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ENVIRONMENTAL CONSEQUENCES FOR DEPLETED URANIUM FIRINGS AT KIRKCUDBRIGHT

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SUMMARY

This report provides an overview of the environmental consequences of past depleted uranium (DU) firings at DERA Kirkcudbright, assessments of potential doses to people in the vicinity of the Kirkcudbright range, a comparison of these with the effects of other sources, and the additional effect of further DU firings.

DU has not been found in any of the considerable number of marine environmental samples of fish, shellfish, sea water or sediment, so no radiation dose to members of the public in the vicinity of the Kirkcudbright range can be attributed specifically to DU contamination of the marine environment. However, because of the presence of DU penetrators in the bottom sediment of the Solway Firth, members of the public may exceptionally be exposed, to an unpredictable extent, on the chance finding and subsequent handling of a penetrator. The probability of this occurring is assessed as very low.

Contamination of range land by malfunctioning DU projectiles impacting the ground surface is generally very low and limited to relatively small and widely interspersed areas. Only in one land area is the level of contamination above the DUFERC investigation level. Of several potential exposure pathways to members of the public from terrestrial contamination, monitoring results indicate that only inhalation of resuspended contamination from vegetation, inhalation of DU particulates from the gun during firings and the ingestion of meat and milk from animals grown on the range are relevant. Exposures to members of the public from these terrestrial pathways are assessed as very low and below the level of regulatory concern.

Approximately 27 tonnes of DU have been fired on the Kirkcudbright range since commencement of the firings programme in 1982. It is anticipated that a further 1275 kg will be fired before completion of the current firings programme in mid-2001, representing some 5% of the mass of DU already fired. Since environmental monitoring results to date indicate no radiation exposure to members of the public from DU projectiles which have entered the sea and only very low exposures, well below the level of regulatory concern, from DU contamination of the range itself, it is considered that the proposed additional firings of a limited quantity of DU ammunition will have no appreciable effect regarding radiation exposure of, or risk to, people in the vicinity of the Kirkcudbright range.

A question remains on the eventual fate of the penetrators in the environment. It is essential that comprehensive monitoring of the environment continues until such time as the behaviour of DU is fully understood. A programme of investigations has been prepared in order to gain this understanding and negotiations on its funding are in progress.

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INTRODUCTION

1. An action was placed on DRPS at the Depleted Uranium Firing Environmental Review Committee (DUFERC) meeting on 12 June 1998 to prepare a report summarising current knowledge on the environmental consequences of past depleted uranium (DU) firings. The task required assessment of potential doses to people in the vicinity of the Kirkcudbright range and comparing these with the effects of other sources where possible, and the additional effect of further DU firings.

2. DU projectiles have been test fired on the Kirkcudbright range since 1982. The objective of the programme is to test and prove the behaviour and accuracy of individual projectile configurations. As such, the firing at Kirkcudbright is intended to be non destructive. For normal operations, the projectiles are intended to travel across the range, pass unhindered through a plastic mesh target mounted on the cliff top, and continue their trajectory out to sea, ending up in the Solway Firth. Under normal firing conditions no contamination of the range land can take place, except possibly by small amounts of DU that may be released from the gun barrel at the time of firing and from discarded sabots.

3. Since commencement of the firing programme a number of malfunctions have occurred during which the projectile trajectory has been such that penetrators have impacted on the ground or other hard surfaces on the landward side of the target. These malfunctions have occasionally resulted in fragmentation of the penetrator and dispersal of DU in the impact area.

4. Additionally, potential contamination of the land may be caused by sabots (outer sections of the projectile which detach from the DU penetrator after firing), which from normal firings land in a fairly well defined zone 600 metres in front of the firing position. Approximately 10% of sabots remaining on the range are reported as being slightly contaminated with DU. Sabots are retrieved whenever possible for examination after firings but a large number, estimated at several thousand, remain on the ground surface or mixed in with the top soil [1].

