principally of the collection and analysis of grass and stream sediment/water samples, along with soil and grass sampling around the active battery-target combination. Animal indicator samples were also collected.

9.2 No sample was radioactive within the meaning of RSA93, nor did it exceed a small fraction of the relevant GDL. The samples contained levels of uranium which are generally consistent with those expected due to naturally occurring uranium. The survey results indicate that past and current safety arrangements are providing adequate protection against the very limited and localised areas of low level DU contamination on site.

9.3 Based on the findings of this survey – which are consistent with those of previous surveys – potential doses to representative persons, site personnel and members of the public are not significantly different from natural background exposure.

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ANNEX A KTA Terrestrial Survey Results

Sample station number	Sample type and number of samples			Environmental dose rates
	Soil	Grass	Animal indicators (faeces)	
K1	×	1	×	✓
K2	×	1	×	✓
K3	×	1	1	✓
K4	1	1	×	✓
K5	1	1	×	✓
K6	1	1	1	✓
K7	×	1	×	✓
K8	×	1	×	✓
K9	×	1	×	✓
K10	×	1	×	✓
K11	×	1	1	✓
K12	×	1	1	✓
K13	1	1	1	✓

Table 5. Summary of soil, grass and animal indicator samples collected 2011

Note: × denotes sample not collected.

Sediment sample number	Water sample number	Location name	Burn
S1	W1 & W2	Burnfoot Bridge	Abbey and Netherlaw
S2	×	Netherlaw Wood	Netherlaw
S3	×	Cross roads	Netherlaw
S4	×	Craigrapploch	Quatercake
S5	W5	Downstream	Quatercake
S6	×	Mullock Farm	Brandy
S7	W4	Mullock Bay	Dunrod and Overlaw
S8	×	Upstream	Dunrod
S9	×	Balig Gun turn off	Dunrod
S10	×	Dunrod Mill gate	Ring
S11	×	Overlaw Burn	Overlaw
S12	×	Bailey Bridge	Overlaw
S13	×	EM Gun	Overlaw
S14	×	Gypsy Barrier	Balmae
S15	W3	Gypsy Point	Balmae

Table 6. Summary of stream sediment and water samples collected 2011

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	
K01	2120.00	126.50	7.59	0.12 ± 0.05	< 0.04	< 0.04	0.16 ± 0.05	n/a
K02	1470.00	127.75	7.05	0.05 ± 0.03	< 0.04	< 0.04	0.09 ± 0.04	n/a
K03	1069.00	145.33	8.72	2.26 ± 0.31	0.04 ± 0.02	0.32 ± 0.07	2.62 ± 0.32	6.97 ± 1.84
K04	1462.00	163.00	9.78	0.22 ± 0.07	< 0.04	0.06 ± 0.03	0.29 ± 0.08	3.63 ± 2.38
K05	1115.00	144.17	8.65	< 0.05	< 0.05	< 0.05	0.04 ± 0.03	n/a
K06	853.00	154.18	8.67	< 0.04	< 0.04	< 0.04	0.03 ± 0.02	n/a
K07	1188.00	129.81	10.32	< 0.04	< 0.04	< 0.04	0.04 ± 0.03	n/a
K08	1056.00	175.28	11.55	< 0.05	< 0.05	< 0.05	0.04 ± 0.03	n/a
K09	2110.00	184.21	9.71	< 0.04	< 0.04	< 0.04	0.03 ± 0.02	n/a
K10	1098.00	165.34	11.68	< 0.04	< 0.04	< 0.04	0.03 ± 0.03	n/a
K11	2320.00	148.27	7.20	< 0.03	< 0.03	< 0.03	0.02 ± 0.02	n/a
K12	2039.00	160.09	9.70	< 0.03	< 0.03	< 0.03	0.02 ± 0.02	n/a
K13	1144.00	163.08	10.27	< 0.05	< 0.05	< 0.05	0.04 ± 0.03	n/a

