Comparison of Kirkcudbright and Eskmeals Environmental Monitoring Data with Generalised Derived Limits for Uranium

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Abstract

In order to ensure that the firing of Depleted Uranium (DU) munitions at the Kirkcudbright and Eskmeals ranges is not having an adverse environmental impact, routine environmental monitoring surveys have been carried out since the early 1980's. The results of these environmental surveys are published in annual or biennial reports.

This study compares the measured uranium levels reported in the environmental surveys to published guidelines for interpreting monitoring levels, in order to identify if further investigation is needed. These guidelines, published by the National Radiological Protection Board, are known as Generalised Derived Limits (GDLs) and are based on cautious assumptions relating to risks to members of the public.

As several techniques have been used to gather and analyse the data over a twenty-year period, the data has been normalised using very cautious assumptions, to provide a year on year comparison. All soil data has been presented in this report for Kirkcudbright and Eskmeals. Seawater and sediment data for Kirkcudbright are also given.

Comparison of the soil data shows that some monitoring sites occasionally report small quantities of DU as being present. However, no site has produced measurements that have exceeded the GDL limit of 20,000 Becquerels per kilogram (Bq per kg) for uranium-238. No site has produced soil samples that have exceeded a suggested 'level for further investigation' of 2000 Bq per kg when averaged over the course of a year. No evidence of DU contamination has been found in Kirkcudbright seawater and marine sediment samples.

Executive summary

Background

The test firing of Depleted Uranium (DU) munitions in the UK began with a small research programme at Eskmeals in the early 1960's. This involved small-scale trials being carried out in the V.J. Butt area on an occasional basis until the late 1970s. This work led to a more extensive test and evaluation programme that commenced in the early 1980's after decontamination and rebuilding of the original test facilities. This programme involved the test firing of 120mm Depleted Uranium (DU) ammunition at two MoD sites in the United Kingdom: the firing range at Eskmeals and the range at Dundrennan, Kirkcudbright in Dumfries and Galloway. In order to ensure that the firing is not having an adverse environmental impact, regular environmental monitoring surveys have been carried out since the early 1980's. The results of these environmental surveys are published in annual or biennial reports.

The National Radiological Protection Board (NRPB) has published guidelines relating to levels of anthropogenic uranium in the environment known as Generalised Derived Levels (GDLs). They have also recommended lower levels, above which, further investigation and site specific assessments are required. The GDLs are determined from the UK annual effective dose limit of 1milli-Sievert (mSv) for members of the public and are based on cautious assumptions that will overestimate rather than underestimate the risk. Of the data contained in the environmental reports, guidelines exist for soil, air, marine sediment, and freshwater.

Scope

The scope of the study is to compare the historical environmental monitoring data to the published GDLs in order to determine if the firing activity has resulted in depleted uranium emissions that exceed or have previously exceeded current GDLs.

Aims

- To collate data contained in the environmental reports for Kirkcudbright and Eskmeals.
- To identify environmental data that is compatible with GDL guidelines.
- To normalise the data, using cautious assumptions to account for variations in sampling and analytical methodology.
- To present the data in a form that would allow a year on year comparison to GDLs.
- To identify areas that exceed recommended action levels.

Summary

The environmental reports spanning the period from 1980 to 1999 have been reviewed to identify data that could be compared with GDLs. Of the data contained in the environmental reports, guidelines exist for soil, marine sediment and freshwater and so most other types of samples have not been considered in this study. However, as all DU tests at Kirkcudbright involve firing projectiles into the sea, seawater data have been included in this study.

The environmental samples have been collected and analysed using a number of techniques resulting in differences in reporting units. Such changes would be expected over the course of a twenty-year programme. In order to present the data in a form suitable for a year on year

comparison, some data has been normalised. Any normalisation process that has been carried out is described in the text.

The total uranium measurement has been used as the main indicator of contamination levels. This has sometimes been supplemented by a second measurement parameter, the U-238/U-234 activity ratio. This may used to confirm that the contamination is DU as opposed to other sources high in uranium such as fertiliser.

Results

Total uranium data for all regular sampling sites are presented in this report. Individual measurements and site annual average results are given. U-238/U-234 isotopic ratio measurements are given for selected sites where total uranium levels are consistently above background.

There is no evidence of any DU contamination of seawater and sediment samples taken from offshore near Kirkcudbright. Total uranium and U-238/U-234 activity ratios are similar to values of natural uranium levels in seawater reported in peer reviewed-literature.

Uranium levels at all of the terrestrial monitoring sites were significantly below both the GDL and further investigation level for uranium (20,000 and 2000 Becquerels per kilogram (Bq per kg) respectively). In most cases the measured uranium levels are over three orders of magnitude lower than the GDL. Some Kirkcudbright and Eskmeals sites have occasionally produced soil samples that contain slightly elevated levels of uranium. This contamination has been confirmed as DU through the U-238/U-234 activity ratio. However, the average reported uranium levels at these sites are still significantly below the ‘level for further investigation’ of 2000 Bq per kg.

Conclusions

The Kirkcudbright and Eskmeals firing programmes have only resulted in very low levels of DU that are measurable in the terrestrial environment. Given that the ‘worst case’ uranium levels in soil are significantly below the published levels where further investigation is required, it may be concluded that there is negligible risk to anyone arising from DU contamination outside the controlled areas at the Eskmeals and Kirkcudbright ranges.

Recommendations

The Eskmeals environmental reports do not relate to the fenced area containing VJ Butt and so this area is outside the scope of the study. This area was designated to be a controlled area and was operated under the relevant Ionising Radiations Regulations. Unauthorised access is prohibited and staff working in this area are considered to be Classified Radiation Workers and as such were subjected to a separate regime of monitoring, and protection. Given that VJ Butt is the location for DU firing on the Eskmeals range, it is reasonable to assume that this area would exhibit higher levels of contamination than the surrounding area. It is therefore suggested that this study be widened to incorporate data from the controlled area.

List of contents

1 Introduction

1.1 Scope of Work

1.1.1 The work contained in this report has been carried out in response to a requirement issued by the Directorate of Safety Environment and Fire Policy [1]. The scope of the work is to compare the data contained in Kirkcudbright and Eskmeals environmental reports to guidelines published by the National Radiological Protection Board. The purpose of this comparison is to determine if the firing activity has resulted in environmental levels of DU that exceed or have previously exceeded the present recommended limits**.**

1.2 Background

1.2.1 Uranium, chemical symbol U, is a naturally occurring element, comprising a mixture of three isotopes: U-238, U-235 and U-234, primarily the isotope U-238. It is a radioactive material, emitting alpha, beta and photon radiation during the decay process. It is also a toxic heavy metal. Depleted Uranium (DU) is produced as a by-product of the enrichment of natural uranium and has a higher proportion of U-238. DU has a slightly reduced radioactive content compared with natural uranium. The total specific activity of the uranium isotopes in DU depends on the processing history of the material, but is in the order of 14-15 million Becquerels per kilogram (MBq per kg) [2].

1.2.2 The UK test firing of DU munitions began with a small research programme at Eskmeals in the early 1960's. This programme involved small-scale trials being carried out in the V J Butt area on an occasional basis until the late 1970s when the facility was decontaminated and rebuilt. These trials confirmed the superiority of DU over other penetrator materials and led to the major and much more extensive test and evaluation programme that began in the early 1980's in the new facility. This programme involved the test firing of 120mm DU ammunition being conducted at two MoD sites in the United Kingdom: the firing range at Eskmeals, Cumbria and the range at Dundrennan, Kirkcudbright in Dumfries and Galloway (hereafter referred to as Kirkcudbright).

1.2.3 In order to ensure that these activities were not having an adverse environmental impact, regular environmental monitoring regimes at Kirkcudbright and Eskmeals were instigated under the direction of the MoD Committee of Environmental Experts on DU Firings (CEEDUF). Between 1980 and 1992, the environmental monitoring programme was conducted under the supervision of the Atomic Weapons Establishment Environmental Monitoring Group (AWE EMG). The AWE EMG also undertook the laboratory analysis of all samples obtained during this period. Since 1992, the programme has been overseen by the MoD's Depleted Uranium Firings Environmental Review Committee (DUFERC). In 1993 the DUFERC recognised that an independent examination of MoD's DU firing activities would be an appropriate response to the increasing public interest in DU munitions issues. An independent consultant was commissioned to carry out an assessment of the environmental impact of DU firings at Kirkcudbright and Eskmeals resulting in suggestions for improving the monitoring program [3,4,5].

