Committee on Medical Aspects of Radiation in the Environment (COMARE)

FIFTEENTH REPORT

Radium contamination in the area around Dalgety Bay

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Produced by Public Health England for the
Committee on Medical Aspects of Radiation in the Environment

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FOREWORD

i The Committee on Medical Aspects of Radiation in the Environment (COMARE) was established in November 1985 in response to the final recommendation of the report of the Independent Advisory Group chaired by Sir Douglas Black (Black, 1984). The terms of reference for COMARE are:

> 'to assess and advise government and the devolved authorities on the health effects of natural and man-made radiation and to assess the adequacy of the available data and the need for further research'

ii In 28 years of providing advice to government and the devolved authorities, COMARE has published 14 major reports (see Appendix B), in addition to numerous other statements and documents. These have been mainly related to exposure to naturally occurring radionuclides such as radon and its progeny, or to man-made radiation, usually emitted by major nuclear installations. It has also published reports with a medical focus.

iii COMARE has been considering radioactive contamination in the Dalgety Bay area since 1991 and has been involved in advising Scottish authorities since then. Most of the advice has been channelled through the Scottish Environment Protection Agency (SEPA) since its inception in 1997.

iv In 2011, SEPA notified COMARE of a series of new finds of radioactive sources in higher numbers and containing greater amounts of radioactivity than found in the preceding period and the Committee instituted appropriate investigations as detailed below. In November 2012, before the Committee had prepared a report, two internal working papers were released under a freedom of information request made to SEPA and COMARE. As a result of a subsequent press article, the Scottish Government requested that COMARE prepare an interim report by 31 December 2012 and this was submitted.

v The aim of this COMARE report is to provide further information to the Scottish Government on the risks posed to the public by the contamination at Dalgety Bay, to examine the incidence of potentially related cancers and to recommend whether further actions to protect the public are required. Its methodology and approach may be applied to other sites where such contamination is found.

CHAPTER 1

INTRODUCTION

1.1 The Committee on Medical Aspects of Radiation in the Environment (COMARE) has been considering radioactive contamination in the Dalgety Bay area since 1991 and has been involved in advising the Scottish Environment Protection Agency (SEPA) since its inception in 1997. A SEPA observer attends the meetings of the full committee, as does a Public Health England (PHE) observer, permitting detailed collaboration between the organisations. The Ministry of Defence (MoD) also has observer status.

1.2 Most of the early contamination found in the Dalgety Bay area was in terrestrial locations. In these cases, each area affected was small and the contamination was immobile, easily delineated (ie a static problem) and amenable to remediation by excavation and removal.

1.3 The sources found from 2009 onwards were sited on the foreshore and appear to be evidence of a more dynamic (changing) situation. Under these circumstances, it is not possible to make accurate predictions about future hazard from past evidence.

1.4 In 2011, the most recent series of finds of radioactive sources located by SEPA was notified to COMARE. The Committee took the view that these finds represented a significant change to the previous situation, requiring more in-depth investigation.

1.5 In November 2011, COMARE requested that the NHS Scotland Information Services Division (ISD) conduct an analysis of the incidence of cancers in the vicinity of Dalgety Bay, comparing local incidence rates with the national averages for the whole of Scotland. This was received by the Committee in February 2012 and was copied to NHS Fife.

1.6 The ISD report, covering the period 2000–2009, was considered by COMARE at its meeting in March 2012. Two types of cancer showed an increased incidence that was statistically significant – primary liver cancer and non-Hodgkin lymphoma (NHL). COMARE agreed that a further postcode analysis should be undertaken for these two cancers to determine whether there was any spatial pattern present that might indicate a link to the site of the contamination. It agreed also that Fife Health Board should be asked to conduct a case-note review of the liver cancer cases to double-check that these had been classified correctly.

1.7 The confidential report from Fife Health Board was received by the Chairman of COMARE in July 2012 and the results of the postcode analysis for liver cancer were considered at the committee meeting in October 2012. The postcode analysis led to a request to the ISD for further information and analyses for both liver cancer and NHL cases.

1.8 In November 2012, the ISD report and the postcode analysis paper were released under a freedom of information request made to SEPA and COMARE. As a result of a subsequent press article, the Scottish Government requested that COMARE prepare a report by 31 December 2012.

1.9 On several occasions, as far back as 1992, COMARE has requested information from the MoD on other current and former military sites where such contamination might be present. Recently, the COMARE Contaminations Working Group sought information particularly on 'alienated' sites (those disposed of by the MoD) in September 2012, requesting the following information:

(a) Are alienated sites monitored by the MoD?

(b) Which alienated sites have been looked at in terms of monitoring or resurveying?

(c) What is the minimum detectable level of activity for the monitoring process?

(d) Does the MoD know of any potential pathways for human exposure at any of the sites?

COMARE has found that some of this information is not available.

CHAPTER 2

SITE HISTORY

2.1 Figure 2.1 shows the location of the site in the Dalgety Bay area, which is on the north shore of the Firth of Forth, about 5 km to the east of the Forth road and rail bridges. It forms one of the Firth of Forth Sites of Special Scientific Interest (SSSI) and also is part of the Firth of Forth Ramsar sites (the Ramsar Convention is an international treaty for the conservation and sustainable utilisation of wetlands).

2.2 Figure 2.2 shows the locality, which now includes part of the town of Dalgety Bay, and delineates the area of interest. Information about ownership of the site in the following paragraphs has been taken from a SEPA report (Patton, 2013), and is reproduced by permission.

2.3 Prior to the First World War the site was owned by the Earl of Moray and was open fields and ornamental gardens. The Earl of Moray donated approximately 150 hectares of land at his Donibristle estate during the First World War for use as an airfield. Donibristle airfield opened and was handed over to the Royal Naval Air Service (RNAS) in August 1917, with the Royal Air Force (RAF) taking over in 1918 when Donibristle became a fleet aircraft repair depot. The station was reduced to a care and maintenance basis in 1921.

2.4 In 1924, the Earl of Moray sold a further 22 acres of land to the President of the Air Council. The station was re-opened by the RAF in 1925 as a shore training base for disembarked carrier units and shore-based torpedo bomber squadrons.

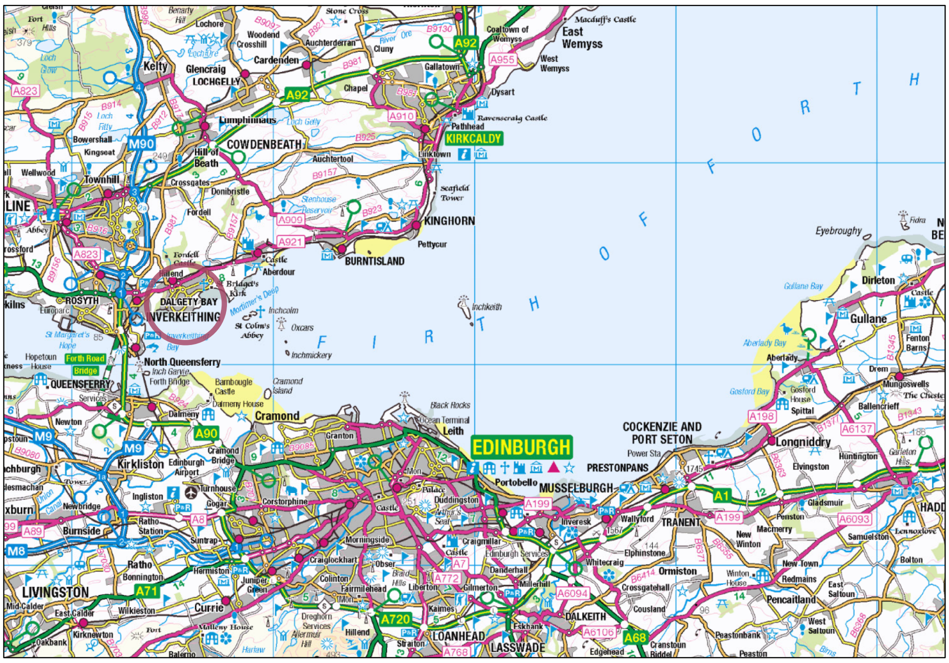


Figure 2.1 Location of Dalgety Bay

Contains Ordnance Survey data © Crown copyright and database right 2014

Figure 2.2 Dalgety Bay locality, showing the study area
Contains Ordnance Survey data © Crown copyright and database right 2014

2.5 In 1939, the airfield was commissioned as HMS Merlin, with the addition of a major aircraft repair yard (Royal Naval Aircraft Repair Yard or RNAY). HMS Merlin included a salvage section, which consisted of a number of buildings in the south east of the airfield.

