

UNCLASSIFIED

**Marine Environmental Depleted Uranium Survey
Report Kirkcudbright Training Area - 2004**

Catherine Toqué

CR/18154 V1

27 April, 2006

Environmental
Sciences Department
c/o Institute of Naval
Medicine
Crescent Road
Alverstoke
Gosport
Hants.
PO12 2DL
© Crown copyright 2006 Dstl

UNCLASSIFIED

UNCLASSIFIED

Release Conditions




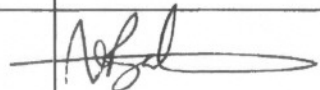
This document has been prepared for MOD and, unless indicated, may be used and circulated in accordance with the conditions of the Order under which it was supplied.

It may not be used or copied for any non-Governmental or commercial purpose without the written agreement of Dstl.

© Crown copyright
Defence Science and Technology Laboratory UK

Approval for wider use or release must be sought from:

Intellectual Property Department
Defence Science and Technology Laboratory
Porton Down, Salisbury, Wiltshire, SP4 0JQ.

Authorisation.			
	Name	Signature	
Department Manager	John Richards 		Date 27/04/06
Project Manager	Nigel Woodcock		Date 06/05/06
Technical Reviewer	Adrian Baker		Date 27/6/06

UNCLASSIFIED

UNCLASSIFIED

Executive summary

During test firing at the Kirkcudbright Training Area (KTA) between 1982 and 2003, approximately thirty-one tonnes of depleted uranium (DU) were deposited into the marine environment of the Solway Firth. Routine environmental monitoring has been carried out at the KTA since 1980 to assess the environmental impact of these firings on the terrestrial and the marine environments. Results of these surveys are published in annual and biennial reports.

This report describes and interprets the results of routine monitoring of the marine environment for DU, undertaken in the vicinity of the KTA in 2004. Samples of intertidal sediments, seaweed and seafood were collected from the shore line in the local area. Underwater sediment samples were collected off shore from the KTA, and samples of locally fished bottom dwelling animals were also obtained.

The results of the 2004 survey do not show evidence of the presence of DU in any of the environmental samples collected. There is no evidence to indicate that members of the public are exposed to a radiological hazard from the marine environment as a result of test firing DU ammunition at the KTA.

UNCLASSIFIED

Table of contents

Executive summary	1
List of figures	4
List of tables	5
1 Introduction	6
2 Background	6
3 Depleted Uranium	8
4 Differentiating DU Input from Natural Uranium	8
5 Sample Collection	9
5.1 Sampling locations and dates of sampling	9
5.2 Intertidal sediments sampling methodology	9
5.3 Seaweed collection methodology	11
5.4 Biota collection methodology	12
5.5 Dose rate measurements methodology	12
5.6 Seafood purchase methodology	12
5.7 Underwater sediment collection methodology	13
5.8 Sample descriptor code	15
6 Sample preparation and laboratory analysis	18
7 Results and interpretation	18
7.1 Dose rates	19
7.2 Intertidal sediments results	19
7.3 Underwater sediments results	20
7.4 Intertidal seaweed results	21
7.5 Biota results	21

UNCLASSIFIED

8	Evaluation of potential exposure pathways.	22
8.1	External radiation	22
8.2	Inhalation of re-suspended DU.	22
8.3	Ingestion of DU Contaminated foodstuffs	22
8.4	Ingestion of DU contaminated seawater	23
9	Conclusions	23
10	Recommendations	23
11	Acknowledgements	23
12	List of references	24
ANNEX A	Historical data	33
ANNEX B	Issues to be considered when interpreting or comparing uranium data	35
ANNEX C	Variability of uranium concentration and uranium isotopic ratios in marine environmental samples	37
ANNEX D	Reference values for uranium in the Solway Firth and the UK	38
ANNEX E	Change In The $^{238}\text{U}/^{234}\text{U}$ Activity Ratio Of A Medium Containing Natural Uranium With The Addition Of Depleted Uranium	40
	Initial distribution	42

UNCLASSIFIED

List of figures

Figure 1: Estimate of the quantity of DU projectiles fired from KTA, from 1982 to 2004.	7
Figure 2: Approximate cumulative mass of DU projectiles fired from KTA, from 1982 to 2003.	7
Figure 3: Kirkcudbright Training Area Shoreline Sampling Areas.	10
Figure 4: KTA- Underwater Sampling Points, Summer 2004.	13
Figure 5: KTA - Underwater Sampling Points, Winter 2004 (also showing lines of fire and estimated splash points for each battery).	14

UNCLASSIFIED

List of tables

Table 1: Intertidal Sample Station Areas, Summer 2004.	10
Table 2: Underwater sampling locations Summer and Winter 2004.	10
Table 3: Summary Intertidal Sample Collection, Summer 2004.	15
Table 4: Summary of Underwater Sample Collection, Summer 2004 and Winter 2004.	17
Table 5: Summary of results, all marine samples 2004.	19
Table 6: Intertidal doserate measurements, August 2004.	19
Table 7: Intertidal (Shoreline) sediment samples, total uranium and isotopic ratio results - August 2004.	25
Table 8: Underwater sediment samples, total uranium and isotopic ratio results - August 2004.	27
Table 9: Underwater sediment samples, total uranium and isotopic ratio results - December 2004.	29
Table 10: Seaweed samples, total uranium and isotopic ratio results – August 2004.	30
Table 11: Marine biota samples, total uranium and isotopic ratio results – August 2004.	31
Table 13: Summary of marine results reported for 1996-2003.	34
Table 14: Typical uranium concentrations and isotopic ratios in marine samples.	37
Table 15: Reported ²³⁸U concentrations in seaweed and marine biota in the UK.	38

1 Introduction

This report presents and interprets the results of the 2004 routine monitoring programme for Depleted Uranium (DU) in the marine environment offshore from the Kirkcudbright Training Area (KTA) during 2004. The monitoring work was undertaken to measure uranium levels in the marine environment bordering the KTA.

Routine marine environmental monitoring has been carried out annually since 1980 (i.e. before firing began). The environmental monitoring programme has consisted principally of the collection of seawater, marine sediment, seaweed, and marine fauna, which were subsequently analysed in the laboratory.

Sea water and sediments were collected from 6 off-shore sites in the Solway Firth, each year from 1980 to 2001. In 2001, it was recognised that the immense dilution present in the Solway would never give rise to uranium levels in sea water that were detectable above background. Therefore, with the agreement of the Scottish Environmental Protection Agency (SEPA), the collection of seawater ceased. Instead, seabed sediment samples were collected from a greater number of locations (20). In 2002, the number of underwater sediment samples for some locations was doubled. This protocol was kept in 2003 and 2004. In 2004, additional samples were collected from a further 19 off-shore locations.

The yearly sampling of sediments, seaweed and mussels, and the measurement of dose rates, from the intertidal shoreline of the Dumfries Coast were added from 1994 onwards, as was the analysis of locally caught seafood. The total number of shore locations sampled in each survey is 11.

The 2004 monitoring for DU in the terrestrial environment at Kirkcudbright is reported separately [1].

2 Background

The KTA is a MOD Range located on the coast of Dumfries and Galloway, near Castle Douglas. The Range became a Defence Evaluation and Research Agency (DERA) site in 1997 and subsequently passed into the control of the Army in April 1998.

DU has been released into the environment at Kirkcudbright as a consequence of the test firing of DU ammunition during design and accuracy assessment

UNCLASSIFIED

trials. DU projectiles are fired through soft vertical targets and then continue their trajectory to finally come to rest in the Solway Firth.

Testing of projectiles historically has taken place at five locations on the Kirkcudbright site. Each battery had a designated target and line of fire, and hence a designated safety template ranging from a few hundred metres to a few kilometres offshore. Although a small fraction of the total number of penetrators malfunctioned and impacted on land, the vast majority of malfunctioning penetrators, and all functioning penetrators, entered the Solway Firth. The number of DU rounds fired each year at Kirkcudbright from the five firing locations and the cumulative mass of DU fired to date, are presented in Figure 1 and Figure 2 respectively.

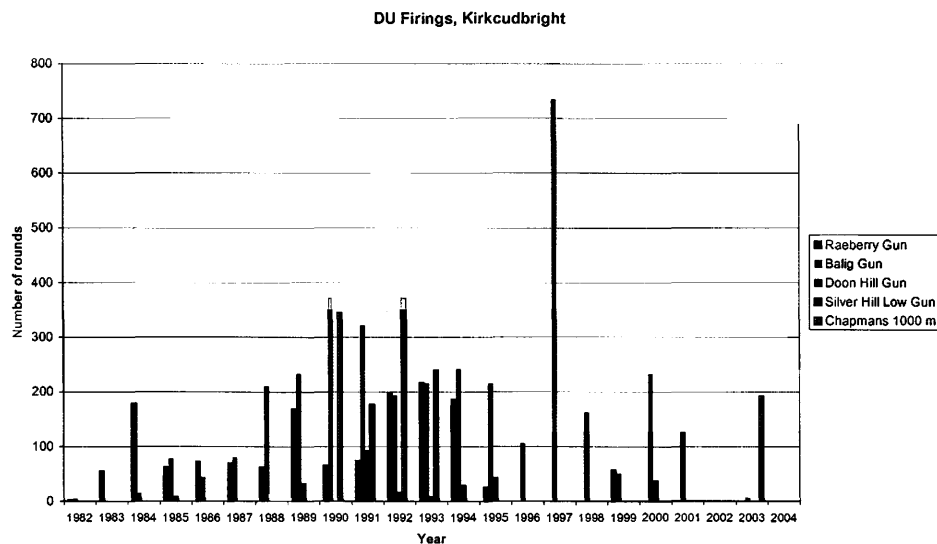


Figure 1: Estimate of the quantity of DU projectiles fired from KTA, from 1982 to 2004.