Table 7. Grass samples: alpha spectrometry results showing total uranium and isotopic ratios 2011

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	
K4 SU	104.43	73.00	61.93	37.43 ± 5.16	0.64 ± 0.39	17.44 ± 2.81	55.51 ± 5.89	2.15 ± 0.45
K4 SL	184.12	134.97	118.49	34.72 ± 4.88	0.73 ± 0.41	17.84 ± 2.87	53.29 ± 5.67	1.95 ± 0.42
K5 SU	77.17	41.82	31.68	12.63 ± 2.20	0.80 ± 0.43	13.26 ± 2.28	26.68 ± 3.20	0.95 ± 0.23
K5 SL	143.51	87.09	70.90	14.06 ± 2.45	0.66 ± 0.41	15.76 ± 2.66	30.47 ± 3.64	0.89 ± 0.22
K6 SU	96.46	52.59	41.54	26.09 ± 5.24	< 1.12	18.71 ± 4.11	45.75 ± 6.70	1.39 ± 0.42
K6 SL	196.43	131.14	114.31	19.44 ± 3.20	0.68 ± 0.43	13.81 ± 2.49	33.93 ± 4.08	1.41 ± 0.34
K13 SU	75.95	48.65	36.80	30.56 ± 4.39	1.17 ± 0.53	34.93 ± 4.90	66.66 ± 6.60	0.88 ± 0.18
K13SL	175.37	139.93	129.59	27.99 ± 3.87	1.50 ± 0.58	29.30 ± 4.02	58.79 ± 5.61	0.96 ± 0.19

Table 8. Soil samples: alpha spectrometry results showing total uranium and isotopic ratios 2011

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	
K6 (cow)	32.96	24.49	3.33	2.40 ± 0.41	0.10 ± 0.06	1.52 ± 0.30	4.02 ± 0.51	1.59 ± 0.41
K13 (cow)	170.76	22.12	2.27	0.13 ± 0.06	< 0.06	0.14 ± 0.07	0.28 ± 0.09	0.93 ± 0.64
K12 (rabbit)	79.48	23.70	9.93	2.71 ± 0.56	< 0.18	2.40 ± 0.52	5.15 ± 0.77	1.13 ± 0.34
K11 (sheep)	61.02	10.77	2.69	0.22 ± 0.13	< 0.16	0.31 ± 0.16	0.56 ± 0.21	0.70 ± 0.55
K3 (fox)	42.15	22.56	1.37	5.95 ± 0.79	0.07 ± 0.04	1.38 ± 0.25	7.40 ± 0.83	4.30 ± 0.83

Table 9. Animal indicators (faeces): alpha spectrometry results showing total uranium and isotopic ratios 2011

Sample descriptor	Measured activity of sample (mBq/l)				$^{238}U/^{234}U$ ratio
	^{238}U	^{235}U	^{234}U	Total U	
W1	< 2.28	< 2.28	< 2.28	1.63 ± 1.31	N/A
W2	< 2.44	< 2.44	< 2.44	1.75 ± 1.40	N/A
W3	< 2.43	< 2.43	< 2.43	3.61 ± 2.02	N/A
W4	< 2.41	< 2.41	< 2.41	1.72 ± 1.38	N/A
W5	< 2.22	< 2.22	< 2.22	2.25 ± 1.52	N/A

Table 10 Water samples: alpha spectrometry results showing total uranium and isotopic ratios 2011

Sample descriptor	Measured activity of sample (mBq/l)				$^{238}U/^{234}U$ ratio
	^{238}U	^{235}U	^{234}U	Total U	
W1 (filter)	< 0.59	< 0.59	< 0.59	0.42 ± 0.34	N/A
W2 (filter)	< 0.63	< 0.63	< 0.63	0.45 ± 0.36	N/A
W3 (filter)	< 0.60	< 0.60	< 0.60	0.57 ± 0.40	N/A
W4 (filter)	< 0.61	< 0.61	< 0.61	0.74 ± 0.46	N/A
W5 (filter)	< 0.52	< 0.52	< 0.52	0.37 ± 0.30	N/A