2.6 Aerial photographs from 1945–48 show aircraft parked on the site; no aircraft are visible in a 1949 photograph. Stored aircraft are again visible in 1955, while the last aircraft left the site in 1959, as the work undertaken at RNAS Donibristle was transferred to Belfast and Fleetlands.

2.7 Moray Estates Development Company sold approximately 280 acres of land to the Commissioners for the Office of the Lord High Admiral of the United Kingdom and Ireland. Although the date of entry is specified as November 1950, it appears these areas were already occupied as part of RNAS Donibristle (HMS Merlin).

2.8 In 1952, a civilian firm contracted by the Admiralty, Airwork Limited, took over communications and the task of running the airfield. In November 1953, RNAS Donibristle (HMS Merlin) was reduced to care and maintenance and was handed over to HMS Cochrane for office flag officer carrier training. The accommodation blocks were used as barracks for naval artificers being trained at Rosyth Naval Base.

2.9 Parts of the area were used as agricultural and grazing land between the mid-1950s and 1960. The airfield was decommissioned during 1959 and was sold by the MoD in three separate parts: 101 hectares to Moray Estates Development Company in 1962, 22 hectares to the Board of Trade in 1964 (see paragraph 2.13) and 27 hectares to Fife County Council in 1968 (see paragraph 2.14).

2.10 In March 1960, Copthall Holdings (Dalgety) Development Limited was formed to build a new town at Dalgety Bay over the next 10 years, sponsored jointly by Moray Estates Development Company Limited. This was then passed to Copthall Holdings (Dalgety) Developments Limited in 1967, with the exception of the foreshore area which is still owned by Moray Estates Development Company Limited. Although Moray Estates Development Company still owns the foreshore, the sale to Copthall Holdings (Dalgety) Developments Limited does include the rights to the minerals and sand on the foreshore.

2.11 Copthall Holdings (Dalgety) Developments Limited later changed its name to Donibristle Investments Limited and is now known as James Harrison Contracts Limited. The last company still owns the land to the north and west of the land that is now owned by Dalgety Bay Sailing Club Limited, as well as the rights to the minerals and sand on the foreshore.

2.12 The area was subsequently developed for residential and leisure uses. Outline planning permission for residential development was granted in May 1961. Groundworks for the infrastructure (roads, drainage, etc) commenced in 1964 and the first houses were built in 1965 in the central area of the former airfield, south of the former runway area. Development in the southern area of the former airfield started in the early 1970s and appears to have been completed by 1983.

2.13 Land purchased by the Board of Trade was used to create Donibristle Industrial Estate. Plots or buildings were sold by the Board of Trade (subsequently the Scottish Development Agency and now Scottish Enterprise) to individual companies from 1968 onwards. The Scottish Development Agency had disposed of all land and property at Donibristle Industrial Estate by 1990.

2.14 Land purchased by Fife County Council became Hillend Industrial Estate. Plots or buildings were sold by Fife County Council (subsequently Dunfermline District Council and Fife Regional Council) to individual companies, starting in 1969 and continuing throughout the 1970s, 1980s and 1990s.

2.15 Dalgety Bay Sailing Club Limited was formed in 1971. The sailing club was formally opened in 1972 on 2.6 acres of land leased from Donibristle Investments Limited at that time.

2.16 The original clubhouse was a wooden garage located at the rear of where the existing top boat shed is now located. The current clubhouse was built in 1975, with an extension added in 2000. From the sailing club archives, it appears that the site was levelled and that material excavated from the foundations was used to create a mound against the masonry footings of the clubhouse on the southern elevation.

2.17 A 1979 aerial photograph shows a second slipway in place to the west of the original slipway. The easternmost beach shows an increase in the number of boats being stored. In addition, further storage is evident to the north in this area.

2.18 Evidence, confirmed by aerial photography, suggests that the rock armour (large quarried blocks) around the headland and the boat park was placed and replenished throughout the 1980s (McPhail, 2011a). It appears that this material was added from the construction site of the Forth Road Bridge and is understood to be mainly smaller rocks and shale. The rock armour in front of the headland area was augmented 8–10 years ago with larger rocks which also came from some additional construction work done in connection with the Forth Road Bridge. It is understood that the rock armour was emplaced by the sailing club and not by Fife Council (McPhail, 2011a).

2.19 The stonework of the New Harbour was restored in 1980 by members of the sailing club, no major earthworks being involved.

2.20 The sailing club purchased two areas of land from James Harrison Contracts Limited, 1.26 acres of land in November 1984 with the pier or jetty known as the New Harbour and sea walls thereon and 2.85 acres of land in September 1985 bounded on the west by the Wynd.

2.21 Fife Council holds the responsibility for coastal defence. The current Fife shoreline management plan (Fife Council, 2011) indicates that Fife Council has a general policy of 'hold the line' for currently defended sections of the coastline in the vicinity of Dalgety Bay, but as the rock armour was not placed by the Council, it is not maintained by the Council. Information from Fife Council Transportation and Environmental Services Department indicates that it holds no records with respect to coastal defence works in the vicinity of Dalgety Bay.

2.22 Fife Council also has the responsibility for the maintenance of Ross Plantation, but has indicated that 'next to no works' within Ross Plantation have been carried out. More recently (since the 1990s), Fife Council, as a precautionary measure, has stopped any community planting or works by Council staff that might involve staff handling the soil, thus avoiding any contamination under their finger nails.

Coastal changes

2.23 The coastline of the area under consideration has changed over time and the changes have been assessed by means of aerial photographs.

2.24 Aerial photographs of the Dalgety Bay area were obtained from the Royal Commission on the Ancient and Historical Monuments of Scotland and analysed by the University of Stirling under a contract from SEPA (Sneddon et al, 2013). This dataset comprised 17 photographs taken between 1945 and 1990. The photographs were all taken on black and white panchromatic film, with the exception of those collected in 1973.

2.25 The aerial photographs were geocorrected to the British National Grid using Ordnance Survey (OS) map data (1 : 10,000 raster product) by a third-order polynomial translation and nearest-neighbour resampling. Initially, the 1990 aerial photograph was geocorrected to the OS map using a large number of ground control points (GCPs – fixed points that could be accurately identified on both the OS map and the aerial photograph). The 1990 geocorrected aerial photograph was then used as the basis for the correction of the next photograph in the time sequence, taken in 1986. This procedure was repeated with the remaining aerial photographs geocorrected in reverse chronological order. This 'back-stepping' approach minimised the variation in geolocational error with each time step.