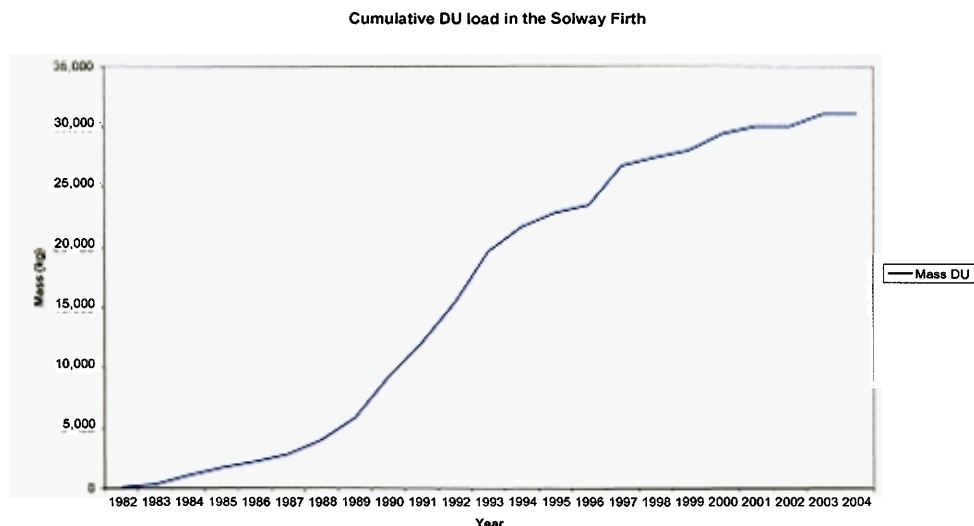


Figure 2: Approximate cumulative mass of DU projectiles fired from KTA, from 1982 to 2003.

UNCLASSIFIED

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 depleted uranium (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.

In natural uranium, ^{234}U is normally in equilibrium with ^{238}U , but as a result of depletion, the $^{238}\text{U}/^{234}\text{U}$ -activity ratio changes. The actual $^{238}\text{U}/^{234}\text{U}$ -activity ratio varies per batch of DU, according to the degree of depletion achieved during processing, but usually 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 (Bq) of ^{238}U to 1 Becquerel of ^{234}U (i.e. a $^{238}\text{U}/^{234}\text{U}$ ratio of 7 rather than 7:1).

When converting uranium concentrations, reported in micro-grams of uranium per gram of sample ($\mu\text{g/g}$) to activity, 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 [2].

	^{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%

4 Differentiating DU Input from Natural Uranium

A fundamental requirement of the DU environmental monitoring programme is to quantify the impact of DU firing. This is achieved, in part, by measuring the amount of total uranium in environmental material and using this as an indicator of contamination. However, uranium with a natural isotopic signature is present in natural materials, which complicates the assessment of the degree of contamination.

A convenient fingerprint marker for DU is the $^{238}\text{U}/^{234}\text{U}$ activity ratio. The DU fired at KTA has a $^{238}\text{U}/^{234}\text{U}$ activity ratio of approximately 7,

UNCLASSIFIED

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 $^{238}\text{U}/^{234}\text{U}$ activity ratio diverges significantly from its natural ratio. For the ratio to approach 7 in an analytical sample, the quantity of DU would have to be about 100 times the amount of uranium naturally present (see Annex E). 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), which can determine the activity ratio of each of the uranium isotopes of concern. Gamma measurements of environmental samples can also yield isotopic information, but this technique is not sensitive enough to reach the limits of detection required for environmental analysis, unless relatively large quantities of uranium are present.

5 Sample Collection

5.1 Sampling locations and dates of sampling

In August 2004, samples of intertidal sediment, seaweed and mussels were collected from the 11 sampling areas shown in Table 1 (and Figure 3). In August and December 2004, samples of underwater sediments were collected from the locations highlighted in Table 2 and Figure 4 and Figure 5. Samples of locally caught scallops and lobsters and crabs were purchased for analysis in August 2004.

5.2 Intertidal sediments sampling methodology

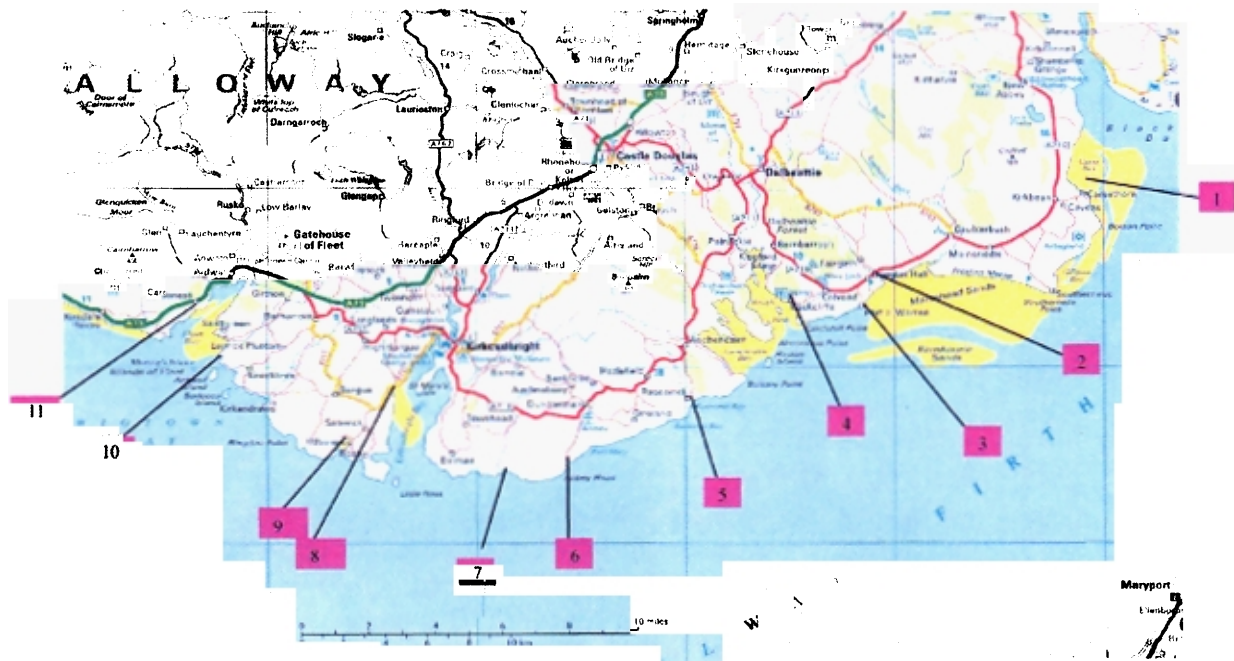
The composition, abundance and availability of sediments vary with time and location. Because of this, each intertidal sediment sample was a composite from a number of locations within each of the sampling areas shown on Figure 3. Sediment sub-samples were collected as near to the Low Water Mark (LWM) as safely possible. Where several sediment types were present in the sampling area, the finest sediment was selected, and shells and stones were discarded. At each sub-sampling location, the uppermost layer of sediment was sampled using a trowel, and combined with other sub-samples in a 1 litre water tight plastic container. This procedure was repeated at intervals along the shore line until the container was full. Excess water was drained from the tub prior to sealing.

UNCLASSIFIED

Sample Station		
Number	Name	Grid reference
1.	South Carse	GR 997 593
2.	Sandyhills Bay	GR 895 551
3.	Port o' Warren Bay	GR 879 532
4.	Port Donnel	GR 848 534
5.	Rascarral Bay	GR 805 480
6.	Abbey Burn Foot	GR 743 444
7.	Mullock Bay	GR 711 437
8.	Lower Nunton Bay	GR 661 485
9.	Brighthouse Bay	GR 635 454
10.	Carrick Point	GR 573 507
11.	Mossyard Bay	GR 554 518

Table 1: Intertidal Sample Station Areas, Summer 2004.

Figure 3: Kirkcudbright Training Area Shoreline Sampling Areas.



Reproduced by kind permission of Harper Collins Publishers © Harper Collins Publishers 2001

Table 2: Underwater sampling locations Summer and Winter 2004.

UNCLASSIFIED

Sample Station Number	Summer 2004		Sample Station Number	Winter 2004	
	Latitude (North)	Longitude (West)		Latitude (North)	Longitude (West)
1	54° 45.52'	4° 1.04'	SP1	54° 45.783'	4° 1.210'
2	54° 45.28'	4° 1.12'	SP2	54° 45.160'	4° 1.426'
3	54° 43.18'	4° 2.30'	SP3	54° 45.450'	3° 57.886'
4	54° 43.06'	4° 1.40'	SP4	54° 44.938'	3° 58.783'
5	54° 43.26'	4° 3.06'	SP5	54° 42.828'	4° 1.324'
6	54° 41.44'	4° 3.24'	1	54° 45.892'	4° 1.170'
7	54° 45.790'	4° 2.541'	2	54° 45.503'	4° 1.491'
8	54° 45.260'	4° 1.318'	3	54° 45.477'	4° 1.310'
9	54° 43.162'	4° 7.357'	4	54° 45.457'	4° 1.126'
10	54° 42.073'	4° 5.730'	5	54° 45.055'	4° 1.467'
11	54° 44.086'	4° 4.686'	6	54° 45.447'	3° 58.082'
12	54° 44.483'	4° 4.868'	7	54° 45.546'	3° 57.822'
13	54° 43.425'	4° 6.249'	8	54° 45.366'	3° 57.751'
14	54° 42.898'	4° 5.207'	9	54° 44.990'	3° 58.950'
15	54° 46.613'	3° 55.958'	10	54° 45.027'	3° 58.664'
16	54° 46.094'	3° 54.777'	11	54° 44.830'	3° 58.752'
17	54° 45.876'	3° 54.188'	12	54° 42.850'	4° 1.133'
18	54° 43.205'	4° 7.880'	13	54° 42.905'	4° 1.454'
19	54° 43.755'	4° 7.552'	14	54° 42.723'	4° 1.376'
20	54° 44.203'	4° 7.176'			
SP ^a	54° 44.432'	4° 2.303'			

(Note:SP – Splash Point)

5.3 Seaweed collection methodology

Seaweed was collected when found in abundance. The collected samples consisted of single species of seaweed, either *F. vesiculosus*, *F. ceranodies*, *F. serratus*. Only the most recent growth of seaweed was collected, by cutting the end 5 cm of fronds. As with the sediments samples, each seaweed sample was a composite from a number of locations within a sampling area. Samples were collected at intervals along the shore line until a 1.8 litre water tight plastic sample pot was full. The seaweed samples were not washed at the time of collection.