1.2.4 During 1992 and 1993, the laboratory analysis of Kirkcudbright samples was undertaken by British Nuclear Fuels Chemical and Metallurgical Services Department (BNFL). Analysis of Eskmeals samples during the period 1992-1994 was carried out at Harwell

Laboratories. In 1994, Dstl Radiological Protection Services (DRPS[1]) took on the task of conducting the monitoring programmes and analysing the samples, and continues in this role.

1.2.5 The results of the environmental surveys are published in annual or biennial reports [2 to 51]. These reports contain a range of environmental data for each monitoring location relating to the total uranium and, depending on the analytical technique employed, the U-238/U-234 activity ratio.

1.2.6 The National Radiological Protection Board has published guidelines relating to levels of anthropogenic uranium in the environment that are known as Generalised Derived Levels (GDLs). They have also recommended lower levels, above which, further investigations and site-specific assessments are suggested. GDLs are determined from the annual effective dose limit of 1mSv for a member of the public and are based on deliberately cautious (i.e. worst case) assumptions. Of the data contained in the environmental reports, guidelines exist for soil, air, marine sediment and freshwater.

1.2.7 Any determination of DU concentrations in the environment is complicated by the existence of naturally occurring uranium. In addition, the environmental samples have been collected and analysed using a number of techniques resulting in differences in reporting units. Such changes would be expected over the course of a twenty-year programme. In order to present the data in a form suitable for a year on year comparison, some data has been normalised. Any normalisation has been carried out using deliberately cautious assumptions and is described in the text.

1.3 Aims of this Study

1.3.1 The objectives of the work may be summarised as

- To collate data contained in the environmental reports for Kirkcudbright and Eskmeals.
- To identify environmental data that is compatible with GDL guidelines.
- To normalise the data, using deliberately cautious assumptions to account for variations in sampling and analytical methodology.
- To present the data in a form that would allow a year on year comparison to GDLs.
- To identify areas that exceed recommended action levels.

1.4 Report Structure

1.4.1 An overview of the sampling and analytical methodology is given in Section 2 together with the methods used to normalise and analyse the data. The results and discussions for monitoring sites in the Kirkcudbright terrestrial, Kirkcudbright marine and Eskmeals areas are presented in Sections 3, 4 and 5 respectively. Conclusions and Recommendations are presented in Sections 6 and 7 respectively.

1. Formerly DERA Radiological Protection Services (DRPS)

2 Comparison of Environmental Data and Generalised Dose Limits

2.1 Introduction

2.1.1 The scope of this study is to compare previously measured concentrations of DU in the environment to current guidelines in order to determine if further action is required. This section describes the basis for the Generalised Derived Limits and reviews the environmental survey and analytical process in order to determine the relevant data. As might be expected in any programme of work that spans a period of twenty years in which there has been major changes in legislation, there have been changes in the way in which the samples and results of the environmental monitoring programmes have been collected, analysed and recorded. In order to present a year-on-year comparison it has been necessary to normalise data. The assumptions made in this process are described.

2.2 NRPB Generalised Derived Limits (GDLs) for Uranium [52]

2.2.1 Generalised Derived limits (GDLs) are intended for use as convenient reference quantities against which the results of environmental monitoring can be compared. These guidelines have been developed by NRPB based on effective dose as defined in International Committee for Radiation Protection Publication 60. They are related to primary dose criteria by a defined model and are calculated such that compliance with them would ensure virtual certainty of compliance with the appropriate dose criteria.

2.2.2 GDLs have been calculated in various environmental media for radiologically significant isotopes including uranium. These values are derived from the annual whole body dose limit for a member of the public of 1 milliSievert (mSv). The radioisotopes of uranium are found naturally in the environment, but the GDLs relate only to possible increases in activity concentrations arising from human activities.

2.2.3 GDLs are calculated using deliberately cautious assumptions and are based on the assumption that the level of environmental contamination is uniform over a year, thus they do not relate to transient conditions. If a measured concentration exceeds about 10% of the GDL then the doses from all exposure pathways should be examined more closely, taking account of site specific factors and the length of time for which the measured level is likely to be maintained. This level is referred to as a further investigation level.

2.2.4 Although GDLs are isotope-specific, it is possible to assume that all the uranium in a sample is uranium-238. This simplifies the calculations and leads to an error of only 1.5% if the sample is entirely natural uranium and 0.6% if the sample is entirely DU. Therefore the GDL for uranium in well-mixed soil can be taken as 20,000 Becquerels per kilogram (Bq per kg). This means that a more detailed examination of potential exposures should be carried out if uranium concentrations exceed a “level for further investigation” of 2000 Bq per kg.

2.3 Routine and Non-routine Sampling

2.3.1 Sampling at Eskmeals and Kirkcudbright consists of both “routine” sampling which is effectively random or fixed point sampling carried out at regular intervals and “special” sampling which is often carried out after an incident and is targeted on the location where the incident occurred. With regard to DU firings, the incidents of importance are those in which a round breaks up or misfires and DU debris is deposited on the range. Special sampling is carried out after such an incident and the results are used to decide whether there is a need for remediation of the affected area. When remediation occurs, the initial monitoring results are obviously inappropriate for assessing environmental impact as the material has been removed. The complication discovered during this review is that the way in which special sampling results have been recorded has changed over time. In some years, the special and routine sampling results are included in the annual or biennial monitoring reports, whereas on other occasions it is only the routine sampling results that are recorded in this way. Special sampling results are often recorded in paper records in large archives and the retrieval of this information would be extremely expensive and out of proportion to the value of the information.

2.4 Sample Locations

2.4.1 During the course of the programme, the monitoring has undergone several reviews in order to identify improvements. The most significant reviews were the environmental impact assessment of 1995 carried out by independent consultants, W. S. Atkins [3,4,5] and the DRPS baseline review [41,42]. These reviews have resulted in changes to some sampling locations and the addition/deletion of others. There are however many sampling sites that have remained largely unaffected during the reviews. This study focuses on data from these sites in order to provide a year on year comparison.

2.5 Sample Types

2.5.1 The environmental programme since 1980 consists of on-site and off-site samples of the following:

- Soil and sand samples
- Vegetation samples
- Seawater and seabed sediment samples
- Passive air samples (airshades).
- High volume air samples
- Animal faecal samples
- Water samples (pond and rainwater)
- Marine biota samples
- Non-routine samples e.g. road dust, house dust, vegetables and leaves.

2.5.2 Many of these samples provide data that relates to transient effects. For instance, contamination on grass may be washed off during rainstorms. Of the data contained in the environmental reports, the GDLs are described for soil, air, marine sediment, molluscs and freshwater. With the exception of seawater, only data of these types are considered further. Seawater samples are of interest as DU munitions are fired into the Solway Firth from the Kirkcudbright range.

Soil and Sand

2.5.3 The Kirkcudbright and Eskmeals soil and sand samples represent the most continuous data sets of all the terrestrial collection methods. Soil or sand sample cores have been consistently collected since the start of the monitoring programme. However, the sampling protocol has varied over time, in particular as to which parts of the soil core were analysed.

- From 1996 the sampling has been uniform in that the root mat has been included in the first 2cm of soil and analysed as the 'upper' sample. The lower 2-5 cm has been analysed as the 'lower' sample.

- For pre-1996 samples, this is not always the case as samples have sometimes been analysed in 5cm slices. In this study, all data has been plotted irrespective of location in the core.

2.5.4 Uranium activities in soil and sand samples have been reported for fresh, ashed or dried weight. Although, the GDLs refer to dry weight, many environmental reports only quote fresh and ashed weight. Therefore, in order to provide a year-on-year comparison, ashed weight is used as the basis for evaluation. As organic matter is 'burned off' during the ashing process and uranium isotopes are concentrated in the residue, ashed samples have a higher activity per unit mass than dried weight (typically 10% - 25%). Therefore, using ashed results as the basis for comparison to GDLs will result in an *overestimation* of the potential exposure.

Seawater and marine sediment

2.5.5 Seawater samples have been collected off-shore from Kirkcudbright at six locations every year since 1980. At each location, water samples have been collected from near the surface and from deep water close to the bottom of the estuary. Seabed sediment samples have also been taken at each of the locations. Each year these samples have been analysed by radiochemical techniques to determine the U-234, U-235 and U-238 content.