2.26 The coastlines were identified by visual interpretation, photographic contrast, brightness and gamma, being modified through a range of interactive image stretches to assist with boundary identification. The coastlines were then superimposed over a 2009 Google Maps™ photograph.

2.27 All the photographs in the period from 1945 to 1950 showed a similar morphology for Dalgety Bay. As the 1949 photograph offered the best image quality, it was used as a baseline against which to compare changes that occurred after 1950.

2.28 The coastline of the bay shown in the 1990 photograph was fairly similar to that of 2009, with overlap found for most of the coastline. Thus, it was assumed that the 1990 photograph provides a relatively accurate representation of the current morphology of the coastline around the bay. Figure 2.3 shows

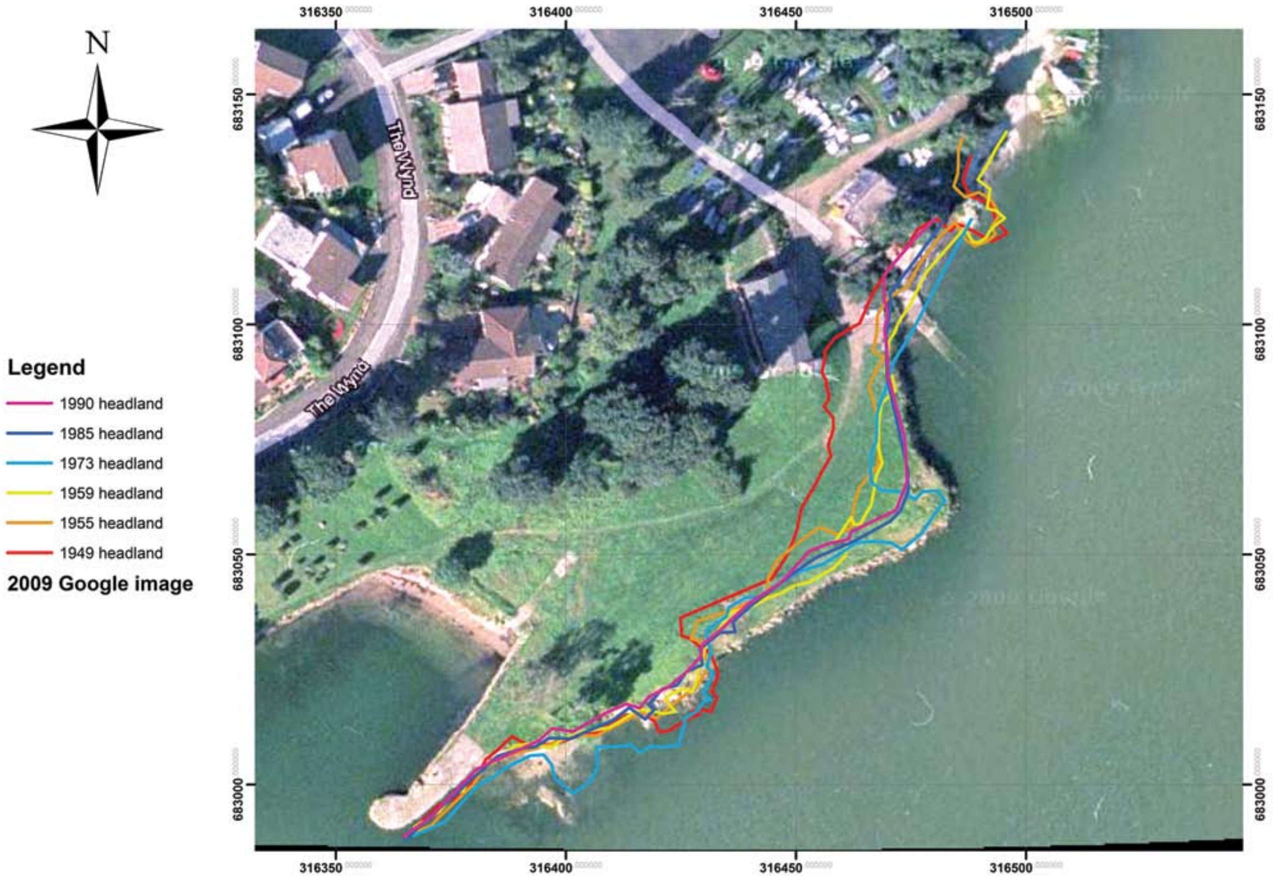


Figure 2.3 Shoreline contours for the west of the study area, the 'headland' area
Coastlines superimposed over a 2009 Google Maps™ image

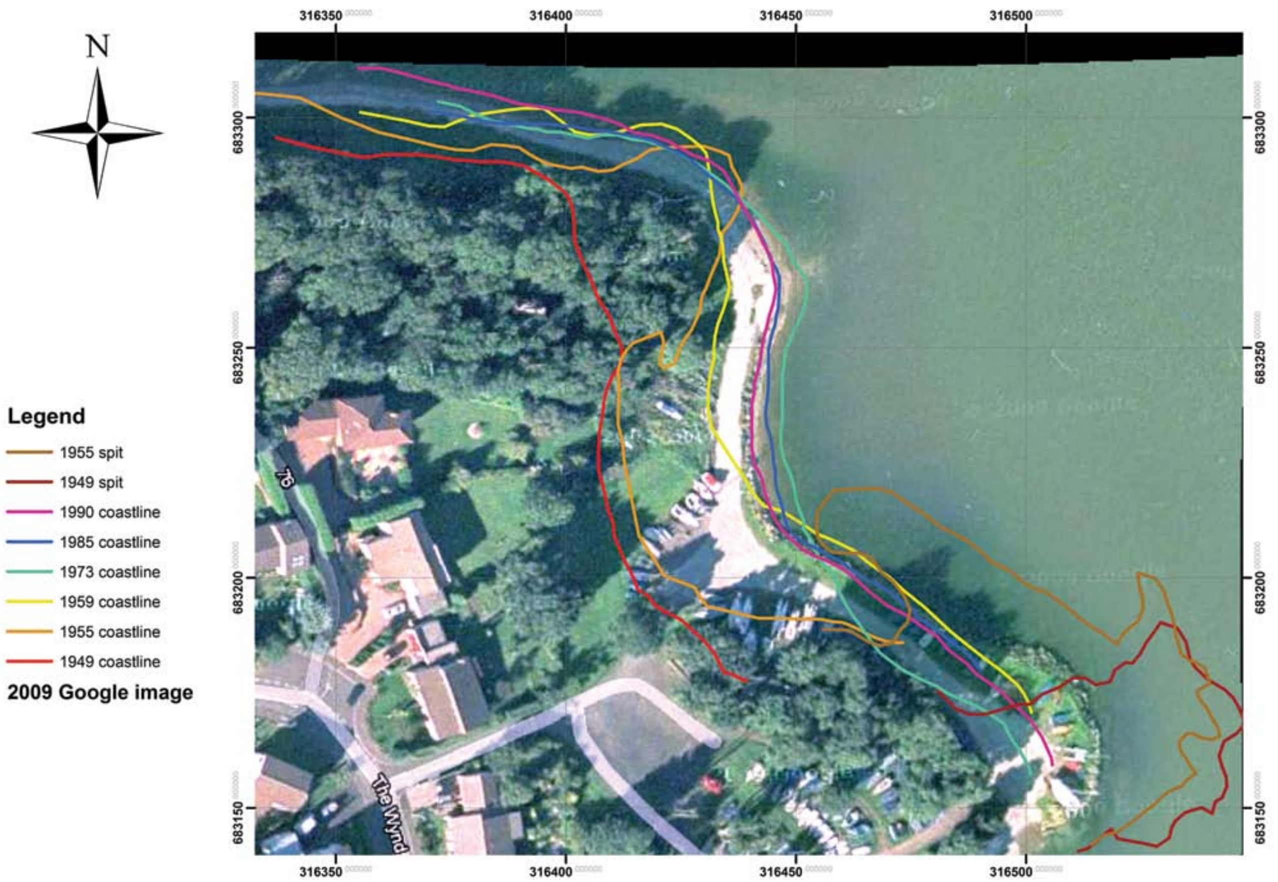


Figure 2.4 Shoreline contours for the east of the study area, the boatyard and 'Mud' bay area
Coastlines superimposed over a 2009 Google Maps™ image

that there is some discrepancy between the 2009 site morphology and the 1990 morphology south of the study site; this discrepancy is caused by the expansion of the coastline in this area after 1990.