UNCLASSIFIED

5.4 Biota collection methodology

Shellfish were only collected when found in abundance. Samples of mussel (*M. edulis*) were collected from 4 of the sampling areas shown on Figure 3 (see Table 1 for details). Mussels were collected at a number of locations along the shoreline of a sampling area, and combined into a composite sample. The composite sample filled two 1 l sampling pots for each sampling area. The mussel samples were not washed at the time of collection. (Limpet or wrinkle samples are sometimes collected when mussels are not available. However during August 2004, neither mussels, wrinkles nor limpets could be found at 7 of the sampling areas.)

The mussel samples were individually boiled in water for two minutes, drained and prised from their shells within two days from collection. The shells were discarded, as were any mussels that remained closed after boiling. The flesh was placed in a individual 1.8 litre water tight plastic sample pot.

5.5 Dose rate measurements methodology

Gamma radiation measurements were made using three Mini Instruments Type 6-80/81 dose rate meters. The instruments were deployed so that the centres of the Geiger Muller tubes were at one metre above ground, at the High Water Mark (HWM) and the low water mark (LWM¹) in each sampling area (away from granite boulders and sea walls). Three 100 sec counts were taken at the LWM. The average of the three counts is used to calculate the dose rate. One 100 s. count was taken at the HWM, and is used to calculate the dose rate at that point.

5.6 Seafood purchase methodology

Three locally caught lobsters (*H. gammarus*) and 0.9 kg of queen scallops (*C. opercularis*) were purchased in Kirkcudbright, and boiled within a day of purchase. These were divided into 3 lobster samples, and 2 scallop samples, which were bagged and frozen pending transport to Dstl laboratory. (Whelks (*B. undatum*) and crabs were not available for purchase at the time of the visit).

5.7 Underwater sediment collection methodology

Underwater sediment samples were collected where there was enough sediment to fill sampling tubs. The sampling locations are shown in Figure 4 and Figure 5, and are listed in Table 2. Location 1 was not sampled in August 2004, and locations 1 and SP1 were not sampled in December 2004 for lack of sufficient sediments. As a result, 34 samples were collected in August

¹ The gamma monitors were placed as near as was safely possible to the LWM

UNCLASSIFIED

2004 from 20 locations, and 30 samples were collected from a further 17 locations in December 2004.

The dynamic nature of the sea makes the sampling of underwater sediment at precise locations difficult. A scooping device fitted with a rubberised bag was lowered in the water at each sampling location. This was dragged along the sea bed over a distance ranging between 50 and 100 m depending on tide and wind conditions. The location coordinates given in Table 2 should therefore be considered to be the approximate centre points of sampling areas of no more than 100 m radius.

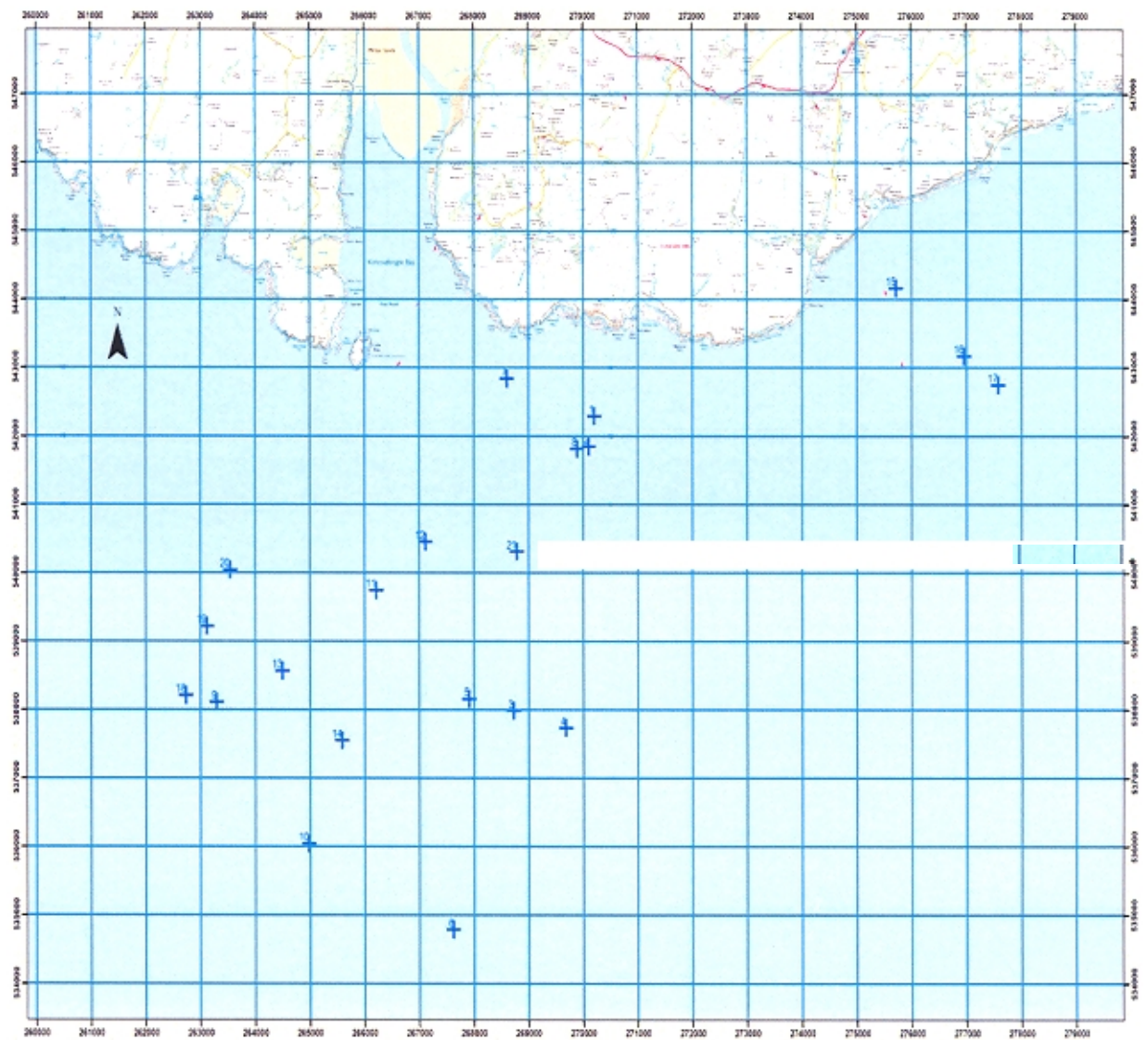


Figure 4: KTA- Underwater Sampling Points, Summer 2004.



UNCLASSIFIED

The provenance, types and numbers of samples procured from the intertidal sampling areas are listed in Table 3. The scoop contents were drained of excess water, and transferred into one or two sampling pots per location, until they were full. A summary of all underwater sediment samples collected at KTA in 2004, including details of duplicate samples where taken, is given in Table 4.

Sample Area Number	Sample Type, and number of samples				Environmental Doserates	
	Sediment	Seaweed	Mussel	Other	LWM @ 1m height	HWM @ 1m height
1	1	x	x	x	✓	✓
2	1	x	x	x	✓	✓
3	1	1	1	x	✓	✓
4	1	1	1	x	✓	✓
5	1	1	x	x	✓	✓
6	1	1	x	x	✓	✓
7	1	1	x	x	✓	✓
8	1	1	1	x	✓	✓
9	1	1	x	x	✓	✓
10	1	1	1	x	✓	✓
11	1	1	x	x	✓	✓

Table 3: Summary Intertidal Sample Collection, Summer 2004.

Notes: LWM – Low Water Mark
collected.

HWM – High Water Mark

x Sample not

5.8 Sample descriptor code

Each sample was given a unique sample descriptor. For intertidal and underwater sediments, seaweed and mussels the descriptor comprised of a descriptor of sample type, followed by a location descriptor. In the case of purchased sea food no location descriptor has been included because the precise provenance of the sample is unknown.

The sample type descriptors are as follows:

- I/T sed - Intertidal sediment,
- U/W sed - Underwater sediment,

UNCLASSIFIED

- F. vesic/ F. ceranodies/ F serratus – sea weed,
- M. edulis – Mussel; and,
- Scallop, Lobster.

In the case of underwater sediment, which was collected in August and December 2004, samples procured in December 2004 are identified by a descriptor in bold type.

For duplicate samples at a particular location, A or B were added. Three examples of the sample descriptors are given below:

I/T sed 3 – for intertidal sediments collected from intertidal location 3.

U/W sed **8/A** – for replicate A of the underwater sediment collected in winter 2004, at underwater location 8, (54°45.366'N and 3°57.751'W).

M.EDULIS 10 – Mussel sample from Intertidal sampling location 10, Carrick Point.