Air samples

2.5.6 Active air-samples collected using high volume air samplers placed at a few specific sites have occasionally been reported in environmental surveys from 1996 onwards [45, 49]. However, the data is of limited use in a study that focuses on long-term trends because of the sporadic reporting and the short period over which such samples have been collected.

Molluscs

2.5.7 In addition to seawater and marine sediment samples, other samples such as seaweed, shellfish and other marine biota have been monitored. These samples act as concentrators for uranium and thus would be a sensitive indicator of DU contamination. Collection however, is dependent on availability and abundance at the time of sampling. Furthermore, there have been no cases of high total uranium or high U-238/U-234 activity ratios in biological marine samples collected. Therefore they have not been considered further in this study.

2.6 Sample Inhomogeneity

2.6.1 The GDLs assume that the uranium contamination is uniform over a year and that the samples are well mixed. However, DU firing generally results in small fragments so that the presence of these in a sample may skew the results. This is particularly relevant to the Kirkcudbright and Eskmeals environmental monitoring programme where only very low levels of contamination have been found. There will therefore be some uncertainty in the reported results. Analysing many samples from the same location and averaging the results may reduce this uncertainty. However, this has to be balanced against cost and the fact that, in general, the measured DU levels are several orders of magnitude lower than the NRPB guidelines.

2.7 Analytical Techniques

2.7.1 Two analytical techniques have been predominantly used to measure uranium concentrations in samples: Delayed Neutron Activation analysis (DNA) and alpha spectrometry. A further technique, X-ray fluorescence analysis was adopted during the period 1992 and 1993 for the determination of the total uranium content of Kirkcudbright soil.

Delayed Neutron Activation analysis (DNA)

2.7.2 DNA is the primary analytical technique adopted by AWE for soil and vegetation sample analysis. In this technique, samples are irradiated in a nuclear reactor. Fissile isotopes such as U-235 and Pu-239 are activated and undergo delayed neutron emission. These neutrons can be measured to provide information on the fissile material present in the sample and hence determine the level of activity. The determination of uranium content relies on the assumptions that the only fissile material present is uranium-235 and that the uranium is of natural isotopic composition (i.e. 0.72% U-235).

2.7.3 In the case of DU, with a U-235 mass abundance of 0.2% [53], DNA measurements will produce an under-estimate of the total uranium content. Therefore, for a sample containing a combination of natural and depleted uranium, a correction factor needs to be applied. This correction factor will vary from 1 (all natural uranium) to 3.62 (all depleted uranium). Additionally, the presence of the isotope plutonium-239 from nuclear weapons manufacture and testing will enhance the U-235 assessment as it also emits delayed neutrons. Given that plutonium has been detected by alpha spectroscopy in some Eskmeals and Kirkcudbright samples, some reported DNA results may be slightly higher than would be the case for DU alone. It has been established in environmental reports that the plutonium does not originate from DU firing [19]. Further consideration of plutonium is beyond the scope of this study.

2.7.4 DNA was also used to measure uranium levels in seawater in 1980 and 1981. However this practice was discontinued as high levels of radioactivity were induced into the sample due to the neutron activation of sodium and chlorine in the seawater.

Alpha spectrometry

2.7.5 Alpha spectrometry is able to measure all of the commonly found uranium isotopes, U-234, U-235 and U-238. Uranium in a sample is generally, chemically separated from the sample matrix, using a weak acid digestion process, and electroplated onto a carrier disk, which is then subjected to alpha spectrometry. Each constituent uranium isotope emits alpha particles at a discrete energy, and the technique can be used to determine the activity of each isotope. Alpha spectrometry has the advantage of providing an indication of the extent to which DU is present as a proportion of the total uranium content of a sample. In natural uranium, the activity from the U-238 isotope is similar to that of the U-234 isotope [54,55]. In depleted uranium some of the U-234 is removed during the manufacturing process so that the U-238/U-234 activity ratio increases. The U-238/U-234 activity ratio uranium will increase with added quantities of DU up to a maximum value of 7 when the sample is saturated with DU [38].

2.7.6 An initial comparison of DNA and alpha spectrometry data has shown that DNA generally reports higher uranium values than alpha spectrometry in measurements of samples with low contamination. Further investigation, carried out by DRPS[3], has shown that this is due to the sample preparation process used in alpha spectrometry. The weak acid used for dissolution only removes the 'loose' surface uranium from the sample matrix. Natural uranium that has become ingrained into the sample matrix over geological timescales is not removed and is therefore discarded. As DNA uses neutrons that penetrate the sample matrix, all uranium is measured. As the GDLs relate only to additional uranium above the natural background, and both DNA and alpha spectroscopy fully report the DU component, no correction has been made for soil samples.

X-ray fluorescence analysis

2.7.7 X-ray fluorescence analysis was adopted by BNFL during the period 1992 and 1993 for the determination of the total uranium content of Kirkcudbright soil. This technique measures characteristic uranium emission lines from the sample when stimulated by radiation. The technique, is low cost and measures total uranium levels. The technique is best used to screen samples in order to determine if further measurement is required. It is therefore not surprising that this technique resulted in somewhat larger uncertainties in measurement during the 1992-1993 period.

2.8 Reporting Units

2.8.1 In the environmental reports uranium concentrations are reported in units of either micro-grams per gram (μg/g) (relative mass) or Becquerels per kilogram (Bq/kg) (activity). The former has been converted to Bq/kg on the cautious assumption that 1 kilogram of natural uranium has an activity of 25 MBq [51]. Use of this conversion factor will give rise to an overestimate of uranium activity in samples where DU is present.

3 To be published later in 2002.

2.9 Background.

2.9.1 The GDLs refer only to anthropogenic uranium in the environment. Any comparison may be complicated by the presence of naturally occurring uranium. The extent to which uranium occurs naturally in UK soils varies from 2 Bq/kg in Surrey to 10000 Bq/kg in Caithness [38]. In addition to regional variations, background levels may be subject to local variations due to external factors, such as the addition of fertilisers, which have a natural uranium level of between 3000 and 7000 Bq per kg [3,51].

2.9.2 Data from the environmental monitoring programmes indicates that the natural uranium background is between approximately 75 and 80 Bq per kg at Kirkcudbright. The Eskmeals soil is more sandy and so has a lower uranium content. This is reflected in many of the measurements where the total uranium levels are between 20 and 60 Bq per kg.

2.9.3 Given that the background levels for total uranium are over three orders of magnitude below the GDL value of 20,000 for uranium-238, no background subtraction has been carried out. For sites where DU contamination is occasionally reported this will result in overestimation, rather than underestimation of the level of contamination present.

2.10 Summary

2.10.1 The environmental reports spanning 1980 to 1999 have been reviewed to identify data that could be compared with GDLs. As GDLs are only published for well-mixed soil, marine sediment and marine biota, data relating to most other environmental samples, with the exception of Kirkcudbright seawater, have not been considered further in this study.

2.10.2 The environmental samples have been collected and analysed using a number of techniques resulting in differences in reporting units. In order to present the data in a form suitable for a year on year comparison, some data has been normalised. This has involved using ashed rather than dried weights, including a factor for natural uranium in discarded filtrate (alpha spectrometry only) and using a pessimistic factor for the conversion of units to Bq per gram. All of these factors will result in an overestimate, rather than an underestimate, of the DU level in the sample.

2.10.3 As the GDLs relate only to the anthropogenic contribution to the environment, it is sometimes necessary to determine and remove the contribution from the natural uranium background. Given that background levels are low (generally less than three orders of magnitude below the GDL) no such subtraction has been used. So the unrealistic and deliberately cautious assumption is that all of the uranium in the samples results from the firing of DU munitions.

3 Kirkcudbright Soil Samples

3.1 Introduction

3.1.1 At Kirkcudbright, the DU ammunition development programme involves firing the projectiles, over distances ranging between a few hundred metres and several kilometres, at soft, hessian targets mounted on the cliff top above the sea. The projectiles are intended to pass through the targets unhindered, and land several kilometres offshore. The trajectory of each projectile is monitored by radar.