Table 11. Water samples (filter paper analysis): alpha spectrometry results showing total uranium and isotopic ratios 2011

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	
S1	46.57	18.08	15.47	16.20 ± 2.66	< 0.49	17.56 ± 2.83	34.26 ± 3.90	0.92 ± 0.21
S3	62.08	35.15	32.58	17.93 ± 2.95	0.55 ± 0.36	17.44 ± 2.89	35.91 ± 4.15	1.03 ± 0.24
S5	58.92	22.95	19.78	12.06 ± 2.12	0.53 ± 0.35	16.24 ± 2.63	28.83 ± 3.40	0.74 ± 0.18
S6	48.88	10.02	7.17	15.06 ± 2.62	< 0.54	17.09 ± 2.88	32.60 ± 3.91	0.88 ± 0.21
S8	53.30	34.16	32.65	12.33 ± 2.32	< 0.59	12.54 ± 2.35	25.01 ± 3.31	0.98 ± 0.26
S9	60.58	28.78	26.19	11.98 ± 2.12	0.52 ± 0.34	11.72 ± 2.08	24.21 ± 2.99	1.02 ± 0.26
S10	49.09	23.44	20.17	10.70 ± 1.98	0.75 ± 0.43	11.87 ± 2.13	23.32 ± 2.94	0.90 ± 0.23
S11	61.53	32.72	30.15	13.02 ± 2.23	< 0.47	13.59 ± 2.30	26.95 ± 3.22	0.96 ± 0.23
S12	81.17	35.40	31.05	12.46 ± 2.22	< 0.53	15.64 ± 2.61	28.37 ± 3.44	0.80 ± 0.19
S13	67.42	46.60	44.21	9.80 ± 1.87	0.54 ± 0.36	13.46 ± 2.33	23.79 ± 3.01	0.73 ± 0.19
S14	64.87	50.70	48.36	10.18 ± 1.94	< 0.52	12.40 ± 2.23	22.76 ± 2.96	0.82 ± 0.22
S15	86.69	60.11	57.37	10.90 ± 1.99	0.83 ± 0.44	11.65 ± 2.08	23.38 ± 2.91	0.94 ± 0.24

Table 12. Stream sediments: alpha spectrometry results showing total uranium and isotopic ratios 2011

Note (for Tables 6 to 11): *Activity results have been rounded to 2 decimal place. All uncertainties are stated at a 95% confidence level. Limits of Detection (LOD) are calculated by a 'modified Currie' formula[6] 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. Therefore, 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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ANNEX B Historical Data

To allow year-to-year comparison, data from the 1996 to 2011 KTA environmental surveys are presented on the following pages. Data for soil, grass and animal indicator analyses are presented separately. Figure 5 shows the number of DU projectiles fired at KTA between 1982 and 2010. There have been no firings since 2008.