5. DU may also be dispersed from the gun during firings. Low levels of residual DU contamination have been detected in the gun barrel after DU firing, implying that DU may also be dispersed from the gun at the time of firing. At present, such releases have not been confirmed and the mechanism by which DU is released into the barrel is not known. However, it is considered that the quantities involved are very small.

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CONTENTS

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From contamination of the marine environment -

a. external radiation exposure to sea water

b. external radiation exposure to sediment

c. ingestion of sediment

d. ingestion of sea water

e. ingestion of fish, shellfish or seaweed

From contamination of the terrestrial environment -

a. external radiation exposure from vegetation or soil or DU fragments

b. inhalation of contamination released into the air or resuspended from vegetation, soil or sediment

c. ingestion of crops or animal products obtained from pasture or soil

d. ingestion of water from streams

ENVIRONMENTAL MONITORING PROGRAMME

11. A MOD environmental monitoring programme has been in place since the start of the DU firing programme on the Kirkcudbright range in 1982.

12. Samples of sea water, underwater and shoreline sediment, seaweed, mussels, scallop and crab are routinely collected from the Solway Firth and the Kirkcudbright shoreline in order to assess the potential radiation exposure of people from contamination of the marine environment.

13. Samples of grass, soil, fresh water and faeces from grazing animals are routinely taken from locations on the range in the vicinity of gun positions and soft target stands in order to assess the potential radiation exposure of people from contamination of the terrestrial environment. The gamma radiation dose rate is also measured at each monitoring location.

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FATE OF DU PENETRATORS IN THE ENVIRONMENT

6. Under normal operational firings, DU penetrators enter the sea approximately two kilometres offshore in the Solway Firth. It is likely that penetrators remain intact but they may fragment as a result of impact with the sea surface and thermal shock on immersion in cold sea water. The DU penetrator, whether intact or in fragments, will sink to the sea bed where, under its own weight and the result of tidal action, it is likely to become buried in the bottom sand and sediment of the Solway Firth where it corrodes. It is reported that the bottom sediments off Kirkcudbright comprise silt, mud and sand [1].

7. From projectile malfunctions, where penetrators have impacted on land, fragments of DU are dispersed over small areas around the impact site (tens of metres square). These fragments may remain on the ground surface or sink into the top soil. Under certain impact conditions, a portion of the projectile may be dispersed as fumes and particulates. The larger particles will settle on to the ground within a short distance from the point of release, while smaller particles will be carried further downwind before depositing on the ground surface.

8. Small DU particles in the air, whether from fragmentation in flight, impact with the ground surface or from the gun barrel, are a hazard to persons if they breathe in the contaminated air. DU particles will eventually deposit onto the ground surface but may be resuspended into the air by movement over the ground surface by passing traffic or weathering effects, thereby recreating the inhalation hazard.

RADIATION EXPOSURE PATHWAYS

9. Substances, whether radioactive or not, may enter the body by three main routes; inhalation, ingestion, and through the skin (either intact or through a wound). The inhalation and contact routes require direct exposure of the person with the substance, whereas the ingestion route may be by a number of complex pathways through eating or drinking food stuffs which are surface contaminated, eg, green vegetables, or are derived from contaminated soil or grass, eg, vegetables, meat and milk.

10. Several possible routes exist for the public exposure to DU released into the environment at Kirkcudbright. Exposure routes will of course only be relevant if the environmental medium or food stuff is contaminated with DU.

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tended pasture where artificial fertiliser has been used. Phosphate fertiliser contains activity mass concentrations of the radionuclides of the ^{238}U decay series 5 to 50 times higher than those in normal soil. Levels of ^{238}U ranging from 1700 to 9200 Bq per kg have been measured in phosphate (P_2O_5) fertiliser [9].

22. Regarding the potential contamination of soil and grass in the immediate vicinity of discarded contaminated sabots, on the basis of the limited amount of monitoring/ sampling conducted so far there is no evidence to show that DU contamination has transferred from sabots to vegetation or soil around the sabots. This indicates that DU contamination is so low as to be indistinguishable from background or that contamination of the sabot is effectively immobile and has been become fixed to the sabot by some mechanism endured by the projectile during the firing process.