2.29 A substantial change in morphology occurred between 1949 and 1955 in the eastern part of the area (Figure 2.4), this change being characterised by a deformation to the south-eastern spit-like feature, suggesting that it accretes across the bay in 1955. There is also a noticeable shift to the south of the bay. The feature also appears to have above-average shadowing, indicating an increased elevation relative to other features within the study area.

2.30 Between 1955 and 1959 the spit-like feature has been lost and the study area has been substantially infilled. This is established by the loss of exposed rock, which has been replaced by coarse sediment infill. This marks the time of most significant change, with the extent of infilling being almost equivalent to the infilling reported for the entire study period.

2.31 Following the infilling period of 1955–59, the coastline was found to vary slightly as accretion and erosion continued at the site for the following 30 years. Between 1959 and 1990, the coastline underwent minor changes, with accretion in the north of the study site, particularly around the northern rock formation. In the south of the study site erosion occurred between 1959 and 1990, with the coastline retreating by several metres, before post-1990 expansion (Figure 2.3).

2.32 Having established the 1949 coastline as the optimal baseline and the 1990 one as a reasonable representation of the current coastline, it was possible to estimate that an area of over 3,110 m^2 has been infilled over this period.

2.33 The headland (Figure 2.4) has undergone two primary changes, one post-1949 and the second post-1960. This interpretation uses higher quality photographs as the headland does not benefit from a well-defined beach that is visible in all tidal conditions, as is found at the bay study site.

2.34 The 1945–1949 headland coastlines demonstrate that there is little in the way of change between 1945 and 1949. Of importance, however, is the 'conical' shaped feature in the 1945 photograph, an area marked as a refuse tip in later OS maps. This coastal section is seen to change over the following years. Comparison of the 1949 and 1955 photographs shows an expansion in the northern part of the headland occurring between 1949 and 1955. Over this time, the coastal part of the tip area is seen to change. There is a minor second expansion in headland post-1955 that occurs mid-way up the headland, as shown in the 1959 and 1960 headlands.

2.35 Sometime between 1960 and 1973, a sandy promontory developed, pointing out towards the ocean. It is believed that this protrusion occurred after 1963 as it is not present in the lower quality 1963 headland photograph. Post-1973, the promontory changed shape, perhaps through erosion on the southern side. The variation in headland shape towards the south between 1973 and 1979 is likely to be a result of the fuzziness caused by sand and vegetation deposited on the rocks near the pier.

2.36 By 1985, the protrusion has been integrated into the headland with a much smoother headland boundary curving around to the north of the study site. This smoother shape remained constant until 1990, with strong overlap found between the 1985 and 1990 headlands. Between 1990 and the present, the middle of the headland accreted, expanding by around 10 metres.

2.37 These data are interpreted further in Chapter 7.

CHAPTER 3

RADIUM, ITS USE AND DISPOSAL

3.1 Radium-226 is a metallic radionuclide that emits alpha and gamma radiations and has a physical half-life of 1,600 years. When it is taken into the body (by ingestion or inhalation), it is the alpha radiation that poses the greater radiological hazard. The first product in its radioactive decay chain is the gas radon-222, which is itself a radionuclide (with a half-life of 3.82 days), also emitting alpha radiation (Figure 3.1). Other radionuclides in the decay chain emit alpha, beta and gamma radiations and include polonium-210 and lead-210; the last nuclide in the chain is stable lead-206. Radium-226 occurs naturally as part of the radioactive decay chain of uranium-238, and it can be extracted from uranium-bearing ores and purified by chemical means.

3.2 In the early 20th century, one of the major industrial uses of radium was in the production of luminescent paint. Fluorescence was achieved by combining radium-226 bromide and potassium sulphate solution with zinc sulphide crystals; glue was then added to produce paint. While this was used in a number of products, its main application was associated with display dials and aircraft instruments (to make them visible in night flying). This process was known as ‘luminising’. Another radionuclide, radium-228 (a beta-particle emitter), was also used, but its use was much less widespread. Owing to its shorter physical half-life of 5.8 years, little of this radionuclide will now remain, even if it had been used on the site in the vicinity of Dalgety Bay.

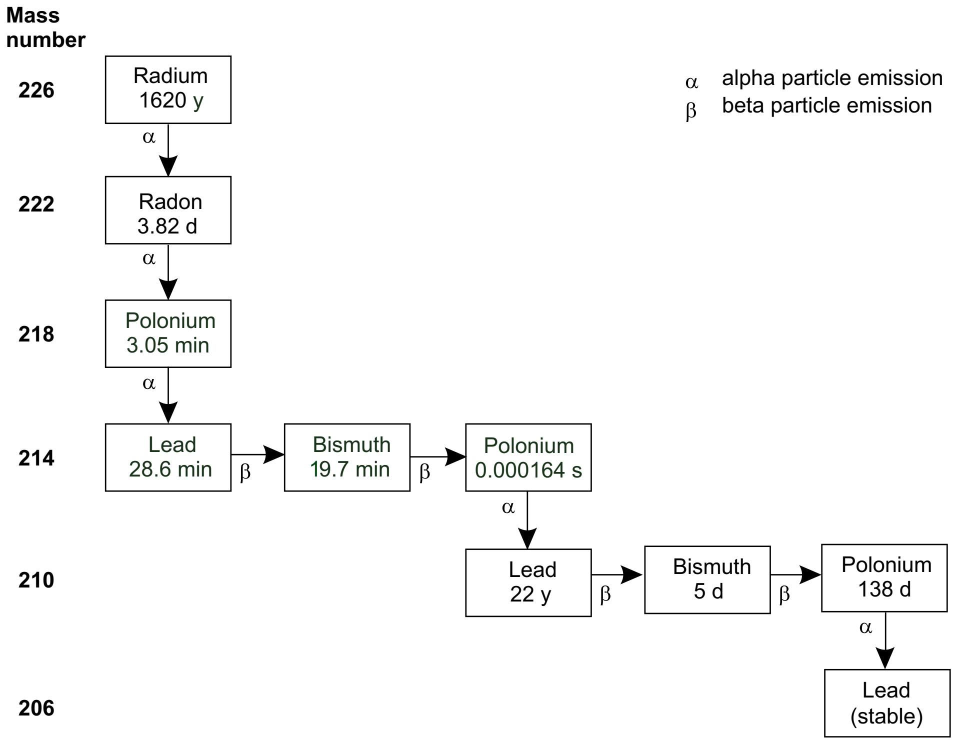


Figure 3.1 Decay chain of radium-226, showing the main radionuclides, with the type of radioactive decay and physical half-life

3.3 The majority of luminising carried out in the UK was before, during and for a short period after the Second World War, peaking during the war years. By the time the Radioactive Substances Act 1960 (RSA60) came into force on 1 April 1963, the luminising industry in the UK had dramatically diminished. Some commercial luminising continued up to the late 1970s in support of military programmes and the watch industry. In addition, parts of the military, mainly the Royal Electrical and Mechanical Engineers (REME), continued to luminise and repair luminised items into the 1980s, but on a diminishing scale.