3.1.2 Because the projectiles are of an experimental nature, malfunctions sometimes occur, with the projectile either breaking up in flight or, very occasionally, striking the ground or a target gantry. When a projectile breaks up in flight, range staff report that the majority of DU fragments still reach the sea. If a projectile is known to break up in flight over land or to have gone astray, special sampling has often been undertaken in the known or suspected area of impact.

3.1.3 A map of the Kirkcudbright area, with sampling and firing points marked, is given in Figure 1 in Appendix A. With reference to this map, the locations of the Kirkcudbright sample points are as follows:

Raeberry 2 (Target)	Location 1
Raeberry 1 (Bunker)	Location 2
Raeberry Gun	Location 3
India Target (Balig)	Location 4
Between Balig gun & target	Location 5
Balig	Location 6
Red Heugh	Location 7
Mullock Farm	Location 8
Silverhill Low	Location 9
EchoTarget (Doon Hill)	Location 10
Between Doon Hill Gun & target	Location 11
Doon Hill	Location 12
Gipsy Point	Location 13

3.1.4 The Doon Hill, Raebury Gun, Balig and Silverhill Low sampling points are situated close to the range firing positions. These positions were chosen to maximise the likelihood of finding contamination resulting from round break-up. The Mullock Farm and Red Heugh sampling sites lie along the trajectory of firings from Silver Hill, the Red Heugh site being the final land location on the trajectory and the Mullock site being approximately half way between the firing point and Red Heugh). The Raeberry Bunker and Raeberry Target sampling sites lie along the trajectory of firings from Raeberry.

3.1.5 Soil samples have been collected from the above sampling positions at intervals of approximately twelve months. Unless specified otherwise, soil sample results are available for all sites from 1984 to 1999 (excluding 1995 when no soil samples were collected by MOD during the environmental impact assessment). Fewer samples were taken in the period between the 1981 pre-firing survey and 1984 when more extensive sampling commenced.

3.2 Comparison of Monitoring Data with GDLs.

3.2.1 A scatter plot of all individual soil measurements for all years is given in Figure 2 (Appendix A). As most reported levels are near background, a logarithmic scale has been used so that GDLs can be seen. From this data the average annual uranium level for each sampling site has been calculated. The results are presented in tabular form in Table 2.

3.2.2 In order that a year-on-year comparison can be made, all results are reported as Bq per kg dry weight. The samples for the period 1980-1991 have been analysed using DNA. The soil samples for 1992 to 1994 have been analysed using an X-ray fluorescence technique. The remaining measurements have been made by alpha spectroscopy.

3.3 Discussion

3.3.1 The table of average annual levels (Table 2) shows that no sample site has reported average annual uranium concentrations that have exceeded the 'level for further investigation' of 2000 Bq per kg. In addition, no individual measurement has exceeded this level.

3.3.2 It may be seen in Table 2 and Figure 2 that the samples from 1980 until 1991 are close to the background level of 75 to 80 Bq per kg. The 1991-1994 samples have a wide distribution of values. This is due to larger uncertainties in measurement associated with implementing the X-ray fluorescence technique as discussed in Section 2.7. From 1996, more sites were sampled, including the Raeberry Gun site.

3.3.3 The highest recorded total uranium values in the Kirkcudbright range area are consistently from the Raeberry Gun site. This site has been used for the majority of firing at Kirkcudbright. The average annual U-238/U-234 activity ratio measurements for this site are given in Figure 3. The elevated U-238/U-234 activity ratio recorded for all years provides positive confirmation that some DU is present on this site.

4 Kirkcudbright Marine Samples

4.1 Introduction

4.1.1 The importance of assessing the levels of DU in the marine environment has always been recognised on account of the firing of DU munitions into the Solway Firth. This monitoring was needed to verify the scientific assessment that no detectable increase in the amount of uranic material in the environment would result from the firing of DU munitions into the sea during strength and accuracy trials. I

4.1.2 The marine sample point locations lie along, and on either side of, a bearing of 200^{o} from the shore position of Raeberry 1. The latitude and longitude of the sample points are shown in Table 1. The marine sampling locations were chosen to lie on the trajectory of firings from Raeberry Gun to maximise the chance of finding any DU that might be present in the marine environment. On the seaward side of the range, underwater sediment and water samples are taken, annually, from the area into which the projectiles fall. Additionally, in recent years samples of intertidal sediment and edible biota (e.g. shellfish) and seaweed have been collected from accessible areas in the vicinity of the range.

Point number	Latitude	Longitude
1	54^{o} 45' 52"	04^{o} 01' 04"
2	54^{o} 45' 28"	04^{o} 01' 12"
3	54^{o} 43' 18"	04^{o} 02' 30"
4	54^{o} 43' 06"	04^{o} 01' 40"
5	54^{o} 43' 26"	04^{o} 03' 06"
6	54^{o} 41' 44"	04^{o} 03' 24"

Table 1. Marine sampling locations

4.2 Kirkcudbright Seawater

4.2.1 Samples are taken from six locations at points near the surface and near the seabed. The first seawater samples were analysed using DNA and are reported in the pre-firing survey [6]. Because of safety concerns arising from the high activity of the sample following neutron irradiation and activation of naturally occurring radionuclides in the water, such as sodium and chlorine, this technique was discontinued in 1981. Alpha spectrometry was also used in 1981 to provide a comparative measurement [8]. Alpha spectrometry was used for all subsequent years.

4.3 Results and Discussion

4.3.1 The total uranium and U-238/U-234 activity ratio results for all samples are plotted in Figure 4 and Figure 5 respectively.

4.3.2 No GDL is given for seawater [52]. Given the uncertainty in measurement, the total uranium levels are consistent with those reported for seawater in the literature which indicate that uranium occurs at an average of 3.3 microgrammes per litre (activity: 82.5 Bq/m^3) [54]. Similarly, comparison of the U-238/U-234 activity ratios show that, allowing for an uncertainty in measurement of typically +/- 0.2 at the 95% confidence level, the results are in good agreement with reported values for seawater of 0.9 [55, 56, 57].

4.4 Kirkcudbright marine sediment

4.4.1 Seabed silt samples are taken at six locations alongside the seawater samples. DNA was used to analyse samples in the period covering 1980 to 1983 and also in 1991. No measurement uncertainties have been quoted for the DNA results. Alpha spectrometry was used for all other years.

4.5 Results and discussion

4.5.1 The total uranium and U-238/U-234 activity ratio results for all marine sediment samples are plotted in Figure 6 and Figure 7 respectively. DNA has been used to measure total uranium concentrations in 1981, 1982 and 1991 alpha spectrometry has been used for all other years. A correction factor of two is used to account for unmeasured natural uranium in the sample matrix that may not have been recorded with alpha spectrometry (see Section 2.7).

4.5.2 The GDL for marine sediment is 100,000 Bq per kg. The total uranium results are more than three orders of magnitude below this level. There is an abnormally high activity ratio for 1993, however the uncertainties in measurement for the 1992 and 1993 data are large as the analytical laboratory had difficulty measuring uranium in this type of sample. All other measurements indicate that DU is not present.

4.5.3 It is interesting to note that a group of experts established according to Article 31 of the EURATOM treaty considered the risks from DU in March 2001and reached a similar conclusion i.e. that DU landing in the sea would cause negligible environmental impact [58].

5 Eskmeals Soil Samples

5.1 Introduction

5.1.1 At Eskmeals, the firing of DU ammunition took place against hard target arrays. Upon impact, fragments of DU and airborne particulate were produced. Whilst, the majority of arisings were contained within the butt containing the target array, some DU particulate was released through the opening where the DU round entered. Over the years, a series of modifications have been made to the butt to minimise the emissions. Firing activities ceased at Eskmeals in 1995. No pre-firing survey was carried out prior to the test firing programme that began in the 1980's.

5.2 Sampling Locations

5.2.1 The number of sampling sites on and around the Eskmeals range has varied throughout the firing programme, however there are 19 locations that have been sampled on an almost continuous basis. These locations, shown on the map in Figure 8, allow year on year comparisons and are described below.

5.2.2 Environmental samples are not collected from the immediate vicinity of the butt, known as the controlled area, since this area is subject to contamination surveys as required by the Ionising Radiations Regulations in force at the time.