UNCLASSIFIED

	Summer 2004		Winter 2004		
Sample Station Number	Sample Type		Sample Station Number	Sample Type	
	Sediment	No of samples		Sediment	No of samples
1	✕	✕	SP1 ^a	✕	✕
2	✓	2	SP2 ^a	✓	1
3	✓	2	SP3 ^a	✓	1
4	✓	2	SP4 ^a	✓	1
5	✓	2	SP5 ^a	✓	1
6	✓	2	1	✕	✕
7	✓	2	2	✓	2
8	✓	2	3	✓	2
9	✓	2	4	✓	2
10	✓	2	5	✓	2
11	✓	2	6	✓	2
12	✓	2	7	✓	2
13	✓	2	8	✓	2
14	✓	2	9	✓	2
15	✓	1	10	✓	2
16	✓	1	11	✓	2
17	✓	1	12	✓	2
18	✓	1	13	✓	2
19	✓	1	14	✓	2
20	✓	1			
SP ^a	✓	2			

Table 4: Summary of Underwater Sample Collection, Summer 2004 and Winter 2004.

Notes: ^a Splash Point

✕ Sample not collected.

UNCLASSIFIED

6 Sample preparation and laboratory analysis

Sample preparation was either carried out in the field at the time of collection, as described in sections 5.3, 5.4 and 5.6, or at the Dstl Environmental Sciences Department UKAS accredited radiochemistry laboratory, on receipt of the sample.

Underwater sediments samples were analysed in duplicate if sampled as such. One mixed sample of mussel flesh was submitted for analysis per location. Cooked lobsters were opened up and the flesh removed for analysis, but the digestive tracts of the animals were not used. Each lobster was analysed as a discrete sample. The scallop samples were analysed in duplicate, as purchased.

The sediments, seaweed and animal samples were dried to remove moisture and then weighed. The samples were then ashed to remove organic material. During this process the quantity of uranium in each of the samples would have remained constant. The ashed samples were then boiled in concentrated mineral acid (HNO_3 and HCl) 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 would not have been removed. The samples were then filtered to remove solids.

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

DU concentrations are been reported in mBq/g (equivalent to Bq/kg) of dry weight.

7 Results and interpretation

The detailed marine monitoring results are given in Table 6 to Table 11. A summary of the results for all marine samples collected in 2004 is given in Table 5.

To identify whether the DU firing activities at KTA have impacted on uranium concentrations in the local marine environment, it is useful to compare the results for the routine monitoring programme with uranium activities and ratios reported for similar sample types across the UK. Two studies have reported ambient dose rates and uranium activity in marine sediment, seaweed and biota samples from a range of coastal locations in the UK [3, 4]. One of the studies [4] included samples from a location in the South-West of Scotland, named Sandyhills, which is sufficiently near to KTA to be of comparable geo-physico-chemistry and sufficiently far to be considered unaffected by activities at the range (See Annex D).

UNCLASSIFIED

Historical monitoring results for the KTA marine environment presented in Annex A provide an overview of the routine monitoring results through time, from 1996 to 2003.

Sample Type	Number of Samples	No. of positive* samples	Mean Total Uranium Concentration (mBq/g)	Mean Ratio of $^{238}\text{U}/^{234}\text{U}$
Shore Sediment	11	3	8.6 ± 1.3	1.1 ± 0.3
Seaweed	9	0	14.5 ± 1.7	0.9 ± 0.2
Mussels	4	0	5.9 ± 0.6	0.9 ± 0.2
Scallops (Queens)	2 ^a	0	3.0 ± 0.3	0.9 ± 0.2
Lobsters	3 ^b	0	0.4 ± 0.1	1.0 ± 0.4
Underwater Sediment	34	0	25.3 ± 2.8	1.1 ± 0.2
Underwater Sediment	30	0	22.5 ± 2.6	1.0 ± 0.2

Table 5: Summary of results, all marine samples 2004 (values have been rounded to 1 decimal place for clarity).

Notes: * At variance with average levels for UK coastal conditions (see Annex D)

a: 2 replicate samples

b: value reported for one sample only

7.1 Dose rates

Dose rate measurement results for 2004 are given in Table 6. The maximum recorded dose rate was 125 nSv/h. Dose rates were not reported in 2000, 2001 or 2002. The results compare with dose rate measurements made in 2003, and are considered to reflect background dose rates.

Table 6: Intertidal doserate measurements, August 2004.

Station Number	Location	Average Dose rate (nSv/h)
1	South Carse	65
2	Sandyhills Bay	95
3	Port o' Warren Bay	125
4	Port Donnel	90
5	Rascarral Bay	125
6	Abbey Burn Foot	90
7	Mullock Bay	100
8	Lower Nunton Bay	80
9	Brighthouse Bay	70
10	Carrick Point	75
11	Mossyard Bay	75

UNCLASSIFIED

7.2 Intertidal sediments results

The intertidal sediment samples all contained ^{238}U at activities that were within the range (3.6 to 32.3 mBq/g of dry weight) for UK coastal sediments (See Table 7). One sample (I/T sed 2) had a ^{238}U value slightly in excess of the value reported for sediment obtained from Sandyhills [4] in Southwest Scotland, but the variation (30%) is not deemed significant where such low activities are concerned (see Annex D). The average concentration for the samples is well below the averages reported for intertidal sediment collected since 1996 (see Annex A). This may not be significant, as variations from year to year should be expected in the shore environment (See Annex B)

The isotopic ratios for 8 of the 11 intertidal sediment samples collected are, within the range of the uncertainty for the analysis, in agreement with values reported in marine sediments in general (see Annex C). Three samples (I/T sed 2, IT sed 5, IT sed 11) have uranium isotopic ratios greater than 0.8, indicating a slight degree of depletion. However, the increases in the isotopic ratio are not accompanied by a corresponding rise in the total uranium activity that would be expected for a natural medium contaminated by DU (see Annex E). Total uranium values for the three samples are low, ranging from 4.3 ± 0.6 to 35.4 ± 3.7 mBq/g of dry weight. The slightly elevated isotopic ratios may therefore be considered to be an artefact of counting statistics and radiologically insignificant.

7.3 Underwater sediments results

The isotopic and total uranium values reported (in Table 8 and Table 9) for all 64 underwater sediments samples were all within the UK coastal sediments ^{238}U range of 3.6 to 32.3 mBq/g of dry weight (see Annex C). Comparison of the results obtained in August 2004 with the results of the December 2004 survey shows close agreement, and the mean total uranium concentrations results also agreed with mean values reported in previous years. This correlation is to be expected in such a well mixed environment

The $^{238}\text{U}/^{234}\text{U}$ isotopic ratios reported for all 64 underwater sediments samples were, within the range of the uncertainty for the analysis, in agreement with values generally reported in marine sediments (see Annex C). Comparison of the August 2004 $^{238}\text{U}/^{234}\text{U}$ isotopic ratios with those for December 2004 shows close agreement, and the results for both sampling rounds agree with mean values reported in previous years. As for total uranium activity, this correlation is to be expected in such a well mixed environment

UNCLASSIFIED

7.4 Intertidal seaweed results

The ^{238}U activity values for the seaweed samples obtained from the 9 locations sampled were low, and in agreement with the range of values reported for seaweed sampled in the UK as a whole. They were slightly higher than values reported for seaweed obtained from Sandyhills. This variation may be due to the fact that the seaweed obtained during the KTA marine environmental survey was not systematically washed to remove sediment that may have adhered to the weed (See Section 5.3). The mean total uranium result is in agreement with mean values reported in previous years (See Annex A).

There are no reported values of the $^{238}\text{U}/^{234}\text{U}$ isotopic ratios in seaweed. Values reported here are in agreement with those reported for the same locations from 1996 to 2003, and do not indicate the presence of depleted uranium.

7.5 Biota results

The four mussel samples collected during August 2004 yielded ^{238}U values that were slightly above the values reported for mussels sampled at Sandyhills, but were at the lower end of the range of values reported for mussels sampled in the UK as a whole. However, the variation is not deemed significant, at such low concentrations. In addition, it may be due to the fact that sediment adhered to the shells was not systematically washed prior to the cooking step (See section 5.4). Sediment from the shells may have accidentally contaminated the mussel flesh that was supplied for analysis. The mean total uranium result is in agreement with mean values reported in previous years (see Annex A).

Uranium-238 was only detected in one of the three lobsters that were analysed, the other two lobster samples having ^{238}U values below their calculated limits of detection. The mean total uranium result is in agreement with mean values reported in previous years. The ^{238}U concentration that was measured was a factor of 10 greater than the mean value for lobsters obtained from the UK as a whole. However, the ^{238}U concentration here is reported per gram of dry weight, whereas the UK results reported by CEFAS are per gram of wet weight [14]. Since the drying step of the lobster sample preparation removed moisture equal to 81% of the sample wet weight, the corresponding wet weight activity for this lobster sample would be 0.07 mBq/g. (Sample preparation is discussed in Section 6.3 and at Annex B). This value is twice the mean value for lobsters obtained from the UK as a whole, but at such a low concentration is not deemed significant.

The ^{238}U values for the duplicate scallop samples are in agreement with each other, and compare with ^{238}U values for other molluscs from Sandyhills and from the UK at large. The mean total uranium result is in agreement with mean values reported in previous years (see Annex A)

UNCLASSIFIED

The $^{238}\text{U}/^{234}\text{U}$ isotopic ratios reported for all marine biota, including the food stuff that was purchased are in agreement with values reported in previous years, and do not indicate the presence of depleted uranium.

8 Evaluation of potential exposure pathways.

The contamination of the marine environment with DU would result in four potential exposure pathways for humans. These are:

- external radiation exposure from contaminated seaweed or sediments;
- inhalation of DU contamination released into the air or re-suspended from sediments;
- ingestion of seaweed crop or animal products contaminated with DU; and,
- ingestion of DU contaminated sea water.