3.4 The diminishing quantity of luminous items represented a shift away from the perceived need of the military for dials to be luminous, accelerated by the introduction of visual display units and the replacement of direct luminous painting with gaseous tritium light devices from the late 1960s.

3.5 For aircraft instrument luminising, the typical radioactivity concentration of the paint was between 2.7 and 3.7 MBq per gram (RSAC, 1958). Documents from Oak Ridge Associated Universities state that aircraft and ship instruments could contain 215 μg of radium per gram of material to conform to British Admiralty standards, which would equate to 8 MBq per gram (Boerner and Buchholz, 2007). The former figure refers to wet paint, while the latter is the dry value, so the two are consistent.

3.6 Particularly following the Second World War, large numbers of military aircraft were scrapped and the instruments stripped out; it was common practice for these materials to be incinerated to reduce the volume of contaminated material and the resulting ash buried. One location where both luminising and dismantling activities are known to have been carried out is at the airfield operated by RNAS Donibristle (HMS Merlin). Wright (1990) noted that the MoD confirmed that some 800 aircraft were scrapped on the site in 1946. A witness statement obtained by SEPA (Patton, 2013) confirms that luminising activities on the site continued up to 1958. As noted in paragraph 2.9, the airfield closed in 1959.

3.7 The Radioactive Substances Advisory Committee (RSAC) noted in its 1958 report (paragraph 40) that:

> 'the solid waste from normal operation is generally combustible in nature and it is fairly general practice to pour contaminated solvent, used for cleaning equipment, on paper and burn the whole under primitive conditions in the grounds. There is some local fall-out of ash; the petrol drum or old dust-bin used for burning the waste becomes fairly highly contaminated; and the ash remains for disposal. Non-combustible waste and the ash are generally buried in the grounds. Sometimes, and apparently usually at services' workshops, all the solid waste is disposed of by burial.' (RSAC, 1958)

3.8 In terms of disposal, the RSAC report (paragraph 130) stated that:

> 'although burial is more suitable for shorter-lived radionuclides, some with longer half-lives can be disposed of by burial provided it can be foreseen that the land will not be used for many years. We doubt whether it is practicable, except for a national site, to foresee possible future use sufficiently far ahead to justify disposal by burial of more than say a hundred microcuries of radionuclides of half-life longer than a year. … Records of burials and burial sites should be kept and handed on to future users of the land.' (RSAC, 1958)

The 'hundred microcuries' referred to is equivalent to 3.7 MBq in SI units.

3.9 The hazards from radium presented by the residual ash relate to the potential ingestion or inhalation of, or skin contact with, contaminated material. A lesser hazard is that from external gamma radiation.

3.10 Radon-222 is the first decay product of radium-226. With its 3.82 day physical half-life, radon gas can diffuse through the ground before decay. If this occurs outdoors, it is diluted rapidly to low concentrations. If buildings are erected over, or near to, a site of radium deposition, the radon gas can reach high concentrations indoors.

3.11 The average concentration of radon-222 in a home in the UK is about $20\,Bq\,m^{-3}$ * and the Advisory Group on Ionising Radiation has concluded that around 1,100 radon-induced lung cancer deaths occur each year in the UK (AGIR, 2009). In 2005 a report from the then Health Protection Agency (HPA)† stated that radon was the largest contributor to the average annual radiation exposure to the UK population, delivering some 1.3 mSv of a total of 2.7 mSv on average, to a member of the population (Watson et al, 2005). The risk of developing lung cancer increases with increasing radon activity concentrations and is higher for smokers. The HPA advised that indoor radon concentrations above an action level of $200\,Bq\,m^{-3}$ should be reduced.

3.12 For this reason, measurements of radon have been carried out by the HPA in buildings that were potentially affected in the vicinity of the site. The precise values obtained remain confidential on the grounds of personal privacy and were not reported to COMARE, which was however assured that the radon levels were not significantly elevated.

* See www.ukradon.org/information/whatisradon.

† On 1 April 2013 the Health Protection Agency was abolished and its functions transferred to Public Health England.

CHAPTER 4

CONTAMINATION HISTORY

4.1 Following the discovery of radioactive contamination on the beach at Dalgety Bay during the routine baseline monitoring campaign by Babcock Engineering Services for Rosyth Naval Base in June 1990, a limited survey was carried out which confirmed the presence of discrete sources of radium-226 on the beach. It was concluded that a more rigorous survey was necessary to determine the extent of the contamination.

4.2 In October 1990, a survey of the beach by the Directorate of Fisheries Research (Camplin, 1990) detected and recovered what was described as a particularly hot source from a depth of 15–20 cm. This source had an external dose rate greater than 28 mSv h^{-1} and its discovery resulted in a recommendation that access to the area should be restricted until a full radiological survey had been undertaken.

4.3 At the request of HM Industrial Pollution Inspectorate for Scotland (HMIPI), a survey was conducted during the latter half of November 1990 by the then National Radiological Protection Board (NRPB)* (Milton, 1991). This investigation indicated that all of the areas surveyed were contaminated with sources of radium-226. Consequently, it was recommended that the survey of the beach and foreshore be continued and extended to include the undeveloped land behind the beach and part of the housing estate close to the beach and foreshore.

4.4 With one exception (a fragment of painted metal found in a garden), all the radioactive contamination found consisted of radium-226 contained in, or associated with, clinker and ash material, and in general consisted of discrete sources. A total of 220 particles and 354 objects were recovered. The contamination was believed to have come from the disposal, by incineration, of dials from instruments painted with radium in the 1940s. The garden was remediated by the removal of some 2 tonnes of contaminated soil containing approximately 100 MBq of radium-226 and its replacement with new topsoil (Milton, 1991); a further 0.7 tonne containing 4 MBq of radium-226 was removed after a follow-up survey. The total activity of the contaminated material removed during the survey has been estimated to be 135 MBq. This material was disposed of as radioactive waste by the NRPB. HMIPI had already decided to continue to survey the beach and foreshore at six-monthly intervals.

4.5 The NRPB selected a representative sample of 24 private houses and direct radon measurements were made in living areas of these houses and surveys of 17 gardens were carried out. The levels of radon were reported to be low. Contaminated material was found in two gardens.

4.6 The NRPB report concluded that the radiation dose to any individual as a result of ingestion of the material would be negligible; the material was deemed insoluble and as such would be eliminated from the body quickly (Milton, 1991).

* The NRPB was subsequently incorporated into the Health Protection Agency (HPA).
As stated previously, on 1 April 2013 the HPA was abolished and its functions transferred to Public Health England.

4.7 The report was considered by COMARE in September 1991. COMARE was largely content with the actions and recommendations expressed in the report, but it asked for the following additional actions:

(a) The ISD should be asked to provide a report on the incidence of cancer in the local population

(b) A reassessment should be made of the frequency of screening contaminated areas

(c) Foundations of new buildings should be monitored for radioactivity

4.8 On querying the possibility of other, similar sites, COMARE was informed that the MoD did not possess the data to give a comprehensive list and that it was probable that in the past disposal of luminised material would have been very widespread. A limited list of 26 sites (including Dalgety Bay) was supplied and the MoD confirmed that information on plants producing luminised material was well documented.