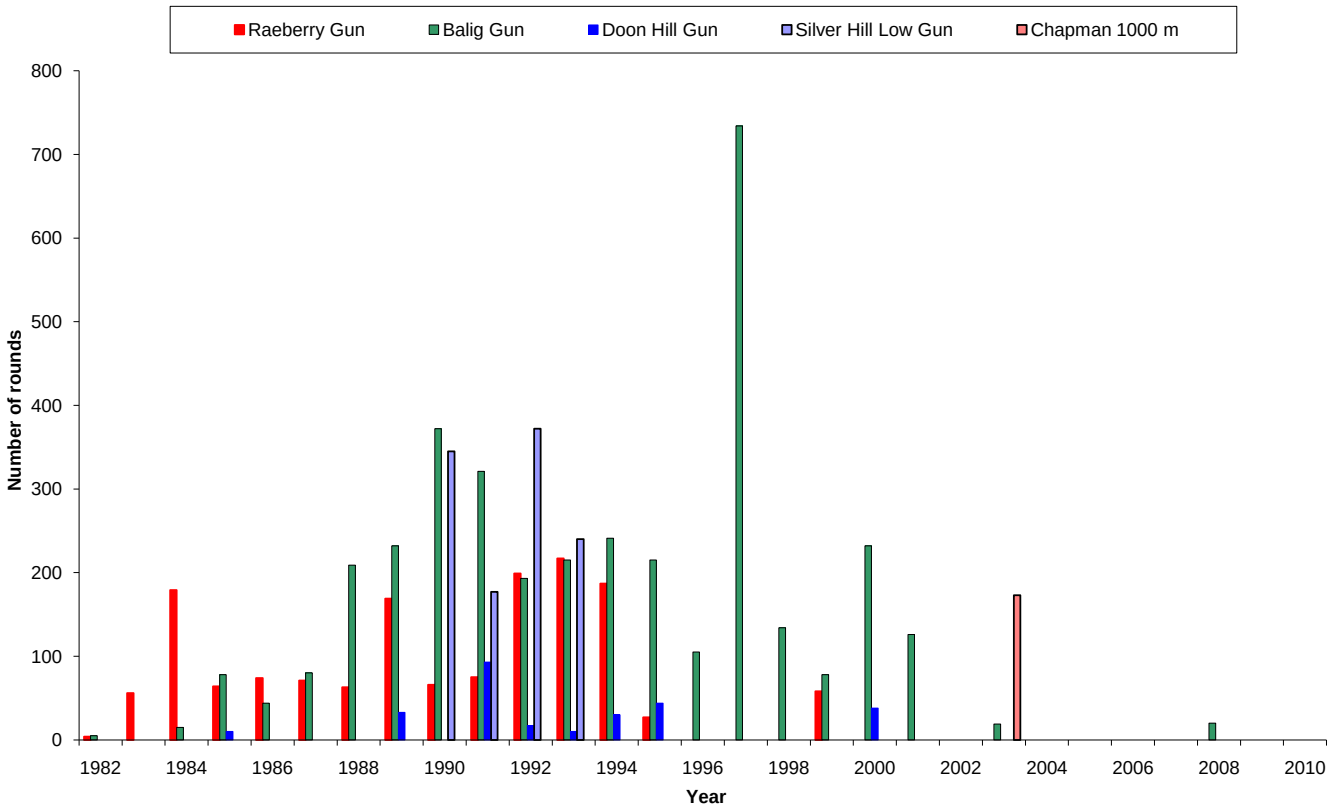