8.1 External radiation

Radiation levels on the shore are indistinguishable from natural background levels and hazards due to external radiation exposure are therefore considered to be insignificant.

8.2 Inhalation of re-suspended DU.

DU that has been deposited in sediment or in sediment attached to objects and plants such as fishermen's netting and seaweed may be re-suspended into the air and subsequently inhaled. Results reported here show that measured total uranium values do not exceed background values for UK sediments and that there is no evidence of depletion in the isotopic ratios. Consequently, it is concluded that there are no risks of additional inhalation exposure to any member of the public.

8.3 Ingestion of DU Contaminated foodstuffs

Total uranium concentrations in the marine foodstuff was in agreement with background levels for such sample types. There was no evidence of depletion in the isotopic ratio. It is concluded that there are no risks of additional ingestion exposure to any member of the public over that of natural background

8.4 Ingestion of DU contaminated seawater

Seawater sampling was discontinued at the recommendation of SEPA in 2001 because the immense dilution present in the Solway would never give rise to uranium levels detectable above background. No radiation dose over that of natural background can be attributed to this exposure route.

9 Conclusions

It is concluded that:

- the survey results show no evidence of DU being present in any marine environmental sample collected in the year 2004; and,
- There is no evidence to suggest that members of the public are subjected to any radiation hazard from the marine environment due to the firing of DU ammunition at Kirkcudbright.

10 Recommendations

Samples have been collected regularly for the last nine years and the data should be subjected to a collective review, to establish whether environmental monitoring should continue in its present form.

11 Acknowledgements

The author would like to acknowledge the contributions made by Mr Aylward, Mr Goble and to Mr Newman of KTA for the sampling and to Mrs Marshall, Miss Mansfield and Mr Gingell (all from Dstl ESD) for the radiochemical analysis. Grateful thanks are also due to Dr. Adrian Baker for the technical review, and Mr. Alan Anderson for Radiation Protection Advisor oversight.

12 List of references

- [1] Toque, C. "Terrestrial Environmental Depleted Uranium Survey Report, Kirkcudbright Training Area, 2004". 7843, (2006)
- [2] Depleted Uranium, Sources, Exposure and Health Effects. World Health organisation WHO/SDE/PHE/01.1, (2001).
- [3] Radioactivity in Food and the Environment, 2003. The Centre for Environment, Fisheries and Aquaculture Science, (2004).
- [4] McDonald P. Cook G.T. and Baxter M.S. Natural and artificial radioactivity in coastal regions of UK. In: Radionuclides in the Study of Marine Processes (Ed. By Kershaw P.J. and Woodhead D.S.), Elsevier Applied Science, London. (1991).

UNCLASSIFIED

Sample Descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of ²³⁸ U / ²³⁴ U		
				²³⁸ U			²³⁵ U			²³⁴ U			Total U					
I/T sed 1	629.44	134.54	132.77	3.8	±	0.9		<	0.4	4.0	±	0.9	7.9	±	1.3	1.0	±	0.3
I/T sed 2	546.54	107.39	103.80	18.1	±	2.7		<	0.4	16.9	±	2.5	35.4	±	3.7	1.1	±	0.2
I/T sed 3	503.36	389.22	91.57	2.1	±	0.4	0.1	±	0.1	2.0	±	0.4	4.2	±	0.5	1.1	±	0.3
I/T sed 4	573.43	417.75	91.25	2.7	±	0.5	0.2	±	0.1	2.5	±	0.4	5.4	±	0.6	1.1	±	0.3
I/T sed 5	507.22	413.72	100.42	3.8	±	0.6		<	0.1	3.2	±	0.5	7.0	±	0.8	1.2	±	0.3
I/T sed 6	548.50	488.27	99.58	2.8	±	0.5		<	0.1	2.6	±	0.4	5.5	±	0.6	1.0	±	0.2
I/T sed 7	496.56	380.66	100.93	4.4	±	0.8		<	0.2	4.7	±	0.8	9.2	±	1.1	1.0	±	0.2
I/T sed 8	498.24	377.19	113.64	3.1	±	0.5		<	0.2	3.0	±	0.5	6.1	±	0.8	1.0	±	0.3
I/T sed 9	444.52	348.51	125.98	2.8	±	0.5		<	0.2	2.8	±	0.5	5.6	±	0.7	1.0	±	0.3
I/T sed 10	464.21	348.47	107.77	2.0	±	0.4		<	0.1	2.2	±	0.4	4.3	±	0.5	0.9	±	0.2
I/T sed 11	512.21	406.71	119.07	2.4	±	0.4		<	0.1	1.9	±	0.4	4.3	±	0.6	1.3	±	0.3

Table 7: Intertidal (Shoreline) sediment samples, total uranium and isotopic ratio results - August 2004.

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 are calculated by a 'modified Currie' formula¹ 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.

¹ Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)
CR/18154 V1

UNCLASSIFIED

UNCLASSIFIED

Sample descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of ²³⁸ U / ²³⁴ U		
				²³⁸ U			²³⁵ U			²³⁴ U			Total U					
U/W sed 2A	602.50	85.30	82.04	10.9	±	1.8	0.5	±	0.3	10.7	±	1.8	22.1	±	2.5	1.0	±	0.2
U/W sed 2B	544.31	82.32	78.87	10.9	±	1.7	0.8	±	0.3	10.9	±	1.7	22.6	±	2.4	1.0	±	0.2
U/W sed 3A	606.58	80.35	76.52	13.0	±	1.9	0.7	±	0.3	13.0	±	1.9	26.7	±	2.7	1.0	±	0.2
U/W sed 3B	586.53	69.65	66.67	11.9	±	1.8	0.8	±	0.3	13.2	±	1.9	25.9	±	2.7	0.9	±	0.2
U/W sed 4A	599.27	71.77	68.81	15.1	±	2.3	0.7	±	0.4	14.0	±	2.2	29.9	±	3.2	1.1	±	0.2
U/W sed 4B	578.10	71.57	68.34	14.1	±	2.3		<	0.52	12.5	±	2.1	27.1	±	3.1	1.1	±	0.3
U/W sed 5A	596.92	78.39	74.90	13.8	±	2.1	0.6	±	0.3	12.8	±	2.0	27.2	±	2.9	1.1	±	0.2
U/W sed 5B	553.49	82.70	78.85	11.8	±	1.9		<	0.4	11.6	±	1.9	23.7	±	2.7	1.0	±	0.2
U/W sed 6A	570.07	77.73	73.89	14.0	±	2.1		<	0.4	14.4	±	2.1	28.7	±	3.0	1.0	±	0.2
U/W sed 6B	524.97	72.51	69.17	16.0	±	2.6		<	0.5	16.6	±	2.6	33.2	±	3.7	1.0	±	0.2
U/W sed 7A	594.40	82.11	78.61	11.2	±	1.9		<	0.5	9.9	±	1.7	21.5	±	2.5	1.1	±	0.3
U/W sed 7B	563.24	83.70	79.48	13.2	±	2.1	0.5	±	0.3	12.1	±	2.0	25.8	±	2.9	1.1	±	0.3
U/W sed 8A	559.82	93.46	88.96	10.3	±	1.6		<	0.3	9.7	±	1.5	20.2	±	2.2	1.1	±	0.2
U/W sed 8B	537.96	73.54	70.05	10.7	±	1.7		<	0.4	10.4	±	1.7	21.4	±	2.5	1.0	±	0.2
U/W sed 9A	550.43	79.94	76.21	13.8	±	2.2	0.5	±	0.3	14.5	±	2.3	28.8	±	3.2	0.9	±	0.2
U/W sed 9B	505.12	67.15	64.19	14.4	±	2.3		<	0.5	13.8	±	2.2	28.6	±	3.2	1.0	±	0.2
U/W sed 10A	612.21	76.36	73.06	12.3	±	2.0	0.8	±	0.4	10.9	±	1.8	23.9	±	2.7	1.1	±	0.3
U/W sed 10B	608.78	84.43	80.66	13.4	±	2.0	0.5	±	0.3	13.4	±	2.0	27.2	±	2.9	1.0	±	0.2
U/W sed 11A	591.98	84.27	80.17	11.3	±	1.8		<	0.4	10.7	±	1.8	22.4	±	2.6	1.1	±	0.2
U/W sed 11B	564.19	84.19	80.09	12.3	±	1.9	0.5	±	0.3	11.2	±	1.8	23.9	±	2.6	1.1	±	0.2
U/W sed 12A	580.36	81.27	77.40	13.3	±	2.2		<	0.5	12.6	±	2.1	26.1	±	3.0	1.1	±	0.2
U/W sed 12B	558.28	78.29	74.90	14.3	±	2.3	0.6	±	0.3	13.1	±	2.2	27.9	±	3.2	1.1	±	0.3
U/W sed 13A	553.84	76.79	73.46	13.8	±	2.1	0.4	±	0.2	12.7	±	2.0	26.9	±	2.9	1.1	±	0.2
U/W sed13B	598.30	85.13	81.09	14.0	±	2.2	0.8	±	0.4	12.5	±	2.0	27.3	±	3.0	1.1	±	0.2
U/W sed 14A	580.87	85.86	81.61	12.2	±	2.0	0.7	±	0.3	11.1	±	1.8	24.0	±	2.7	1.1	±	0.3
U/W sed 14B	571.81	75.15	71.51	13.0	±	2.0	0.5	±	0.3	10.9	±	1.7	24.4	±	2.7	1.2	±	0.3
U/W sed 15	534.68	96.31	93.18	9.2	±	1.5		<	0.4	9.3	±	1.6	18.7	±	2.2	1.0	±	0.2