4.9 The epidemiology report from the ISD was considered at the COMARE meeting in June 1992. It found that the only statistically significant differences observed were for pancreatic and non-melanoma skin cancers. Adjustments for socioeconomic factors using the Carstairs score (Carstairs and Morris, 1989) did not affect these findings. No overall excess of cancer was found in the Dalgety Bay area.

4.10 COMARE had no disagreement with the overall conclusions of the ISD report, and made the recommendation that the report should be published within the open scientific literature (see Black et al, 1994). It recommended also that it would be sensible to continue with the ongoing monitoring programme for the foreseeable future. Finally, it was recommended that Dalgety Bay should be re-evaluated by the ISD in a few years' time, when the matter could again be referred to COMARE.

4.11 In 1996, a survey of the surface gamma radiation dose rate was carried out by the University of Aberdeen, covering 'representative sectors of the beach and foreshore, mudflats, the boat club area and the woods' (Heaton et al, 1996) and reported to COMARE. An average dose rate of $0.088\,\mu Sv\,h^{-1}$ was found for the beach and foreshore, $0.081\,\mu Sv\,h^{-1}$ for the Dalgety Bay Sailing Club and $0.066\,\mu Sv\,h^{-1}$ for the woods and mudflats. These results are not significantly different from the UK average for natural background gamma radiation (Watson et al, 2005). Therefore, even though several 'hot spots' with a reading generally 50% higher than the average were found, it was felt to be very unlikely that any deleterious effects would arise from enhanced exposure to external sources of gamma radiation at Dalgety Bay.

4.12 In June 2006, SEPA carried out a screening assessment of the area, which suggested that there was a realistic probability of harm occurring at Dalgety Bay due to the sources discovered. SEPA, supported by COMARE, recommended that further research be carried out into the risk from exposure to the sources and a desk exercise was undertaken by the MoD Defence Estates. The highest activity source recovered was 1 MBq of radium-226. There was no assessment of the distribution of contamination at that time, only an assessment of the risk of encountering the sources. As a result of this, signs promoting good hygiene were erected for the community, with recommendations to wash hands after visiting the beach. COMARE expressed concern over the timescale involved in the MoD work and any possible delay with remediation.

4.13 Subsequent surveys of the beach area were undertaken by various contractors for the MoD during which sources were removed from the beach to provide some protection to beach users. In 2007, the MoD employed Enviros

Consulting to investigate the extent of radium-226 contaminated soils at Dalgety Bay, including the sailing club grounds, the gardens of 34 nearby residential properties and the coastal path. Radium-226 activity levels above background were identified on part of the coastal path, on sailing club land and in two gardens; the last were remediated.

4.14 COMARE can only make recommendations and, until 2007, SEPA had no statutory powers to implement them. This position changed in 2007 with the introduction of the Radioactive Contaminated Land Regulations (Scotland), which placed a statutory duty on SEPA for sites such as Dalgety Bay. The associated statutory guidance (Scottish Government, 2008) was introduced following these regulations.

4.15 In early 2008, following a report on the above work (Enviros Consulting, 2007), Enviros Consulting undertook supplementary investigations in the gardens of six properties located in the vicinity of the original MoD salvage yard, together with initial surveys on one property for which access had not been previously available and two further properties at the request of SEPA based on the report's findings. Areas that were previously inaccessible at the sailing club were also assessed. Contamination was found in, and removed from, the gardens of six houses.

4.16 A COMARE working group visited the site in 2008 after completion of the remedial work and recommended that radon surveys of homes should be offered to those potentially affected by the new contamination finds. The beaches were examined and some concerns were raised, especially with regard to the integrity of the rock armour, as there was abundant evidence that quite large objects had moved from time to time, including the rock armour. While COMARE was content with the terrestrial work carried out by MoD, it recommended that more extensive surveys of the shore and inter-tidal areas should be carried out. The radon surveys were carried out and did not identify any raised levels of radioactivity.

4.17 SEPA and the MoD then agreed on a suitable monitoring periodicity. The 2008 SEPA survey detected 39 point sources (of which 16 were selected for leachate analysis) together with more diffuse radium contamination (Dale, 2009). The contamination appeared to be limited to an area between the old pipeline and the New Harbour.

4.18 Also in 2008, SEPA prioritised Dalgety Bay for assessment under the Radioactive Contaminated Land Regulations. In support of this, further monitoring, retrieval, sampling and analysis were carried out by SEPA. In response to its report, MoD Defence Estates produced plans which could constitute an appropriate management plan, including an intensive monitoring and removal programme. Representatives from the MoD met SEPA, HPA and Food Standards Agency (FSA) officials to discuss plans for a full risk assessment.

4.19 Annual surveys continued during 2009 and 2010, but COMARE remained concerned about the inter-tidal area at Dalgety Bay. MoD Defence Estates had done no further characterisation and the annual monitoring programme had ceased. As a result, SEPA wrote to MoD Defence Estates requesting the work to be undertaken and, in the interim, took a sample of the point sources in order to fully characterise them and undertake work on the solubility of the radium-226 associated with the sources.

4.20 In 2011, SEPA undertook a physical examination of the headland area in an attempt to delineate the contaminated area and notified COMARE of an increased find rate of sources of higher activity than in previous years from particular locations. COMARE supported SEPA's decision to fence off a demarcated area; the establishment of a routine monthly monitoring programme in conjunction with the MoD; a request to the HPA for a further risk assessment; and work to establish the solubility of the sources recovered.

4.21 In the year to October 2012, SEPA recovered over 800 sources from 36 one-day visits. It should be noted that the total area surveyed during these 36 visits did not cover the affected area in its entirety. The activity of sources recovered ranged from around 1 kBq to 76 MBq. Up to the end of 2012, several hundred additional sources were recovered by the MoD contractors, with around 100 sources being recovered each month over the 800-metre coastline. Given that the population of sources had changed significantly, the gamma radiation dose rate would have changed from that previously measured too and so COMARE recommended that SEPA review this work and undertake further gamma monitoring as required.

4.22 It is the higher activity sources found over the last two years that could give rise to radiation doses of concern (Brown and Oatway, 2012; Dale, 2012). In addition, it is clear that there has been ongoing repopulation (ie areas which had been surveyed and cleared of contamination exhibited further contamination within a short period of time).

4.23 There are several hypotheses as to the source of these recurring sources, as noted in Chapter 7. The situation appears to be a dynamic one, with the currently demarcated area being different from the focus of investigation just a year ago. Figure 4.1 shows the locations where the majority of the sources have been recovered.

4.24 Although a few larger items have been recovered, the vast majority of contaminated materials range in size from a few tens of millimetres down to sub-millimetre and can be classed as artefacts associated with aircraft instruments and instrument panels through to clinker, indicating that the material has been incinerated. Chemical analysis shows that all sources have excess levels of zinc and sulphur, which can be attributed to radium paint.