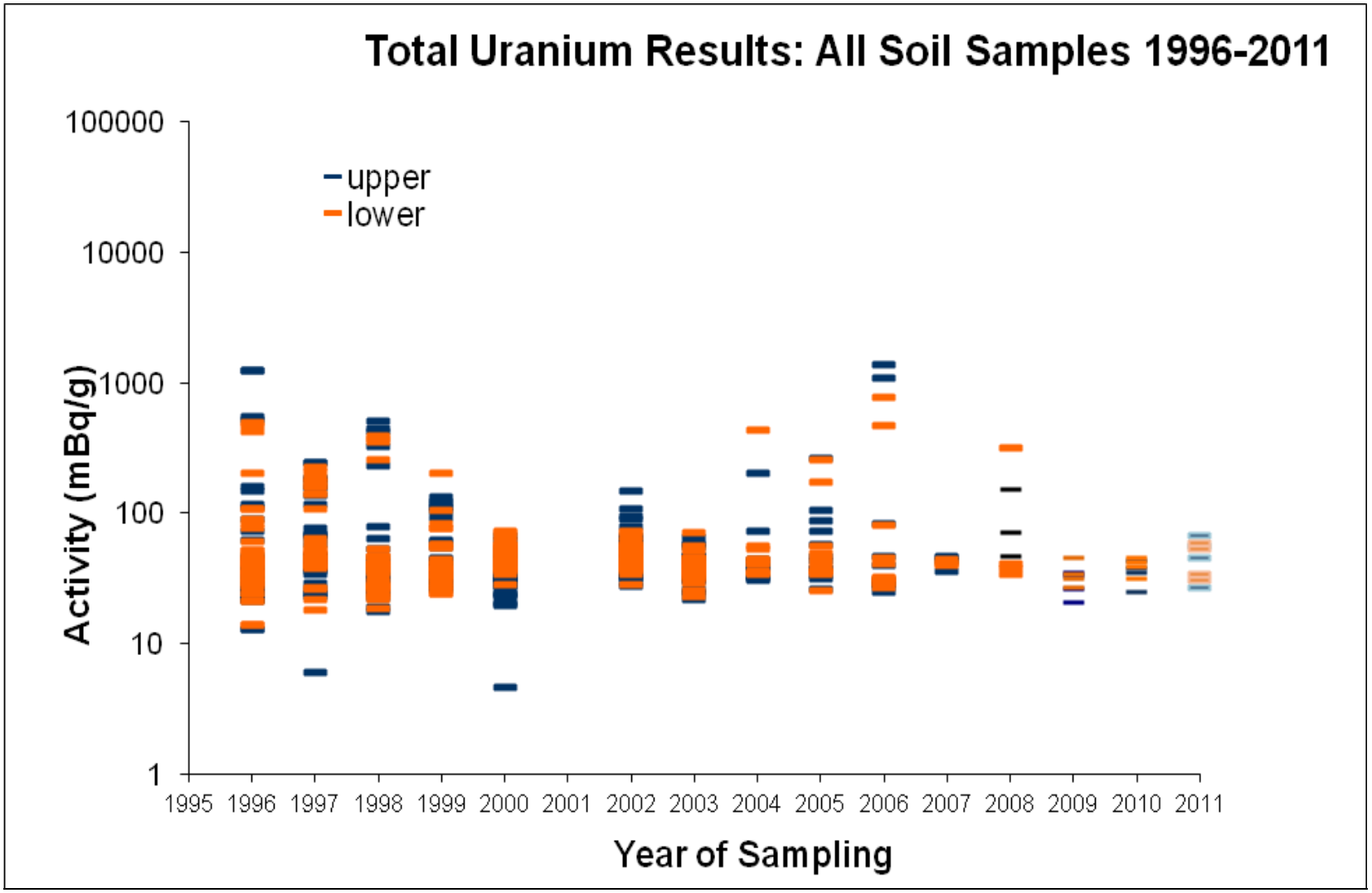