UNCLASSIFIED

UNCLASSIFIED

Sample descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of $^{238}\text{U}/^{234}\text{U}$		
				^{238}U			^{235}U			^{234}U			Total U					
U/W sed 16	526.57	95.44	92.20	10.9	±	1.8		<	0.4	9.5	±	1.6	20.8	±	2.4	1.1	±	0.3
U/W sed 17	530.67	95.69	92.33	9.8	±	1.7		<	0.4	8.0	±	1.4	18.2	±	2.2	1.2	±	0.3
U/W sed 18	552.72	71.77	67.42	16.4	±	2.5	0.6	±	0.3	14.4	±	2.3	31.4	±	3.4	1.1	±	0.2
U/W sed 19	543.24	75.84	71.47	12.9	±	2.1		<	0.5	10.8	±	1.8	24.1	±	2.8	1.2	±	0.3
U/W sed 20	542.45	79.96	75.60	13.1	±	2.0	0.6	<	0.3	12.2	±	1.9	25.9	±	2.8	1.1	±	0.2
U/W sed SP/A	607.00	65.05	62.24	14.3	±	2.2	0.5	<	0.3	12.7	±	2.0	27.4	±	2.9	1.1	±	0.2
U/W sed SP/B	624.94	76.25	72.86	12.0	±	1.9	0.6	<	0.3	12.8	±	2.0	25.3	±	2.7	0.9	±	0.2

Table 8: Underwater sediment samples, total uranium and isotopic ratio results - August 2004.

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 are calculated by a 'modified Currie' formula² 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.

² Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)
CR/18154 V1

UNCLASSIFIED

UNCLASSIFIED

Sample Descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of ²³⁸ U / ²³⁴ U		
				²³⁸ U			²³⁵ U			²³⁸ U			Total U					
U/W sed S/P2	117.21	88.00	84.73	9.6	±	1.6	0.5	±	0.3	10.7	±	1.8	20.8	±	2.4	0.9	±	0.2
U/W sed S/P3	121.82	89.31	85.58	10.2	±	1.9		<	0.6	9.2	±	1.8	19.9	±	2.6	1.1	±	0.3
U/W sed S/P4	128.53	94.44	90.61	8.7	±	1.6	0.7	±	0.3	10.6	±	1.8	20.0	±	2.4	0.8	±	0.2
U/W sed S/P5	114.62	83.71	80.08	12.4	±	2.1		<	0.5	12.6	±	2.1	25.4	±	2.9	1.0	±	0.2
U/W sed 2/A	104.44	75.89	73.01	10.8	±	1.8	0.7	±	0.3	10.4	±	1.7	21.9	±	2.5	1.0	±	0.2
U/W sed 2/B	112.71	83.64	80.32	12.3	±	2.0	0.9	±	0.4	11.7	±	1.9	24.9	±	2.8	1.1	±	0.2
U/W sed 3/A	114.04	84.72	81.22	11.2	±	1.9	0.7	±	0.4	10.5	±	1.8	22.4	±	2.7	1.1	±	0.3
U/W sed 3/B	116.39	86.45	83.05	10.9	±	1.8	0.5	±	0.3	10.6	±	1.7	22.0	±	2.5	1.0	±	0.2
U/W sed 4/A	117.21	86.32	82.99	11.3	±	1.8		<	0.4	10.4	±	1.7	21.9	±	2.5	1.1	±	0.2
U/W sed 4/B	129.04	91.34	87.87	10.5	±	1.7	0.7	±	0.3	10.1	±	1.7	21.2	±	2.5	1.0	±	0.2
U/W sed 5/A	118.43	87.51	84.19	10.9	±	1.9	0.6	±	0.3	11.2	±	1.9	22.7	±	2.7	1.0	±	0.2
U/W sed 5/B	124.56	92.14	88.50	10.2	±	1.9	0.6	±	0.4	9.7	±	1.9	20.6	±	2.7	1.0	±	0.3
U/W sed 6/A	110.40	80.71	77.52	10.9	±	2.0		<	0.6	11.1	±	2.0	22.3	±	2.8	1.0	±	0.3
U/W sed 6/B	122.34	89.50	86.18	10.4	±	1.8		<	0.5	8.7	±	1.5	19.2	±	2.3	1.2	±	0.3
U/W sed 7/A	115.62	82.73	79.14	9.1	±	1.6	0.8	±	0.3	9.6	±	1.6	19.5	±	2.3	1.0	±	0.2
U/W sed 7/B	121.46	86.83	82.96	10.9	±	1.8	0.7	±	0.3	10.4	±	1.8	22.0	±	2.6	1.0	±	0.2
U/W sed 8/A	119.52	84.33	80.26	9.8	±	1.7	1.4	±	0.5	10.8	±	1.8	22.0	±	2.6	0.9	±	0.2
U/W sed 8/B	118.85	85.43	81.66	8.3	±	1.4	0.6	±	0.3	8.1	±	1.3	17.0	±	1.9	1.0	±	0.2
U/W sed 9/A	126.28	92.80	89.21	10.1	±	1.7	0.6	±	0.3	9.6	±	1.6	20.3	±	2.4	1.1	±	0.3
U/W sed 9/B	119.18	84.76	81.49	11.4	±	1.9	0.6	±	0.3	11.5	±	1.9	23.5	±	2.7	1.0	±	0.2
U/W sed 10/A	122.27	90.90	87.23	11.3	±	2.1	4.8	±	1.2	11.7	±	2.2	27.8	±	3.3	1.0	±	0.3
U/W sed 10/B	117.72	84.28	80.26	9.9	±	1.6		<	0.4	10.4	±	1.7	20.6	±	2.4	1.0	±	0.2
U/W sed 11/A	116.53	86.37	82.89	11.7	±	1.9		<	0.4	10.7	±	1.8	22.7	±	2.6	1.1	±	0.3
U/W sed 11/B	119.17	87.98	84.79	9.8	±	1.6		<	0.4	9.9	±	1.6	20.0	±	2.3	1.0	±	0.2
U/W sed 12/A	103.11	72.20	68.89	12.5	±	1.9		<	0.4	11.3	±	1.8	24.2	±	2.7	1.1	±	0.2
U/W sed 12/B	115.45	80.28	76.28	13.9	±	2.2		<	0.5	13.6	±	2.2	27.9	±	3.1	1.0	±	0.2
U/W sed 13/A	115.72	82.53	78.47	13.5	±	2.1	0.6	±	0.3	13.9	±	2.2	28.0	±	3.1	1.0	±	0.2

UNCLASSIFIED

UNCLASSIFIED

Sample Descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of ²³⁸ U / ²³⁴ U		
				²³⁸ U			²³⁵ U			²³⁸ U			Total U					
U/W sed 13/B	109.64	78.71	75.09	11.7	±	1.9	0.8	±	0.4	10.8	±	1.8	23.3	±	2.6	1.1	±	0.2
U/W sed 14/A	110.84	80.27	76.77	12.8	±	2.1		<	0.5	12.5	±	2.1	25.7	±	3.0	1.0	±	0.2
U/W sed 14/B	110.07	78.91	75.39	13.3	±	2.1	0.5	±	0.3	10.8	±	1.8	24.5	±	2.7	1.2	±	0.3

Table 9: Underwater sediment samples, total uranium and isotopic ratio results - December 2004.

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 are calculated by a 'modified Currie' formula³ 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.

³ Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)
CR/18154 V1

UNCLASSIFIED

UNCLASSIFIED

Sample Descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of ²³⁸ U / ²³⁴ U		
				²³⁸ U			²³⁵ U			²³⁸ U			Total U					
F.VESIC 3	316.55	68.89	19.03	6.5	±	1.1	0.3	±	0.2	8.5	±	1.4	15.3	±	1.8	0.8	±	0.2
F.VESIC 4	218.61	48.68	12.14	6.6	±	1.1		<	0.2	7.3	±	1.2	14.0	±	1.6	0.9	±	0.2
F.VESIC 5	237.72	55.68	15.13	5.6	±	1.1		<	0.4	5.4	±	1.1	11.3	±	1.6	1.0	±	0.3
F.VESIC 6	249.19	50.70	13.66	8.8	±	1.3	0.2	±	0.1	9.6	±	1.4	18.6	±	1.9	0.9	±	0.2
F.CERANODIES 7	255.69	70.69	14.81	5.3	±	0.8	0.2	±	0.1	6.6	±	1.0	12.1	±	1.3	0.8	±	0.2
F.SERRATUS 8	202.98	42.39	7.93	4.3	±	0.7		<	0.1	4.8	±	0.7	9.2	±	1.0	0.9	±	0.2
F.SERRATUS 9	255.88	45.95	10.67	5.3	±	0.8	0.2	±	0.1	5.9	±	0.8	11.4	±	1.1	0.9	±	0.2
F.SERRATUS 10	169.47	45.08	10.83	7.4	±	1.1	0.3	±	0.1	8.2	±	1.2	15.9	±	1.7	0.9	±	0.2
F.SERRATUS 11	213.09	59.35	17.17	10.3	±	1.7		<	0.4	12.0	±	2.0	22.6	±	2.6	0.9	±	0.2

Table 10: Seaweed samples, total uranium and isotopic ratio results – August 2004.

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 are calculated by a 'modified Currie' formula⁴ 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 10, 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.