4.25 Table 4.1 shows the number of sources known to have been recovered from 1990 until the end of 2012.

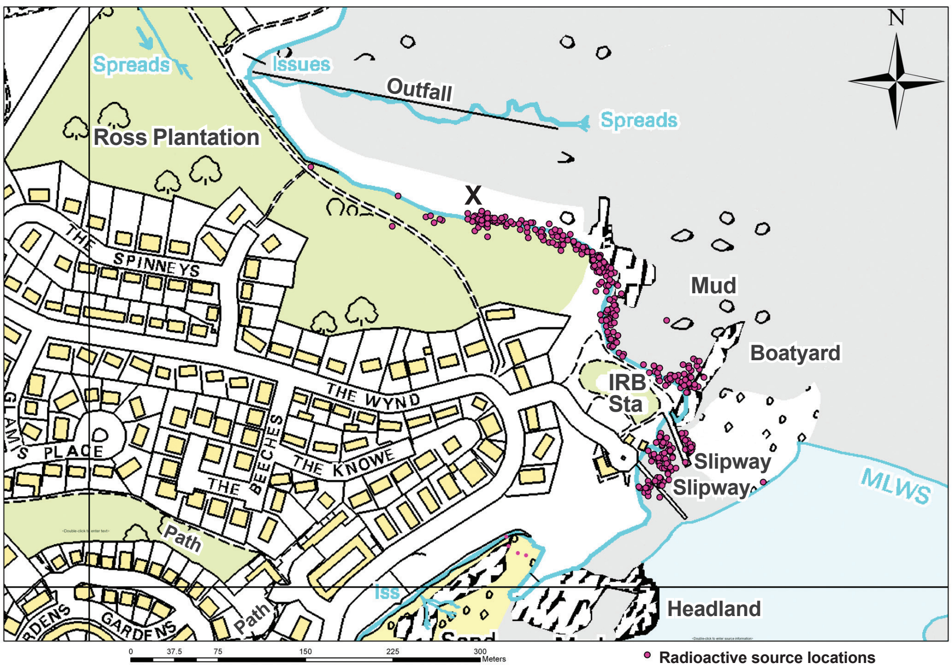


Figure 4.1 Dalgety Bay site showing the distribution of radioactive items found by MoD and SEPA surveys in 2011 and 2012 (provided by SEPA)

4.26 In earlier reports, there appeared to be inconsistency in the source activities being reported by MoD contractors and SEPA. Once this had been resolved, the COMARE Contaminations Working Group suggested a standard for the detection limit to be used in the programme (20 kBq to a depth of 100 mm with 95% probability of detection), which was accepted by both parties and implemented in 2012.

4.27 The Contaminations Working Group considered whether the radium-226 activities reported by SEPA were correct. If these were overestimates, however, the values for source solubility reported below (paragraph 5.27) would increase, reaching values which would not be credible. In addition, the solubility data were obtained from a UKAS accredited laboratory. It is unlikely, therefore, that there was any significant error.

4.28 The radium-226 activities of sources recovered since 2008 are shown in Table 4.2.

Table 4.1 Beach monitoring finds: in 2009, 49 finds were a result of intrusive excavations (provided by SEPA)

Year	**Number of sources removed**
1990	226
1991	602
1992	108
1993	78
1994	34
1995	No monitoring data
1996	No monitoring data
1997	102
1998	11
1999	No monitoring data
2000	80
2001	No monitoring data
2002	93
2003	No monitoring data
2004	No monitoring data
2005	97
2006	37
2007	No monitoring data
2008	37
2009	104
2010	24
2011	530
2012	1,369
Total	**3,532**

Table 4.2 Source activity (using MoD contractor’s conversion factors where appropriate)

	Year				
Source activity (kBq)	**2008**	**2009**	**2010**	**2011**	**2012**
No data	0	0	0	49	14
0–10	19	100	24	83	790
10–100	16	4	0	389	549
100–1,000	2	0	0	4	15
>1,000	0	0	0	5	1

Table 4.3 Dalgety Bay shellfish sampling

Sample	Analysis results (Bq kg^{-1})					
	Feb 2012	Mar 2012	Apr 2012	May 2012	Jun 2012	Jul 2012
Cockles	<10	n/a	n/a	n/a	n/a	n/a
Winkles (site 1)	<10	<10	<10	<10	NS	NS
Winkles (site 2)	<10	<10	<10	<10	<10	NS
Winkles (site 3)	<10	<10	<10	<10	<10	NS
Winkles (site 4)	<10	<10	<10	<10	<10	<10
Winkles (site 5)	NS	NS	NS	NS	<10	NS
Mussels (site 1)	<10	<10	<10	<10	NS	NS
Mussels (site 2)	<10	<10	<10	<10	<10	NS
Mussels (site 3)	<10	<10	<10	<10	<10	NS
Mussels (site 4)	<10	<10	<10	<10	<10	<10

n/a – sample not available
NS – not sampled in order to maintain sustainability

Food and Environment Protection Act (FEPA) ban

4.29 In response to the 2011 source finds, the FSA in Scotland carried out a screening assessment of the potential foodchain dose based on the available data, and several results exceeded the 1 mSv annual allowable dose to members of the public, indicating a potential risk.

4.30 Responding to advice from the FSA in Scotland, Scottish ministers placed an order under the Food and Environment Protection Act 1985 (UK Parliament, 1985) as a precautionary measure, restricting the removal of seafood from the area. Although there are no commercial fisheries in the area, individuals had been observed collecting shellfish, possibly for consumption. This was despite warning signs indicating that radioactive contamination had been found in the area and seafood should not be collected.

4.31 The Food Protection (Emergency Prohibitions) (Dalgety Bay) (Scotland) Order 2012 (SSI 2012 No. 135) (the 'FEPA Order') was placed on 9 May 2012 and approved by the Scottish Government Health and Sport Committee on 22 May 2012, making it an offence to remove fish and shellfish from the Dalgety Bay area.

4.32 Monthly sampling of cockles, mussels and winkles from Dalgety Bay was undertaken for a year from February 2012. The results for the first six months are shown in Table 4.3. No contaminated particles were detected in this exercise and this sampling programme has now been replaced by surface monitoring of the mussel bed areas.

4.33 The FSA in Scotland gave an undertaking to the Health and Sport Committee to review the FEPA Order in the light of new evidence and/or effective remediation of the contamination. On 16 April 2013, a summary of monitoring undertaken and a restatement of this undertaking were provided to COMARE. This review is dependent on site remediation to be agreed between SEPA and MoD with whom the FSA in Scotland will continue to liaise through the Dalgety Bay Particles Advisory Group*.

* The Dalgety Bay Particles Advisory Group was formed in 2011. Its remit is to provide impartial scientific advice to SEPA and other parties on actions that are needed to ensure that the public and environment are adequately protected, and to comment on the work being undertaken and the results being obtained (www.sepa.org.uk/radioactive_substances/dalgety_bay/particles_advisory_group.aspx).

CHAPTER 5

DOSIMETRY AND RISK

5.1 For radioactive material to pose any risk to the public there is a need for a pathway to exist between the source (particles) and members of the public. These pathways are the route by which members of the public can become exposed to the source and thereby harm can occur. While a radioactive source will present a hazard, it cannot pose a risk to the public without the existence of a pathway. The potential pathways of interest in the current situation are ingestion, inhalation, direct skin contact and external irradiation.

5.2 It is usual to consider that sources are encountered haphazardly or accidentally (ie on a chance basis), but some of the objects found in the Dalgety Bay area, such as luminised aircraft dials, would stand out from other items. The possibility of preferential selection, that someone would seek to investigate or collect such items, thus increasing the probability of encounter, must be taken into account when considering these pathways.

Habits survey

5.3 COMARE had recommended in 2008 that a habits survey should be undertaken. This was conducted at Dalgety Bay in October 2012 by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) (Clyne et al, 2013) and involved interviewing people using the beach area. As the survey was undertaken in the autumn, it may have missed the higher occupancies and/or different habits of both tourists and the local population over the summer months.