Location	
1	Field battery
2	Eskmeals Battery
3	Overland Cut (top) on North Cut
4	Overland Cut (bottom) on South Cut
5	Main Battery Tower
6	Administration Block
7	Shore Top:Shore 1/Overland Butt
8	Barrier 3
9	VJ Battery rear blast wall
10	Met station
11	Monk Moors
12	Ammo compound: gate by main post
13	Skelda Hill
14	Bootle
15	Newbriggen Road, past Eskmeals Viaduct
16	Broad Oak Area
17	Waberthwaite
18	Corney Radar
19	Buck Barrow Bridge

5.2.3 Typically, soil samples have been collected from the above sampling positions at intervals of approximately six months up to 1992 and annually thereafter. Unless specified otherwise, soil sample results are available for all sites from 1981–1998. The samples are now reported on a biennial basis and the 1999 and 2000 results were not available at the time of preparing this report. The samples for the period 1981-1991 have been analysed using DNA. The soil samples from 1992 onwards were analysed

using alpha spectrometry at Harwell Laboratories (1992-1994) and DRPS (1994-present). Sample sites 1 to 6 are on sand, which has a low natural uranium background level.

5.3 Results

5.3.1 A scatter plot of all individual soil measurements for all years is given in Figure 9 (Appendix A). As most reported levels are near background, a logarithmic scale has been used so that GDLs can be seen. From this data the average annual uranium level for each sampling site has been calculated. The results are presented in tabular form in Table 3.

5.3.2 In order that a year-on-year comparison can be made, all results have been converted to Bq per kg dry weight. Sampling of Eskmeals sites has occurred several times per year prior to cessation of firing activity and annually thereafter. No samples were collected by MOD during 1995 when the environmental impact assessment was being conducted.

5.3.3 Of particular interest is the area close to VJ Butt. The Butt itself, is surrounded by a fence and is a controlled area to which the public has no access. The area inside the fence is not part of the routine survey, and so is not considered in this report. Routine sampling is taken at the rear of the facility outside the controlled area. As any DU contamination on the Eskmeals site originates from V.J. Butt, it is expected that nearby areas would receive higher levels of contamination. Therefore, the total uranium results from the rear of VJ Butt have been highlighted in red and the U-238/U-234 activity ratios considered separately.

5.4 Discussion

5.4.1 The table of average annual levels (Table 3) shows that no sample site has reported average annual uranium concentrations that have exceeded the ‘level for further investigation’ of 2000 Bq per kg.

5.4.2 There is one single measurement at the rear of the VJ Butt where the total uranium value of 2230 Bq/kg in 1986 exceeded the further investigation level of 2000 Bq/kg. Other samples taken from the same site at the same time show near background levels. The U-238/U-234 activity ratio data, shown in Figure 10, confirms the presence of DU. The design of the butt was subsequently modified to reduce DU emissions by adding a 10m long tunnel directly in front of the target area.

6 Conclusions

6.1 The scope of the study is to compare the historical environmental monitoring data to the published GDLs in order to determine if the firing activity has resulted in depleted uranium emissions that exceed or have previously exceeded current GDLs. The results indicate that:

- There is no evidence of DU contamination of seawater and sediment samples taken from offshore near Kirkcudbright. Total uranium and U-238/U-234 activity ratios are similar to values of natural uranium levels in seawater reported in peer reviewed literature.

- Some Kirkcudbright and Eskmeals sites have occasionally produced soil samples that contain slightly elevated levels of uranium-238. However, no monitoring site produced average annual contamination levels that exceed even the 'level for further investigation' which is set at 10% of the GDL.

6.2 The Kirkcudbright and Eskmeals firing programme has only resulted in very low levels of DU that are measurable in the terrestrial environment. There is no evidence of DU contamination in the Kirkcudbright marine environment. Given that, the 'worst case' uranium levels in soil are significantly below the published levels where further investigation is required, it may be concluded that there is negligible risk to anyone from DU contamination outside the controlled areas at the Eskmeals and Kirkcudbright ranges.

7 Recommendations

7.1 The Eskmeals environmental reports do not relate to the fenced area containing VJ Butt and so this area is outside the scope of the study. This area was designated to be a controlled area and was operated under the relevant Ionising Radiations Regulations. Unauthorised access is prohibited and staff working in this area are considered to be Classified Radiation Workers and as such were subjected to a separate regime of monitoring, and protection. Given that VJ Butt is the location for DU firing on the Eskmeals range, it is reasonable to assume that this area would exhibit higher levels of contamination than the surrounding area. It is therefore suggested that this study be widened to incorporate data from the controlled area.

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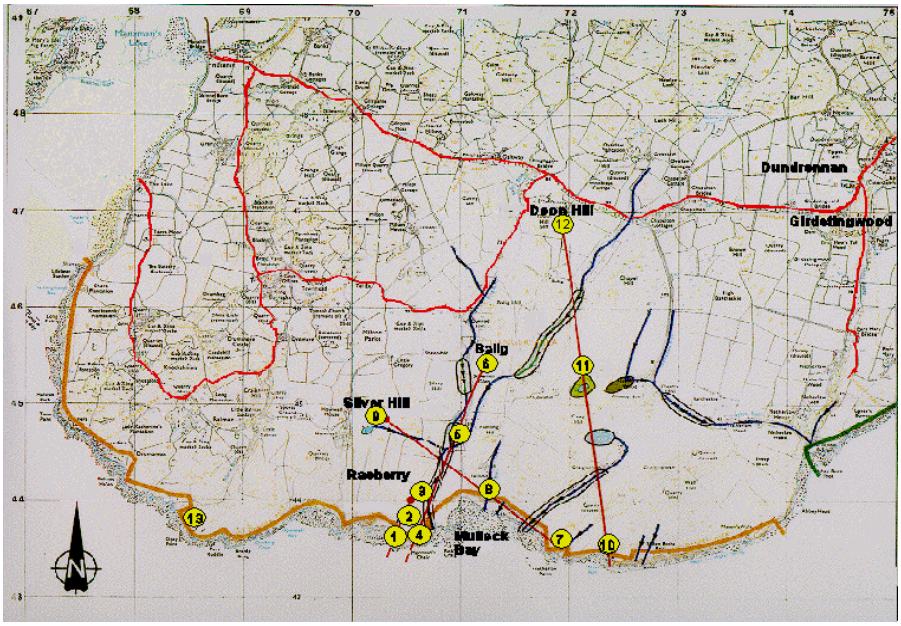
A Appendix. Kirkcudbright Soil: Figures and Tables



Raeberry 2 (Target)	Location 1
Raeberry 1 (Bunker)	Location 2
Raeberry Gun	Location 3
India Target (Balig)	Location 4
Between Balig gun & target	Location 5
Balig	Location 6
Red Heugh	Location 7
Mullock Farm	Location 8
Silverhill Low	Location 9
EchoTarget (Doon Hill)	Location 10
Between Doon Hill Gun & target	Location 11
Doon Hill	Location 12
Gipsy Point	Location 13

Figure 1: Map of Kirkcudbright showing firing and sampling locations

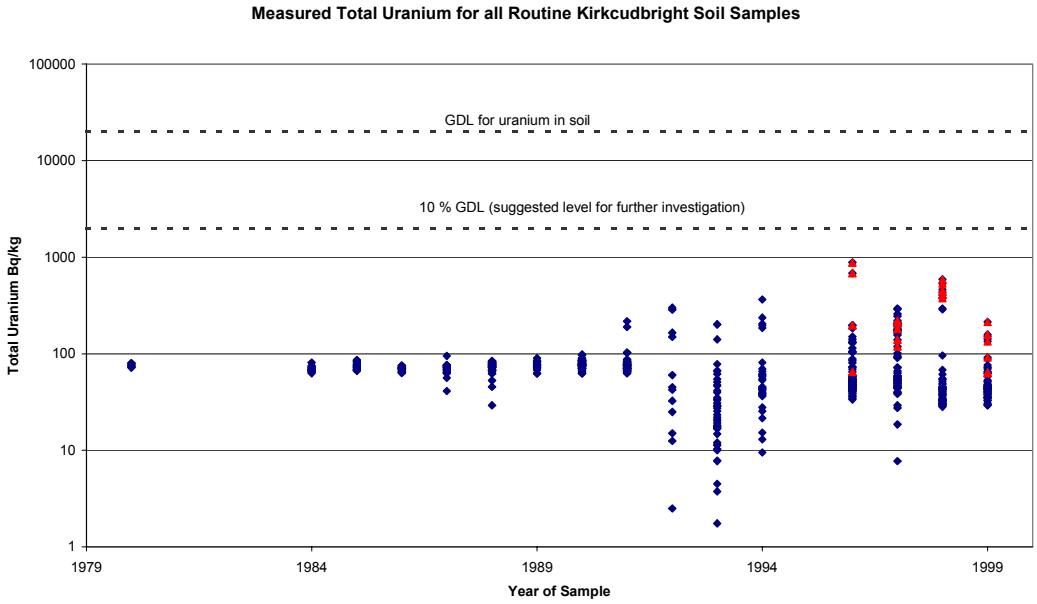


Figure 2. Scatter plot of measured total uranium for all samples. Raeberry Gun Samples have been highlighted in red.