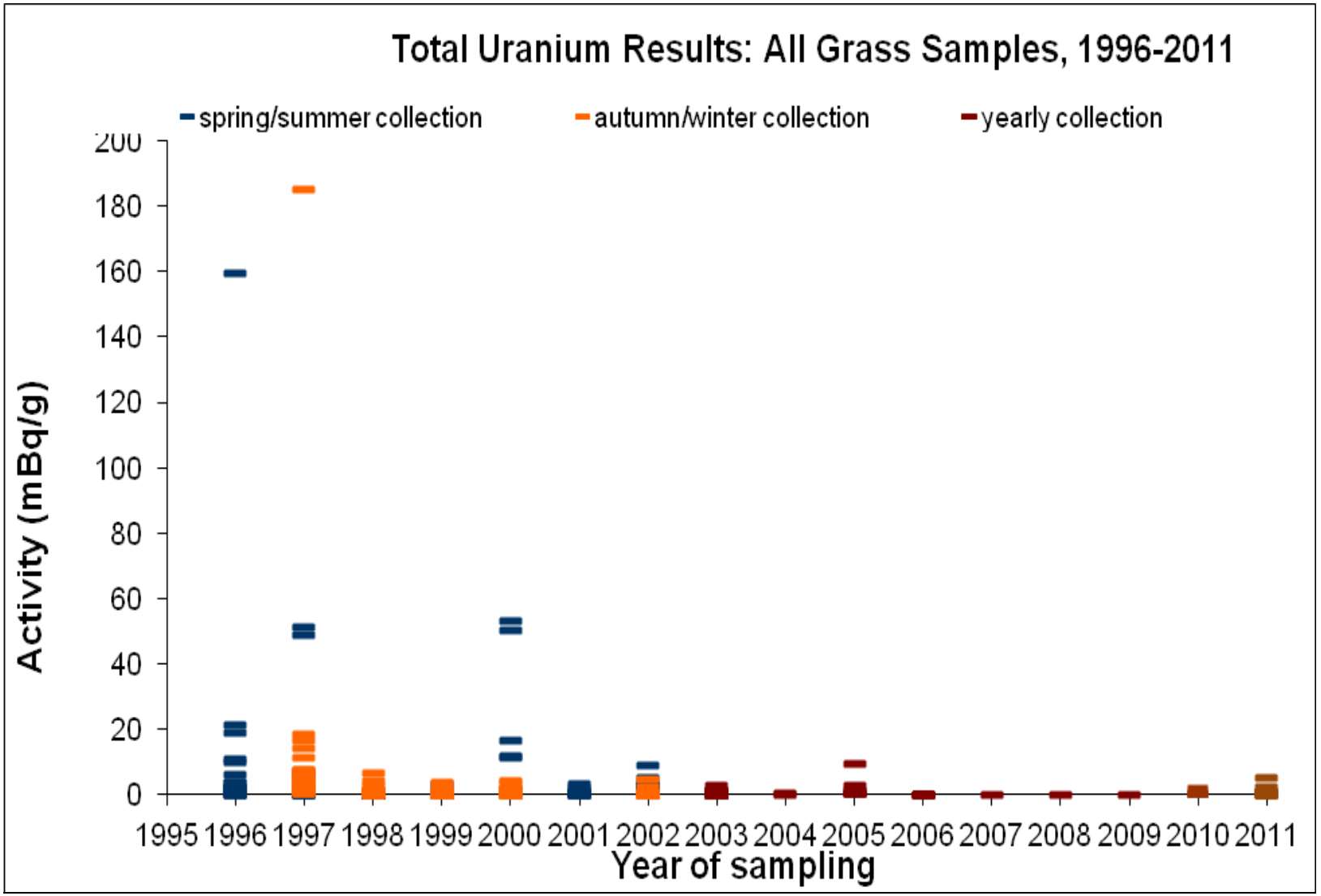