RADIATION DOSES TO MEMBERS OF THE PUBLIC IN THE VICINITY OF THE KIRKCUDBRIGHT RANGE

Doses from marine contamination

23. Since DU has not been found in any marine environmental samples [1] [3], no doses to members of the public can be attributed to DU contamination of the marine environment. However, since it is known that DU penetrators are present on or in the bottom sediment of the Solway Firth and that DU corrodes in sea water, localised DU contamination must exist, if only temporarily. The absence of DU contaminated samples indicates either that DU projectile corrosion products are being so thoroughly dispersed that they make no detectable difference to natural levels of uranium in the marine environment or that corrosion products are trapped in the bottom sediment and any release to sea water is at present insufficient to show in the current sampling programme.

Doses from terrestrial contamination

24. DERA are aware that despite efforts to retrieve all projectile fragments resulting from firing malfunctions, some remain buried in the range ground. However, since measurements of surface gamma radiation doserates are essentially indistinguishable from background, no additional external radiation exposure can sensibly be attributed to the low levels of DU found in grass and soil samples on the range. It is considered that no external radiation hazard exists from any buried fragments present in the ground providing they remain in situ. In line with MOD policy, range personnel are provided with full safety instructions

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ENVIRONMENTAL MONITORING RESULTS

Marine monitoring results

14. Marine monitoring results have been reported at References 1 and 3. Reference 1 reported that all marine organisms sampled contained very low concentrations of ^{238}U and the presence of DU was not indicated. No DU was found in whelks, crab, dogfish or lobster taken from catches by local fishermen. The observed uranium concentrations were similar to those found for natural uranium in marine flora and fauna elsewhere in the UK.

15. Reference 3 reported that average concentrations of ^{238}U in sea water, sediment, seaweed and mussels at Kirkcudbright were very similar to natural concentrations of uranium in the marine environment.

16. Although DU projectiles are known to be present in bottom sediment of the Solway Firth, marine monitoring results from the Kirkcudbright area show that no DU has ever been found in any samples of sea water, underwater and shoreline sediments or biological specimens.

Terrestrial monitoring results

17. Terrestrial monitoring results have been reported at References 1 and 2. The results are summarised below.

18. MOD survey results indicate that although low levels of DU have been found in the terrestrial environment at some locations on the Kirkcudbright range, eg, Raeberry and Balig gun locations, only at the Raeberry gun position have soil samples registered concentrations of DU above the DUFERC investigation level of 0.3 Bq per gram. Uranium levels in soil, other than at the Raeberry gun position, are within the range expected for naturally occurring uranium found elsewhere in the UK.

19. Gamma radiation dose rates at all monitoring locations around the range are essentially indistinguishable from natural background levels.

20. In surface stream water samples, $^{238}U/^{234}U$ ratios indicate that only naturally occurring uranium is present.

21. Samples of animal faeces from sheep and cattle contain only low levels of naturally occurring uranium. Cattle faeces did show higher uranium levels, due to cattle grazing on

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from either marine food chain sources or air emissions arising from the firing or malfunctioning of DU projectiles."

NATURALLY OCCURRING URANIUM IN THE ENVIRONMENT

31. Uranium radionuclides exist naturally in the environment. ^{238}U and ^{235}U are primordial radionuclides that have half lives of 4.51 and 0.71 billion years respectively. Examples of the concentrations and variability of naturally occurring uranium in different environmental media and foodstuffs are given below.

Naturally occurring levels of uranium in soils and rocks [9,10]

[redacted]	[redacted]
Soil	25
Igneous rock	48
Sandstone	15
Shales	15
Limestones	15
Agricultural phosphate fertiliser	1700 - 9200

Naturally occurring levels of uranium in seafood [5]

[redacted]	[redacted]	[redacted]
Fish	3.9	4.5
Crustaceans	35	40
Crabs	46	55
Lobsters	35	40
Molluscs	890	990
Winkles	890	990

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regarding finding ordnance on the range and there are MOD notices around the range warning the public not to touch any items found on the range.