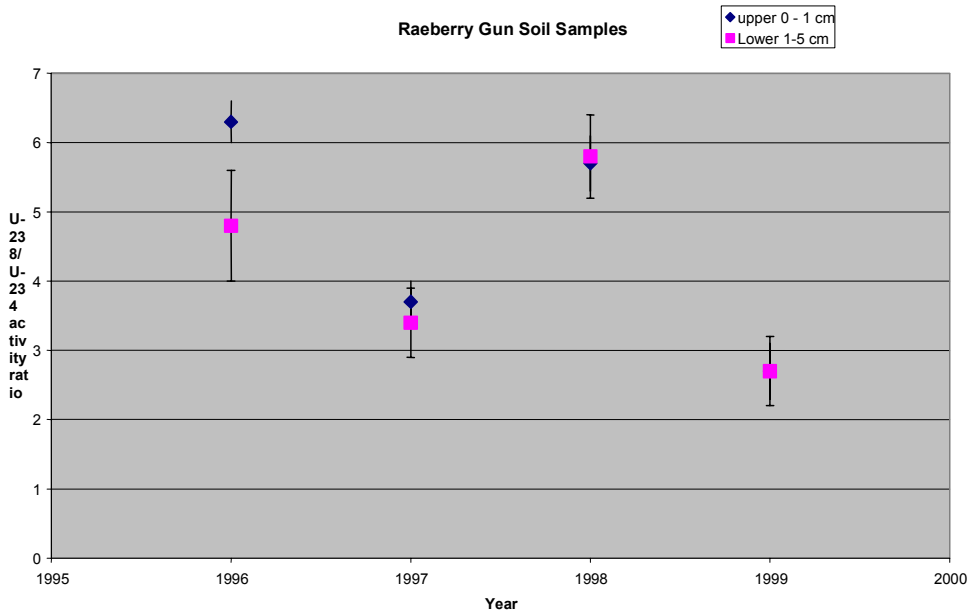


Figure 3. U-238/U-234 activity ratio for upper (diamond) and lower (square) soil samples taken at Raeberry Gun.

Location	1980	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1996	1997	1998	1999
1	80	71± 6	80 ± 5	71± 7	77 ± 8	78 ± 8	79 ± 8	78 ± 8	73 ± 8	30 ± 12	18 ± 11	138 ± 6	62 ± 6	60 ± 4	42 ± 4	49 ± 4
2	78	69 ± 6	70 ± 5	71± 10	69 ± 7	73 ± 8	78 ± 8	79 ± 8	71 ± 8	166 ± 38	21 ± 11	84 ± 8	68 ± 5	93 ± 7	106 ± 9	81 ± 6
3	77	n/s	n/s	n/s	n/s	n/s	n/s	N/s	n/s	n/s	n/s	n/s	698 ± 50	179 ± 13	473 ± 29	102 ± 9
4	n/s	n/s	n/s	n/s	n/s	n/s	n/s	N/s	n/s	n/s	n/s	n/s	48 ± 4	46 ± 4	35 ± 4	50 ± 4
5	60	n/s	n/s	n/s	n/s	n/s	n/s	N/s	n/s	n/s	n/s	n/s	52 ± 4	64 ± 5	44 ± 4	41 ± 3
6	77	n/s	73 ± 3	67 ± 6	69 ± 5	77 ± 4	76 ± 5	78 ± 5	119 ± 8	104 ± 18	85 ± 11	169 ± 10	137 ± 10	257 ± 24	93 ± 7	46 ± 3
7	87	n/s	n/s	n/s	n/s	n/s	n/s	78 ± 8	71 ± 8	76 ± 25	18 ± 11	22 ± 4	43 ± 4	52 ± 4	31 ± 3	35 ± 3
8	72	n/s	n/s	n/s	n/s	n/s	n/s	75 ± 8	77 ± 8	155 ± 67	22 ± 11	27 ± 3	57 ± 5	46 ± 6	40 ± 3	33 ± 3
9	n/s	n/s	n/s	n/s	n/s	n/s	n/s	82 ± 8	87 ± 8	36 ± 20	32 ± 11	47 ± 4	54 ± 4	52 ± 4	39 ± 3	43 ± 4
10	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	37 ± 4	74 ± 12	32 ± 3	60 ± 7
11	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	55 ± 4	49 ± 4	45 ± 4	69 ± 5
12	75	n/s	n/s	70 ± 13	65 ± 9	60 ± 8	69 ± 9	76 ± 9	66 ± 9	26 ± 16	34 ± 14	39	70 ± 6	155 ± 10	54 ± 4	64 ± 5
13	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	47 ± 4	43± 3	42 ± 4	38 ± 3

Table 2: Average annual total uranium results for each Kirkcudbright sample site. Figures quoted are in Becquerels per kilogram. Reported measurement uncertainties are at the 95% confidence level. n/s indicates that no samples were taken for a particular site during that year. No samples were obtained during 1982, 1983, and 1995.

B Appendix. Kirkcudbright marine results: Figures

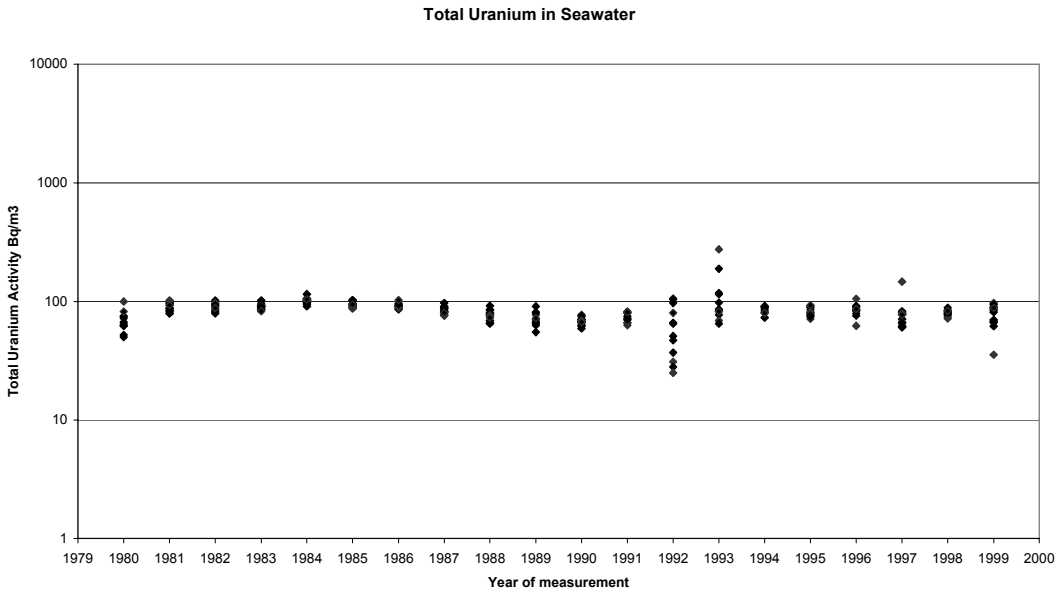


Figure 4 Scatter plot of all reported total uranium data for Kirkcudbright seawater samples