⁴ Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)
Page 30 of 44

UNCLASSIFIED

Sample Descriptor	Wet weight (g)	Dry weight (g)	Ashed weight (g)	Measured Activity of Dry Sample (mBq/g)												Ratio of $^{238}\text{U} / ^{234}\text{U}$		
				^{238}U			^{235}U			^{238}U			Total U					
M.EDULIS 3	106.00	34.70	4.40	3.1	±	0.5		<	0.1	3.6	±	0.6	6.8	±	0.8	0.9	±	0.2
M.EDULIS 4	106.2	34.11	4.07	3.4	±	0.5	0.2	±	0.1	4.1	±	0.6	7.8	±	0.8	0.8	±	0.2
M.EDULIS 8	230.82	69.57	5.76	1.9	±	0.3		<	0.1	2.0	±	0.3	4.0	±	0.4	0.9	±	0.2
M.EDULIS 10	115.84	33.08	3.76	2.4	±	0.4	0.1	±	0.1	2.5	±	0.4	5.0	±	0.5	0.9	±	0.2
SCALLOP A	430.04	21.51	1.71	1.4	<	0.2	0.1	±	0.0	1.6	±	0.3	3.1	±	0.3	0.9	±	0.2
SCALLOP B	472.88	20.65	1.72	1.3	<	0.2		<	0.1	1.5	±	0.2	2.8	±	0.3	0.9	±	0.2
LOBSTER	130.76	24.26	2.06	0.2	±	0.1		<	0.0	0.2	±	0.1	0.4	±	0.1	1.0	N/A	0.4
LOBSTER	121.00	26.66	1.64		<	0.1		<	0.0	0.1	±	0.0	N/A	±	N/A		N/A	
LOBSTER	136.80	24.90	2.01		<	0.1		<	0.0	0.1	±	0.0	N/A	±	N/A		N/A	

Table 11: Marine biota samples, total uranium and isotopic ratio results – August 2004

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 are calculated by a 'modified Currie' formula⁵ 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 11, 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.

⁵ Revisiting Currie - how low can you go? by Hurtgen C, Jerome S, Woods M. Applied Radiation and Isotopes 53 pp 45-50 (2000)
CR/18154 V1

UNCLASSIFIED

UNCLASSIFIED

This page is intentionally blank

UNCLASSIFIED

ANNEX A Historical data

UNCLASSIFIED

Sample Type	1996	1997	1998	1999	2000	2001	2002	2003
Shore Sediment	22.0 ± 2.4 (1.0 ± 0.2)	29.2 ± 2.8 (1.0 ± 0.2)	21.7 ± 2.0 (1.0 ± 0.1)	23.1 ± 2.3 (1.0 ± 0.0)	13.0 ± 4.5 (1.1 ± 0.1)	20.6 ± 8.3 (1.1 ± 0.2)	22.7 ± 12.4 (1.1 ± 0.2)	21.3 ± 9.9 (1.0 ± 0.2)
Seaweed	15.5 ± 2.3 (0.9 ± 0.2)	16.7 ± 1.6 (0.9 ± 0.2)	10.4 ± 1.4 (1.0 ± 0.0)	10.8 ± 0.7 (1.0 ± 0.1)	3.1 ± 0.3 (0.9 ± 0.1)	9.3 ± 0.2 (1.0 ± 0.2)	11.0 ± 5.3 (0.9 ± 0.1)	16.4 ± 7.6 (0.9 ± 0.1)
Mussels	9.6 ± 0.9 (0.9 ± 0.2)	8.5 ± 0.8 (0.9 ± 0.2)	9.7 ± 0.8 (0.9 ± 0.1)	8.44 ± 0.89 (0.9 ± 0.0)	4.9 ± 0.7 (0.8 ± 0.1)	8.2 ± 2.9 (0.5 ± 0.3)	7.5 ± 1.7 (0.9 ± 0.1)	6.5 ± 0.7 (0.8 ± 0.1)
Whelks	x	x	2.8 ± 0.1 (0.9 ± 0.1)	0.3 ± 0.03 (0.9 ± 0.2)	1 ± 0.1 (0.9 ± 0.2)	4.3 ± 3.2 (0.8 ± 0.3)	3.5 ± 2.0 Not reported	x
Scallops	x	3.3 ± 0.6 (0.9 ± 0.3)	3.0 ± 0.1 (0.9 ± 0.1)	0.9 ± 0.1 (1.5 ± 0.1)	1.0 ± 0.1 (0.9 ± 0.2)	9.6 ± 3.8 (1.1 ± 0.3)	x	8.1 ± 12.4 Not reported
Crabs	x	0.0 ± 0.0 (0.9 ± 0.5)	x	0.4 ± 0.0 (1.6 ± 0.1)	x	1.8 ± 0.8 (1.0 ± 0.1)	2.2 ± 0.0 Not reported	0.9 ± 1.2 Not reported
Lobsters	x	x	0.2 ± 0.0 (0.1 ± 0.1)	0.3 ± 0.0 (0.3 ± 0.2)	0.4 ± 0.1 (1.2 ± 0.5)	2.7 ± 0.4 (1.1 ± 0.4)	1.5 ± 0.4 Not reported	1.9 ± 1.6 Not reported
Underwater Sediment	27.4 ± 3.1	25.5 ± 2.4 (1.0 ± 0.2)	25.4 ± 1.1 (0.9 ± 0.1)	22.2 ± 2.4 (0.9 ± 0.1)	7.8 ± 1.7 (1.0 ± 0.1)	24.1 ± 2.9 (1.0 ± 0.1)	25.4 ± 3.5 (1.0 ± 0.1)	26.9 ± 2.8 (1.0 ± 0.1)

Table 12: Summary of marine results reported for 1996-2003.

Note: Mean uranium concentrations are given in mBq/g of dry weight. The isotopic $^{238}\text{U}/^{234}\text{U}$ ratio is given in parenthesis

UNCLASSIFIED

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

A number of issues may give rise to uncertainties, when interpreting or comparing uranium data:

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

Analytical approaches

Sediment 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 sediments data, which may be reported as wet weight. Sediment samples reported as dry weight will appear to have concentrations of uranium at least 20% higher than those reported as wet weight (although this will depend on the moisture content).

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

Uranium concentrations in seaweed may be affected by contamination of surfaces with sediment particles. Preparation of seaweed 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 seaweed analyses.

Seaweed and marine biota 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. For marine biota, samples reported as dry weight will appear to have concentrations of uranium higher than those reported as wet weight. The relative increase in uranium concentration will depend on the moisture content, and can be as much as 300% for molluscan species (welks, scallops) [5].

Statistical variations

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

Spatial variations

Any DU contamination will not be uniformly distributed within a sampling area, but will depend on the surface water flow, and the movement of tides and sediments. Hence, the repeat sampling and analysis of sediment from within an area may give rise to a significant degree of variation.

In addition to DU contamination due to firing at the KTA, 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 fertilisers to agricultural land. Veins rich in uranium minerals occur naturally along the coast of the Solway Firth, such as uraninite found at Needle's Eye on the north coast of the estuary. These features are thought to be present on a more regional basis, although this has not been studied [6, 7].

Temporal variations

There will be natural temporal variations in the uranium concentration and abundance of the various isotopes in the seawater, for example, due to seasonal variations in rainfall. Rainfall can impact on the dissolution of uranium, and its migration in surface waters, which eventually enter the sea in coastal regions.

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).

Marine 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 substrate characteristics (uranium concentration and speciation as well as other physico-chemical characteristics) and varies with plant species.

Animal uptake of uranium is affected by their life habits, feeding patterns, physiology and the uranium concentration in their foodstuffs and the environment. The marine animals that have been sampled were chosen for their importance in the human food chain. Animals that live in intertidal fringes have been selected to provide samples representative of a diet of sea food gathered by the consumer. In addition, animals that live on the sea bed were selected for their relevance to a diet of local sea food purchased by the consumer.

ANNEX C

Variability of uranium concentration and uranium isotopic ratios in marine environmental samples

There are few specific examples that demonstrate the variability of uranium concentrations and isotopic ratios within marine environmental samples. To understand these, it is useful to consider the flux of uranium between the various components of the marine environment.

Uranium occurs naturally in seawater and its concentration generally varies in proportion to salinity. It is present in open seawater at an average concentration of $82.5 \pm 5 \text{ Bq/m}^3$, with a $^{238}\text{U}/^{234}\text{U}$ activity ratio of 0.88 ± 0.03 at a salinity of 35 ‰. The isotopic ratio of seawater is below unity, as ^{234}U is preferentially mobilised from the soil during chemical weathering, thus enhancing its presence in seawater [10,8]. The physical mixing of low U- river water¹ and high U- sea water in estuary environments generally results in a dilution of uranium in the estuarine waters. As a result uranium concentrations in estuarine water are mostly lower than open ocean values, and increase linearly with salinity. [10].

Concentrations of uranium in marine sediments are variable (from 32.5 to 1,625 mBq/g dry weight) and vary primarily as a function of the geology of the area.

Sample type	Uranium concentration	Typical $^{238}\text{U}/^{234}\text{U}$ ratio
Ocean water	82.5 Bq/m^3	0.88
Estuarine water	$<82.5 \text{ Bq/m}^3$	<0.88
Marine sediments (^{238}U)	32.5-1,625 mBq/g	0.81

Table 13: Typical uranium concentrations and isotopic ratios in marine samples [9, 10, 11].

Levels of uranium also vary depending on the precise location and depth of the sediment sample, as these directly affect its chemical characteristics, and hence its potential for concentrating uranium from the marine waters [10, 11]. Both low oxygenation² and low salinity³ provide favourable conditions for uranium scavenging from the water column by a variety of processes. These include the precipitation of U-rich colloids into the low salinity zone and the reduction of uranium into insoluble forms. [11, 12]

1 Concentrations of uranium in rivers vary considerably, with carbonate and dissolved solids concentrations, with an average of 7.5-15 Bq/m³, and an isotopic $^{238}\text{U}/^{234}\text{U}$ activity ratio of 0.77-0.83 as ^{234}U is preferentially mobilised during chemical weathering.