25. DU that has been deposited on soil and vegetation may be resuspended into the air and subsequently inhaled. However, as contamination levels are low and the areas of contamination are relatively small and widely interspersed on the range, doses to a person walking over the range have been assessed as insignificant. Calculations, based on pessimistic assumptions for the resuspension inhalation exposure route from surface contamination of grass, have indicated individual doses of less than 1 μSv per year. The principal annual dose limit for a member of the public is 1000 μSv per year. Resuspension from exposed soil is not considered an important exposure pathway as vegetation covers virtually all of the range land.

26. Surface water samples indicate the presence of natural uranium only. No dose due to DU contamination of surface drinking water can be attributed to this exposure route.

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

28. As limited numbers of cattle and sheep graze on the range, the exposure pathway of ingestion of animal products derived from contaminated soil or pasture is relevant. However, for DU in soil, ingestion of animal products such as meat and milk is not a dominant pathway, contributing only some 16% to the Generalised Derived Limit for ^{238}U in well mixed soil [4]. Because contamination levels are very low, the areas of contamination relatively small and interspersed, and no DU has been found in livestock faeces on the range, the maximum potential dose to any person ingesting beef, mutton or milk derived from range animals is considered to be insignificant.

29. At present there is no data on the total amount, spread or respirable fraction of DU particulate released from the gun barrel during firing of DU projectiles. However, if an approximate comparison is made with DU firings at Eskmeals, where, as a result of destructive testing of DU, releases of DU particulate to atmosphere are considered to be greater than at Kirkcudbright, the highest doses from inhalation of DU in air to personnel 600 metres away from the point of release, were of the order of 2 μSv per year [11]. Inhalation doses to people further away were lower.

30. Reference 1 concludes that "there is no evidence to suggest that the firing of DU at Kirkcudbright constitutes any significant risk to members of the public or site personnel,

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36. Discharges of radioactive waste into the sea for 1996 from BNFL establishments at Sellafield, Drigg and Chapelcross may be compared with those from DERA Kirkcudbright in the table below.

Sellafield sea pipelines	Alpha + Plutonium + Americium (mostly ^{241}Pu) Uranium (liquid)	4.91 1158 kg
Chapelcross	Alpha (unspecified radionuclides)	1.22×10^{-3}
Kirkcudbright	Uranium (solid) Alpha (Specific activity of DU =14 kBq g^{-1})	750 kg 1.05×10^{-2}

37. Samples of fish are taken by MAFF from numerous marine locations including the Irish Sea and off the Cumbrian coast, sea areas of the Solway Firth and off Kirkcudbright. Further samples of shellfish, sediment and sea water are taken from various locations around the UK coastline, including along the Cumbrian coast northwards to Inner Solway and along the North Solway coast westwards to Southemess, Carsluith, Kirkcudbright, Bladnoch and Garlieston. Marine sampling locations therefore extend to the east and west of the Kirkcudbright firing range coastal strip on the North Solway coast and along the Cumbrian coast to the south.

38. Samples are analysed using gamma ray spectrometry and radiochemical analysis, though are generally not analysed for Uranium activity.

39. It is reported that the important radiation exposure pathways for disposals from the Sellafield and Chapelcross sites are consumption of fish and shellfish and external exposure to gamma rays and beta particles from occupancy over sediments. Dose estimates for 1996 for most exposed persons in the Sellafield and Chapelcross areas are for people in the local fishing communities who received doses of 140 µSv and 32 µSv respectively from eating fish and shellfish. These exposures to critical group persons arising from radioactive disposals are well below the principal annual whole body dose limit of 1000 µSv per year for members of the public.

HAZARDS FROM DU PENETRATORS OTHER THAN ENVIRONMENTAL HAZARDS

40. Although marine and terrestrial environmental monitoring results for DU show that there is no significant exposure, and hence no significant risk, to members of the public through environmental pathways, there is a significant potential hazard which may arise if a

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Naturally occurring levels of uranium in crops [1]

Crop	Uranium concentration (μg/g) wet weight
Cereals	25 - 75
Fruit	8 - 125
Root vegetables	12 - 250
Vegetables	12 - 250

32. From the data shown above it can be appreciated that a fundamental problem for the monitoring programme is to separate and determine the effects of environmental contamination arising as a result of DU firings from variable levels of uranium occurring naturally in the environment.