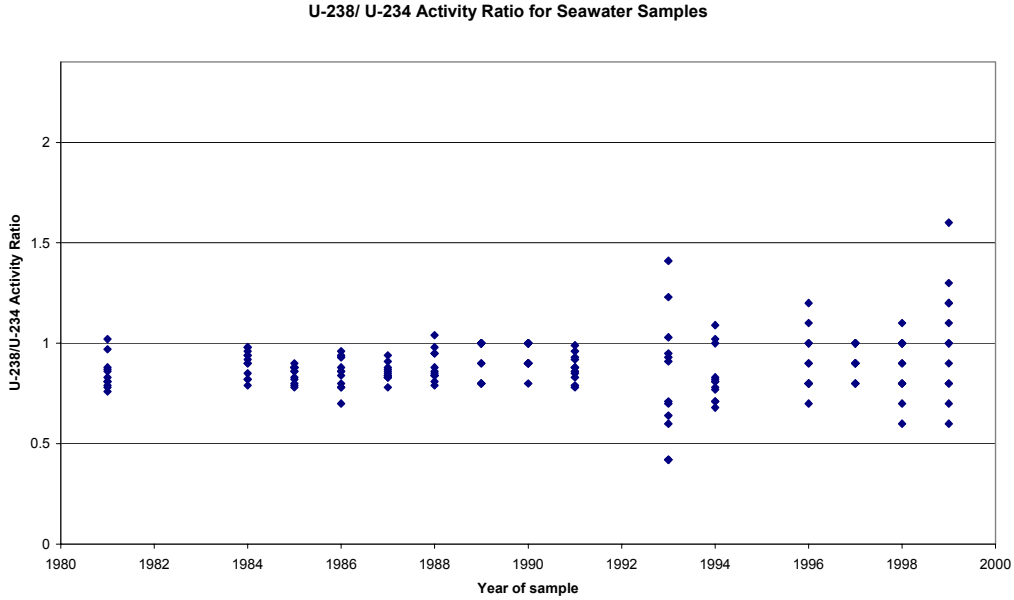


Figure 5 Scatter plot of all U-238/U-235 activity ratio data for Kirkcudbright seawater samples

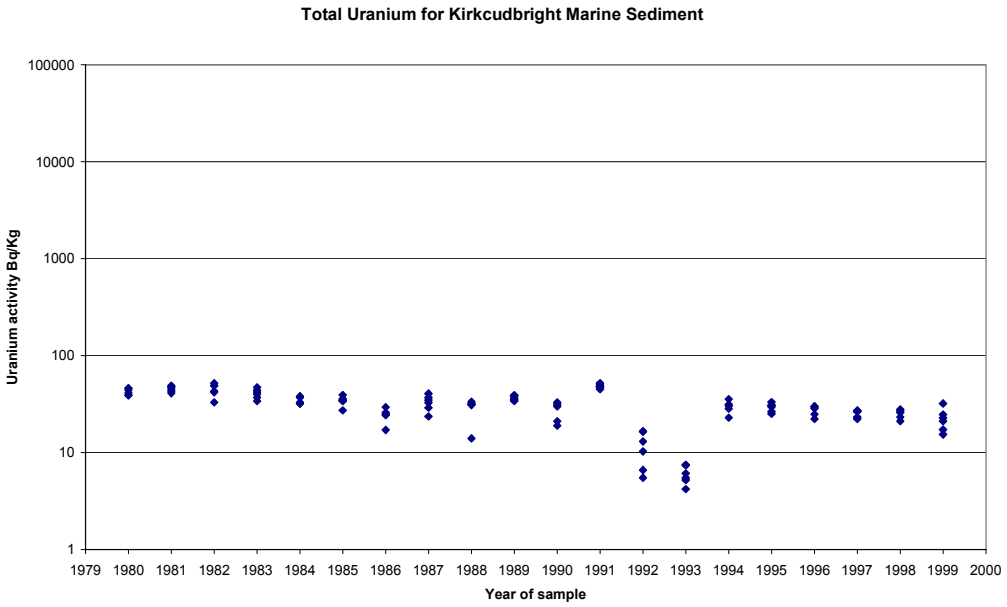


Figure 6. All reported total uranium data for Kirkcudbright marine sediment.

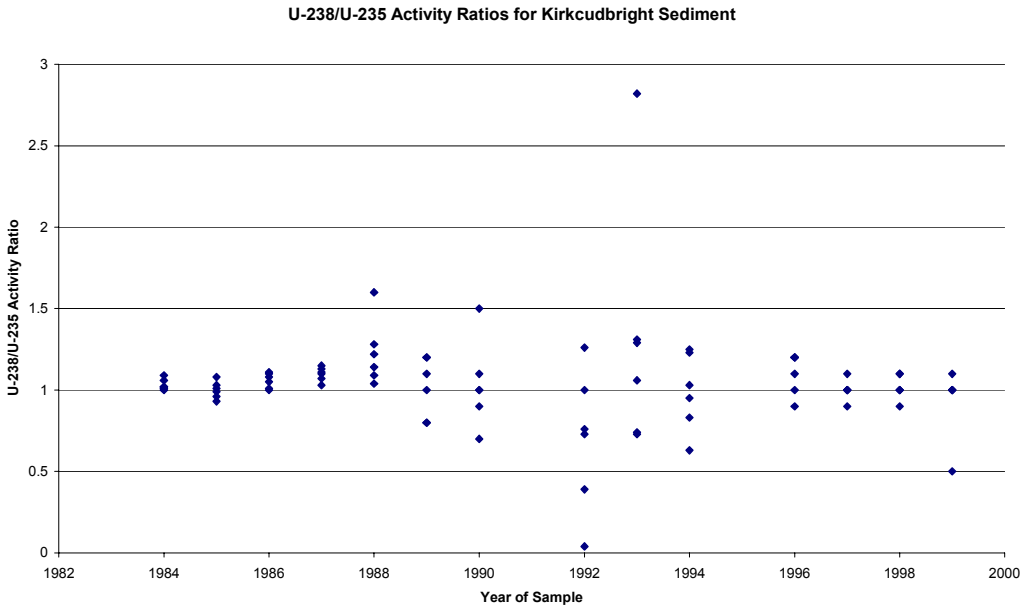
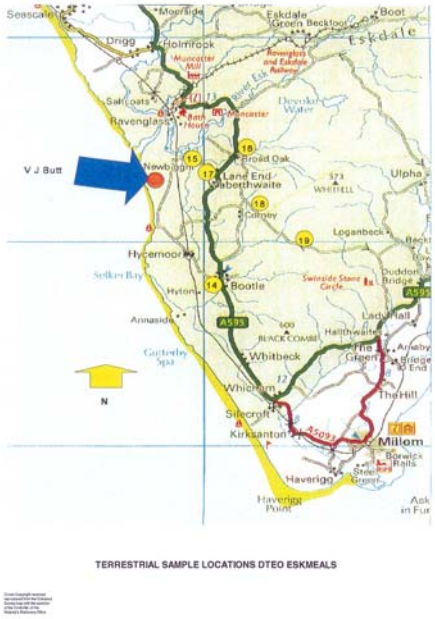
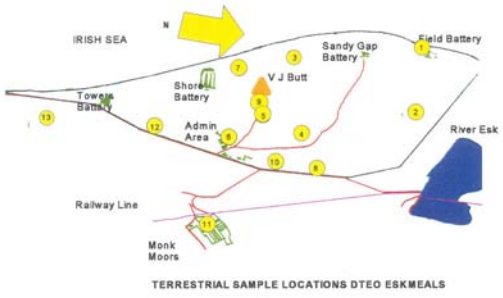


Figure 7. U-238/U-234 activity ratio data for Kirkcudbright marine sediment

C Appendix. Eskmeals soil: Figures and Table





Location	
1	Field battery
2	Eskmeals Battery
5	Overland Cut (top) on North Cut
6	Overland Cut (bottom) on South Cut
5	Main Battery Tower
6	Administration Block
7	Shore Top:Shore 1/Overland Butt
8	Barrier 3
9	VJ Battery rear blast wall
10	Met station
11	Monk Moors
12	Ammo compound: gate by main post
13	Skelda Hill
20	Bootle
21	Newbriggen Road, past Eskmeals Viaduct
22	Broad Oak Area
23	Waberthwaite
24	Corney Radar
25	Buck Barrow Bridge