2 Low oxygenation is found with increasing depth and increasing organic content

3 Low salinity is dependent on river rate of flow, proximity to river outflow and depth of water.

ANNEX D Reference values for uranium in the Solway Firth and the UK

For UK coastal sediments, ^{238}U concentrations generally range from 3.6 and 32.3 mBq/g of dry weight [12]. Values reported for shore sediment uranium concentrations in the Solway Firth vary with location and the specific uranium rich geology of the area:

Values reported for ^{238}U concentrations at Sandyhills Bay, in South West Scotland, were lower than worldwide average values for seawater and sediments reported in Annex C. Seawater and sediments from Sandyhills had ^{238}U concentrations of 40 ± 3 Bq/m³ and 14 ± 0.4 mBq/g dry weight⁴, respectively [13]. No other uranium isotope was measured, so no indication could be provided for the isotopic ratio.

However, semi-quantitative analysis of shore sediments samples obtained from the mudflats offshore from the uraninite vein, located a few miles east from Kirkcudbright at Needle's eye, yielded uranium values of up to several hundred parts per million. These activities were measured both around open, oxygenated root channels and in near surface peat material. This analysis has suggested that uranium disperses seawards from the vein and ground waters, and is retarded in this by organic material in the sediments. [7]

Sample	Location	Activity per wet weight (mBq/g)	Activity per dry weight (mBq/g)
Seaweed	[13] Sandyhills [13] UK		3.8 ± 0.1 3.8 – 18.6
Mussel	[13] Sandyhills [13] UK		1.1 ± 0.1 1.01 – 37.1
Mollusc	[13] Sandyhills (winkle) [13] UK [14] UK (mollusc & winkle) [14] Parton (winkle)	0.89 1.2	2.72 ± 0.01 1.36 - 18.9
Crab	[14] UK [14] Parton	0.046 0.051	
Lobster	[14] UK [14] Parton	0.035 0.015	

Table 14: Reported ^{238}U concentrations in seaweed and marine biota in the UK

Literature values reported for ^{238}U in seaweed and marine biota samples are shown in Table 14, for the Solway Firth area and for the UK [14, 13]. Uranium values reported for seaweed and marine biota at Sandyhills Bay were: ^{238}U concentrations of $3.8 \pm$

⁴ Sample preparation for the sediment sample included drying of the wet sample, grinding, homogenising, followed by acid leaching, electroplating and ICP-MS analysis for U.

UNCLASSIFIED

0.1 mBq/g dry weight for seaweed (*F. vesiculosus*) and 1.1 ± 0.1 mBq/g dry weight for mussel (*M. edulis*) [13]. In 2002, ^{238}U concentrations for marine samples procured in Parton, near Whitehaven, ranged from 0.015 mBq/g wet weight for

lobster, to 0.051 mBq/g wet weight for crab [14]. However, it should be noted that the uranium inventory in Parton is dominated by historical anthropogenic input of uranium from a local phosphate processing plant.

ANNEX E Change In The $^{238}\text{U}/^{234}\text{U}$ Activity Ratio Of A Medium Containing Natural Uranium With The Addition Of Depleted Uranium

Mass of depleted uranium added ⁵	Activity ⁶ (mBq/kg)			Ratio of Total Activity Natural Uranium to Total Activity	$^{238}\text{U}/^{234}\text{U}$ Activity Ratio
	^{238}U	^{235}U	^{234}U		
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	3.9×10^5	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^{-1} soil).
2. Table assumes 3 mg/kg^{-1} of natural uranium in a medium, prior to addition of DU, and present in the following proportion: ^{238}U ($2.978 \text{ mg U kg}^{-1}$); ^{235}U ($0.022 \text{ mg U kg}^{-1}$); ^{234}U ($2\text{e-}04 \text{ mg U kg}^{-1}$),.

Annexes References

- [5] Correspondance from Mr G Hunt (CEFAS) to Mr Phillips (MoD Directorate of Safety, Environment and Fire Policy), 23 February 2001.
- [6] Basham, I R; Milodowski, A E; Hyslop, E K; Pearce, J M. The location of uranium in source rocks and sites of secondary deposition at the Needle's eye natural analogue site, D&G, British Geological Survey Technical Report WE/89/56, (1989).
- [7] Milodowski, A E. et al. Uranium-mineralised micro-organisms associated with uraniferous hydrocarbons in South West Scotland. *Nature*, 347, 465, (1990).
- [8] Murphy WM., Shock EL. Environmental Aqueous Geochemistry of Actinides, in *Uranium: Mineralogy, Geochemistry and the Environment*, edited by Burns P., and Finch R, Reviews in mineralogy, Vol 38 ,The Mineralogical Society of America, (1999).
- [9] Toole, J.; Baxter, M.S; Thomson, J. The behaviour of uranium isotopes with salinity change in three U.K. estuaries. *Estuarine, Coastal and Shelf Science*, 25 , 283, (1987).
- [10] Cochran, J.K. "The oceanic chemistry of the U- and the Th-series nuclides", in *Uranium series disequilibrium: Applications to environmental problems*", Ivanovich M. and Harmon R.S eds, Clarendon Press, Oxford, (1982).
- [11] Van den Berg C.M.G. Huang Z. Q. *Analytica Chemica Acta* 164 209-222,(1984)
- [12] Ragnarsdottir V., Charlet L. *Uranium Behaviour in Natural Environments in: Environmental Mineralogy: Microbial Interactions, Anthropogenic Influences, Contaminated Land and Waste Management*, Mineralogical Society Series, Vol 9, Mineralogical Society of Great Britain & Ireland, (2000).
- [13] McDonald P. Cook G.T. and Baxter M.S. Natural and artificial radioactivity in coastal regions of UK. In: *Radionuclides in the Study of Marine Processes* (Ed. By Kershaw P.J. and Woodhead D.S.), Elsevier Applied Science, London. (1991).
- [14] *Radioactivity in Food and the Environment*, 2003. The Centre for Environment, Fisheries and Aquaculture Science, (2004).

Initial distribution

CESO (Army) SO2 RAD (12 copies)

Catherine Toque

Nigel Woodcock

Knowledge Services

Knowledge Services

Report Documentation Form

1. Originators Report Number		CR/18154 V1	
2. Report Protective Markings and any other markings e.g. Caveats, Descriptors, Privacy markings UK UNCLASSIFIED			
3. Title of Report Marine Environmental Depleted Uranium Survey Report Kirkcudbright Training Area - 2004			
4. Title Protective Markings incl. any Caveats		UNCLASSIFIED	
5. Authors Catherine Toqué			
6. Originator's Name and Address Environmental Sciences Department c/o Institute of Naval Medicine Crescent Road Alverstoke Gosport Hants. PO12 2DL		7. MOD Sponsor Name and Address CESO (A) SO2 RAD Headquarters Land Command Airfield Camp Netheravon SALISBURY SP4 9SF	
8. MOD Contract number and period covered		574635 01A 2004/5	
9. Other Report Nos.			
10. Date of Issue 27 April 2006	11. Pagination 44	12. No. of References 14	
13. Abstract <p>Routine environmental monitoring has been carried out at Kirkcudbright Training Area (KTA) since 1980 to assess the environmental impact of Depleted Uranium (DU) firings on the terrestrial and the marine environments. This report describes and interprets the results of routine monitoring of the marine environment for DU, undertaken in the vicinity of the KTA in 2004. Samples of intertidal sediments, seaweed and seafood were collected from the shore line in the local area. Underwater sediment samples were collected off shore from the KTA, and samples of locally fished bottom dwelling animals were also obtained.</p> <p>The results of the 2004 survey do not show evidence of the presence of DU in any of the environmental samples collected. There is no evidence to indicate that members of the public are exposed to a radiological hazard from the marine environment as a result of test firing DU ammunition at the KTA.</p>			
14. Abstract Protective Marking including any Caveats UNCLASSIFIED			

UNCLASSIFIED

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

Depleted uranium, DU, Kirkcudbright, KTA, environmental, monitoring, marine, 2004

16. Report Announcement (refers to title/abstract being included in accessions lists e.g. Defence Reports Abstracts)

☒ Announcement of this report is UNLIMITED

If there are limitations on the announcement of this report please indicate below the groups to whom it can be announced (more than one if required)

☐ Can be announced to MOD and its Agencies

☐ Can be announced to UK Defence Contractors

☐ Can be announced to Overseas Defence Departments

☐ Other (please specify)

17. Report Availability

☐ UNLIMITED distribution

☒ No Release without approval of the Release Authority

If the above do not apply, please indicate below the groups to whom the report may be released upon request without further Need-To-Know checks.

☐ Can be released to MOD and its Agencies

☐ Can be released to other UK Government Departments

☐ Can be released to UK Defence Contractors

☐ Can be released to Overseas Defence Departments


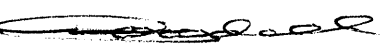
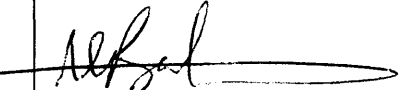
☐ Other (please specify)

18. Downgrading Instructions (check as appropriate)

☐ This report may be automatically downgraded to after years

☐ This report may be reviewed years after publication

19. Authorisation (Complete as applicable)

	Name	Signature	
Department Manager	John Richards PP		Date 27/04/06
Project Manager	Nigel Woodcock		Date 06/05/06
Technical Reviewer	Adrian Baker		Date 27/4/06

When complete the form is to be bound into the report to which it refers and is to form the last numbered pages of the report. Dstl Knowledge Services, Porton Down will enter an abstract and other details onto the relevant report management systems.

UNCLASSIFIED

This page is intentionally blank

UNCLASSIFIED

UNCLASSIFIED

This page is intentionally blank

UNCLASSIFIED