Figure 5: Number of DU projectiles fired at KTA between 1982 and 2010


Total Uranium Results: All Soil Samples 1996-2011
upper
lower
Activity (mBq/g)
100000
10000
1000
100
10
1
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year of Sampling


Total Uranium Results: All Grass Samples, 1996-2011
spring/summer collection
autumn/winter collection
yearly collection
Activity (mBq/g)
200
180
160
140
120
100
80
60
40
20
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year of sampling

Sample Type	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cow Faeces	31.5 *(1.1)*	0.2 *(0.8)*	1.6 *(0.5)*	0.5-1.5 *(0.6-0.8)*	0.4-7.7 *(0.7-1.5)*	1.1-1.5 *(0.9-1.0)*	1.0-2.6 *(0.7-1.2)*	0.9-1.5 *(0.6-0.9)*	0.7-14.3 *(0.8-1.2)*	0.2-2.2 *(0.6-1.1)*	0.28-4.02 *(0.1-0.5)*
Sheep Faeces	3.9 *(1.3)*	5.2 *(0.7)*	0.9 *(1.5)*	0.5 *(1.5)*	×	0.3 *(1.0)*	1.2-14.5 *(0.8-0.9)*	7.4 *(1.0)*	×	0.2-0.5 *(0.7-1.1)*	0.6 (0.2)
Fox Faeces	46.7 *(6.7)*	8.7 *(0.6)*	5.2 *(2.2)*	×	×	12.4 *(1.8)*	×	×	×	×	7.4 *(0.8)*
Deer Faeces	×	1.0 *(0.7)*	0.5 *(0.7)*	×	1.4 *(1.0)*	0.5 *(2.7)*	×	0.5 *(n/a)*	4.9 *(0.7)*	×	×
Rabbit Faeces	3.9 *(2.0)*	42.6 *(7.2)*	0.5 *(1.0)*	0.5 *(1.5)*	1.2 *(0.9)*	1.3 - 5.8 *(1.2 – 1.4)*	1.2-13.2 *(1.1-2.3)*	0.7-1.4 *(0.9-1.2)*	1.2 *(0.8)*	×	5.2 *(0.8)*
Badger Faeces	×	×	×	×	×	×	0.1-1.2 *(1.3 ± 0.5)*	×	×	×	×
Deer Kidneys	×	×	×	×	0.1 ± 0.0 *(n/a)*	×	0.0-0.1 *(n/a)*	0.1 *(n/a)*	×	×	×
Mushroom	×	×	0.5 *(n/a)*	×	×	×	×	×	×	×	×
Black-berries	×	0.2 (n/a)	×	×	×	×	×	×	×	×	×
Water samples	12.3-13.0 *(n/a)*	2.7-7.1 *(n/a)*	1.7-4.7 *(n/a)*	<11 *(n/a)*	1.8-5.1 *(n/a)*	1.8-9.1 *(n/a)*	2.0-7.5 *(n/a)*	2.7-6.4 *(n/a)*	3.7-9.6 *(0.4)*	1.8-7.9 *(0.7)*	0.37-3.6 *(n/a)*

Total uranium results for all terrestrial biological indicator samples (mBq/g of dry weight) and water samples (in mBq/l) 2000-2011

Notes: × denotes no sample of this type was collected. For simplicity, results for both the total uranium activity and the isotopic $^{238}U/^{234}U$ ratio are reported as follows: (1) The activity is reported first in mBq/g, followed by the isotopic ratio (italicised and in parenthesis); (2) 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/a'; (3)When only one result is reported for a sample type; the result is reported together with its uncertainty. Where there is 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%.

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

C1 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

C2 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).

C3 For analysis techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or alpha spectrometry, 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. Leached samples, in comparison, will only contain uranium that is either easily dissolved or is adhered to the surfaces of mineral grains. This limitation is acceptable as any DU contamination which may be present at Kirkcudbright is likely to be leachable. 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 the differences are appropriately discussed.

C4 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. It is therefore important to be aware of the preparation approaches that have been applied when comparing the results of different plant analyses.

Statistical variations

C5 There is a statistical uncertainty associated with the result of a radiochemical analysis (identified in the counting statistics for the technique). However, this uncertainty is likely to be small in comparison with the overall variation in activity between environmental samples.

Spatial variations

C6 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.

C7 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 fertiliser 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 [C1]. Veins rich in uranium minerals occur naturally along the coast of the Solway Firth, such as uraninite found at Needle's Eye, Caulkerbush, approximately 24 km away from KTA on the north coast of the estuary. These features are thought to be present across the region [C2, C3], although this has not been studied specifically.

Temporal variations

C8 There will be natural temporal variations in the uranium concentration and in 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 as well as 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.

C9 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).

C10 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

C11 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 [C1].

C12 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 (see Reference C4). Although this environmental survey does not aim at compiling a dose assessment for non-human species, wherever possible, animal faeces samples have been collected and analysed.

Annex C References

[C1] Mortvedt, JJ. (1992) Plant and soil relationships of uranium and thorium decay series radionuclides – A review, *Journal of Environmental Quality*, 23, 643.

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

Mass proportion of DU added*	Activity Concentration (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

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* 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).

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

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