Figure 8: Eskmeals sampling locations

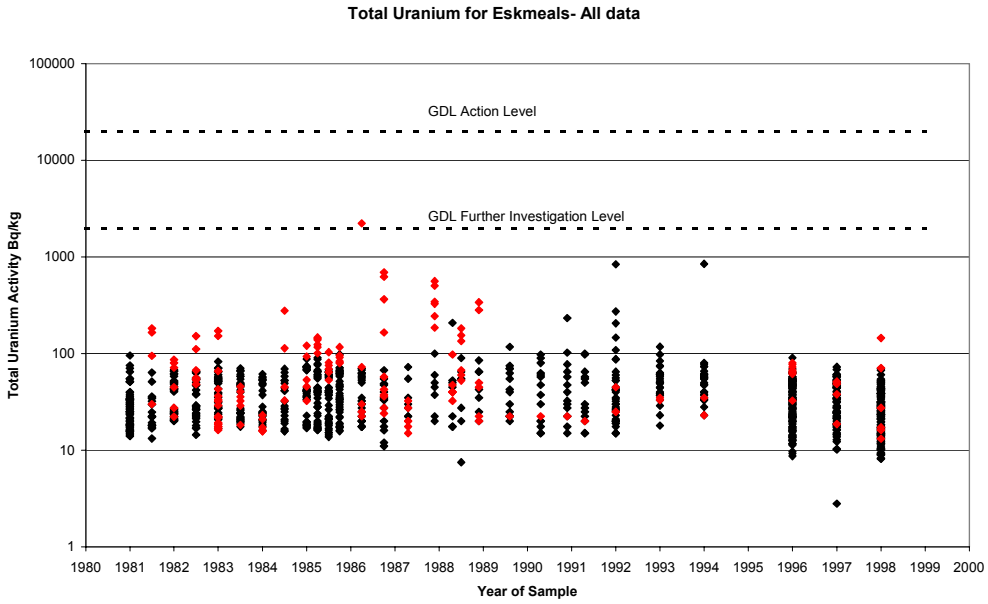


Figure 9 Scatter plot of all results from total uranium samples for all Eskmeals sites. Data from the Rear of VJ Butt site is highlighted in red.

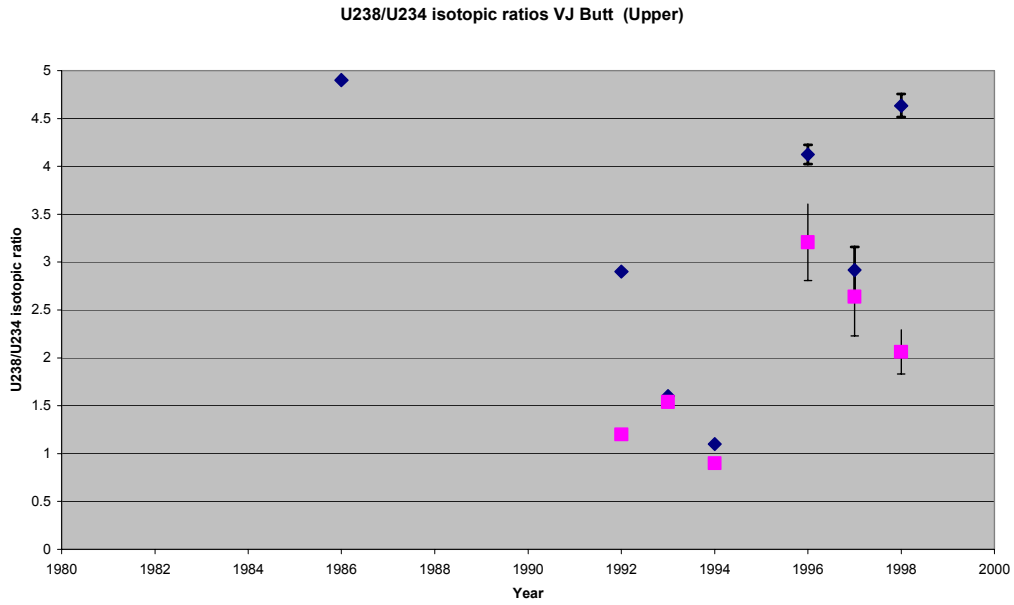


Figure 10. U-238/U-234 activity ratio data for upper (squares) and lower (diamond) soil samples 'Rear of VJ Butt' site.

Locn	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1996	1997	1998
1	17	24	24	24	20 ± 3	18 ± 3	22 ± 5	15 ± 5	23 ± 5	20 ± 6	25 ± 5	18	31	26	17 ± 2	19 ± 2	12 ± 1
2	23	23	23	21	18 ± 3	19 ± 3	23 ± 5	21 ± 5	20 ± 5	23 ± 5	30 ± 5	22	39	34	11 ± 2	14 ± 2	11 ± 1
3	N/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	23 ± 5	19 ± 5	15 ± 5	22	45	39	22 ± 2	31 ± 2	14 ± 2
4	N/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	23 ± 5	15 ± 5	20 ± 5	44	28	48	21 ± 2	19 ± 2	19 ± 2
5	N/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	40 ± 5	50 ± 5	23 ± 5	32	58	42	23 ± 2	19 ± 2	19 ± 2
6	33	43	49	45	40 ± 4	41 ± 4	38 ± 6	49 ± 8	55 ± 8	48 ± 5	n/s	44	68	67	30 ± 3	35 ± 3	36 ± 3
7	N/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	25 ± 5	24 ± 5	15 ± 5	25	48	443	45 ± 3	37 ± 3	29 ± 3
8	N/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	30 ± 5	35 ± 5	28 ± 5	26	34	37	23 ± 2	23 ± 2	11 ± 1
9	118	69	40	58	92 ± 6	280 ± 8	191± 11	95 ± 8	23 ± 5	23 ± 5	20 ± 5	35	34	29	65 ± 5	39 ± 3	52 ± 4
10	23	23	28	22	28 ± 3	28 ± 3	32 ± 4	28 ± 5	n/s	n/s	n/s	n/s	n/s	n/s	43 ± 3	25± 2	16 ± 2
11	42	52	53	56	64 ± 5	54 ± 5	58 ± 5	76 ± 8	70 ± 8	64 ± 8	58 ± 8	43	56	78	37± 3	32 ± 3	24 ± 2
12	ns	n/s	n/s	n/s	n/s	n/s	n/s	n/s	43 ± 5	131 ± 9	50 ± 8	34	48	55	18 ± 2	20 ± 2	26 ± 2
13	64	n/s	n/s	29	50 ± 4	40 ± 5	43 ± 6	60 ± 6	63+/-8	53 6	55 ± 8	41	61	55	25 ± 2	45 ± 3	29 ± 3
14	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	63	54	60	38 ± 3	41 ± 3	40 ± 3
15	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	117 10	78 10	100 ± 8	109	101	57	52 ± 4	59 ± 4	22 ± 2
16	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	52 ± 3	56 ± 3	33 ± 3
17	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	54±.4	41 ± 3	47 ± 5
18	44 ± 12	61	69	62	65 ± 5	67 ± 5	86 ± 8	112 ± 10	75 ± 8	84 ± 8	65 ± 8	389	77	77	46 ± 3	47 ± 3	38 ± 3
19	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s	70 ± 8	92 ± 10	98 ± 10	96	56	63	54 ± 3	29 ± 2	54 ± 4

Table 3: Average annual total uranium results for each Eskmeals sample site. Figures quoted are in Becquerels per kilogram. Reported measurement uncertainties are at the 95% confidence level. n/s indicates that no samples were taken for a particular site during that year. No samples were obtained during 1982, 1983, and 1995.

Report documentation page

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10a. Abstract. (An abstract should aim to give an informative and concise summary of the report in up to 300 words).

In order to ensure that the firing of Depleted Uranium (DU) munitions at the Kirkcudbright and Eskmeals ranges is not having an adverse environmental impact, routine environmental monitoring surveys have been carried out since the early 1980's. The results of these environmental surveys are published in annual or biennial reports.

This study compares the measured uranium levels reported in the environmental surveys to guidelines published by the National Radiological Protection Board. The guidelines, known as Generalised Derived Limits (GDLs) and are based on cautious assumptions relating to risks to members of the public.

As several techniques have been used to gather and analyse the data over a twenty-year period, the data has been normalised using very cautious assumptions, to provide a year on year comparison. All soil data has been presented in this report for Kirkcudbright and Eskmeals. Seawater and sediment data for Kirkcudbright are also given.

Comparison of the soil data shows that no monitoring site has produced measurements that have exceeded the GDL limit of 20,000 Becquerels per kilogram (Bq per kg) for uranium-238. No site has produced soil samples that have exceeded a suggested ‘level for further investigation’ of 2000 Bq per kg when averaged over the course of a year. No evidence of DU contamination has been found in seawater and marine sediment samples.

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