33. The average concentration of naturally occurring uranium in sea water of 35% salinity is 3.3 μg per litre [6]. In a triangular body of water such as the Solway Firth with dimensions of, say, 50 km long by 40 km wide and an average depth of 20 m there will be of the order of 66 tonnes of natural uranium present. Preliminary experimental work at DRPS [8] indicates that, due to progressive corrosion of DU, the residence time for a DU penetrator in sea water is about 20 years . Thus, from some 27 tonnes of DU fired into the sea, approximately 110 kg of DU corrosion products will be added each month. This represents less than 0.2% of the total level of uranium in the Solway Firth.

ARTIFICIAL SOURCES OF RADIOACTIVE CONTAMINATION IN THE SOLWAY FIRTH

34. Reference 5 provides results of radioactivity monitoring programmes for food and the environment in the UK carried out by the Ministry of Agriculture Fisheries and Food (MAFF) and the Scottish Environment Protection Agency (SEPA). The report covers sampling programmes for both the terrestrial and aquatic environments.

35. The nuclear sites of interest nearest to the Kirkcudbright range are the British Nuclear Fuels PLC (BNFL) sites at Sellafield and Drigg on the Cumbrian coast to the south of Kirkcudbright, and Chapelcross on the North Solway coast in the Dumfries and Galloway region to the east of Kirkcudbright. Each of these sites is within 60 km of Kirkcudbright. Liquid radioactive wastes from both Sellafield and Drigg are discharged via pipelines to the same body of water on the Irish Sea coastline. From Chapelcross, liquid waste is discharged to the Solway Firth.

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Mass of depleted uranium fired each year at Kirkcudbright

[redacted]	[redacted]
1982	38
1983	240
1984	765
1985	650
1986	505
1987	646
1988	1163
1989	1856
1990	3399
1991	2847
1992	3339
1993	4199
1994	2018
1995	1197
1996	628
1997	3267
Total	26757

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member of the public was to find and handle a DU penetrator for any length of time. The 'worst case' scenario, where a member of the public could receive significant doses above the statutory dose limit, though well below a level where any deterministic (short term) health effects would be seen is perceived to be a child who finds a corroded penetrator and carries it home to play with. He/she could potentially receive a whole body dose of some 20 000 μSv in the first year. As the principal dose limit to a member of the public is 1000 μSv per year, the potential dose considerably exceeds the dose limit [7]. However, given the environment at Kirkcudbright, the risk of this happening is considered to be very small.

41. Public attention, despite essentially negligible public risk, would undoubtedly focus on the methodology of a firings programme which permits release of DU into areas to which the public have access or from which certain food stuffs are derived, without a reasonable awareness of the eventual fate of the penetrators or their possible effect on marine ecosystems. It is therefore essential that comprehensive monitoring of the environment continues until such time as the actual residence time of DU penetrators on the sea bed is determined and the fate of the corrosion products understood.

ADDITIONAL EFFECT OF FURTHER DU FIRINGS

42. From 1982 to 1997 approximately 27 tonnes of DU in projectiles have been fired on the Kirkcudbright range site as detailed in the table below.

43. It is anticipated that prior to completion of the current programme of DU projectile firings at the Kirkcudbright range in mid-2001, a further 1275 kg of DU will be fired as part of the current programme. This amounts to some 425 kg of DU per year over the next 3 years being added to the existing DU present in the Solway Firth. This represents less than 5% of the quantity of DU already fired.

44. Environmental monitoring results to date indicate no radiation exposure to members of the public from DU projectiles which have entered the sea and only very low exposures, well below the level of regulatory concern, from DU contamination of the range itself. It is therefore considered that under normal circumstances, the proposed additional firings of approximately 250 rounds of DU ammunition will have no appreciable effect regarding radiation exposure of, or risk to, the public.

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