5.4 The survey reported that there were many access points to the area and that walkers with and without dogs walked through part or all of the area. Many local walkers followed a regular route, while others preferred to vary their route from day to day. Although most walkers reportedly stayed predominantly on the paths and grass areas above the shore, approximately 60% of the dog walkers and 30% of the walkers without dogs regularly visited one or more of the beaches as part of their walk.

5.5 Several families spent time on the small sand beach to the west of the New Harbour, engaged in activities such as playing and building sandcastles or rock pooling in the rocks nearby. They reported that they also visited this beach in the summer time, when they took picnics and paddled or swam in the sea. A few families also played and paddled on the small sand beach at the New Harbour and one family was identified that spent a small amount of time playing on the shore at the slipways. The families were noted to include very young children.

5.6 A few individuals, who were walking, dog walking or playing, picked up shells or stones from the beaches at Ross Plantation, the slipways, the New Harbour and the area to the west of the New Harbour. Some people took the stones and shells home with them. No one was seen to be deliberately searching for old aircraft artefacts on the shore at the time of the survey, although this has been reported to occur (McPhail, 2011b).

5.7 A small number of runners and joggers were recorded and they took similar routes to the walkers through the survey area. A few cyclists passed through all or part of the survey area and they stayed on the paths and grass areas above the shore. Horse riders were observed on the Fife coastal path, but were not interviewed. Four bird watchers were interviewed. They mainly used the beach at Ross Plantation since it provides a good vantage point across the mudflats of the bay, which attract many birds. The bird watchers also spent time on the grass areas and paths above the shore at the headland and in other zones.

5.8 Several people commented that the sand beach at the west end zone could be very busy with families having days out on the beach in the summer, and that the Fife coastal path attracted more walkers in the summer months.

5.9 Boating activities centred on the Dalgety Bay Sailing Club. The club caters for dinghy sailors, keelboat sailors and users of powerboats, mainly rigid inflatable boats (RIBs). Adults and children sail at the club. The main sailing season was found to be between April and October, although a minority of sailors continued through to December. One individual was identified who used a powerboat throughout the year. The club ran regular racing programmes for dinghies and keelboats and sail training courses. During the summer it held a youth sailing week event to encourage youngsters to sail. Most dinghy sailing took place in the waters close to the club. The keelboats and powerboats also sailed locally, but also went further afield in the Firth of Forth, and some keelboats went cruising to areas outside the Firth of Forth. In 2012, a large number of the club's regattas and events were cancelled; as a result, the number of people using the slipway areas was significantly lower in 2012 than it had been in previous years. Local people have reported that the regattas had been very popular, often resulting in crowded beach areas.

5.10 Boat maintenance was identified as taking place on the land close to the shore in the boatyard area, on the fringe of the upper shore near the main slipway and on the beach at the New Harbour. Boat maintenance included work carried out on the club raft as well as on boats. Keelboats were kept moored offshore from the sailing club and most boat owners lifted their moorings once or twice a year to check the condition of the chains and shackles.

5.11 Several people reported that they had seen one or two people digging for angling bait in the area of mud, sand and stones on the lower shore of the area to the west of the New Harbour. This activity was reported to take place only around the time of spring tides (ie fortnightly) when more of the shore was exposed at low tide. This activity was observed during the physical investigations at Dalgety Bay. It was reported also that gangs of commercial winkle pickers had occasionally been seen on the shore, both within the survey area and also just outside the survey area on the shore near St Bridget's Kirk, further east in Dalgety Bay. However, interviewees were uncertain how long ago they had last seen this activity taking place.

5.12 It was reported that one individual spent a number of nights sleeping on the beach at Dalgety Bay, and although this was not observed during the habits survey itself, the individual is known to Fife Council as this activity occurs periodically. In 2011, SEPA also received a telephone call regarding the presence of a scout group using the now demarcated area for recreational purposes.

5.13 In 2010, following recovery of sources from the slipway area, SEPA requested that the local pre-school playgroup cease using the location and move to the New Harbour. Following the identification of radioactive contamination at the latter location also, in 2012, the playgroup was advised to move to an area further to the west where no contamination has been detected.

5.14 Having established the various groups that might encounter sources, it is necessary to establish the consequences of the routes by which the public could be exposed.

Inhalation

5.15 For inhalation to be a hazard, the source would have to be a very small particle. The radiation dose from a given source activity increases with the depth in the respiratory tract at which deposition occurs. This depth increases with decreasing particle size.

5.16 Particles of more than a few tens of micrometres in diameter have a very low probability of reaching the airways and alveolar region of the lungs – if inhaled, they are likely to be trapped in the nose and extrathoracic airways.

5.17 It has been suggested (Breslin, 2011) that particles of radium of a size which could be inhaled would be present at Dalgety Bay.

5.18 In 2012, the then HPA reported that 'for a particle containing 100 Bq of radium-226 and a diameter of 100 μm the committed effective dose would be around 0.1 mSv' (Brown and Oatway, 2012). Such a dose would present a low hazard if encountered in isolation (Smith, 2010).

5.19 Wilkins (2008) calculated that if a particle containing 1 kBq of radium-226 was sufficiently small to be deposited in the alveolar regions of the lung, the committed effective dose would be 1–25 mSv for an adult or 50–150 mSv for a 1-year-old child. The doses would be higher for bronchiolar deposition.

5.20 Heaton et al (1996) reported, however, that less than 1% of a sediment sample from the beach was composed of particles smaller than 45 μm and stated that 'there would be a low risk of members of the public inhaling fine material'.

5.21 While all of the sources recovered in recent months have been of a size greater than 100 μm, several have been shown to be friable. This raises the possibility that, over time, larger sources containing high levels of radium-226 could break down into a large number of lower activity sources, which would not be detectable by the current routine monitoring equipment, but would be capable of being inhaled.

5.22 In order to exclude the possibility of such a mechanism, SEPA examined a number of grab samples of surface material which were assayed on a more sensitive detector. No evidence of the presence of low activity sources was found.

5.23 On the basis of the above information, COMARE is of the view that there is no reason to believe at present that the inhalation pathway is significant in terms of public health at Dalgety Bay.

Ingestion

5.24 The most important variable in calculating the radiation dose from ingestion is the solubility of the material, as this determines the fraction of radium-226 transferred into the bloodstream and thence to body organs.

5.25 With support from COMARE (see paragraph 4.19), SEPA contracted the University of Stirling to carry out a study of the solubility of a representative sample of sources. Sources were digested in solutions mimicking stomach and small intestine (Tyler et al, 2013), following the protocol established for Sellafield and Dounreay (Harrison et al, 2005).

5.26 A sample of 60 sources were selected, on the basis of their activity and dimensions, and subjected to digestion in simulated stomach and lower intestine solutions. The study demonstrated that significantly more radium-226 and lead-210, driven by polonium solubility, was dissolved from sources in 'stomach' solutions compared with 'lower intestine' solutions. The combined 'gut' solubility for radium-226 and 'apparent' lead-210 varied from less than 1% up to 35%. This range could be due to the effects of burning at different temperatures affecting the chemical form of the radium and thus the solubility. For example, burning may result in the production of radium oxide which would be highly soluble in the gastrointestinal tract.

5.27 The solubility results were not normally distributed and so a logarithmic transformation was applied. Following Gilbert (1987), the corrected estimates quoted by Tyler et al (2013) for the mean and standard deviation were 7.6% and 2.5%, respectively, with a 95th percentile value of 20.2%. Subsequent to publication, an error in the mean value was found by the MoD; the correct value for the mean should be 5.7%, the other values remaining unchanged. If a cautionary approach were to be adopted, a reasonable level of caution would be to use the 95th percentile for the assessment of hazard.

5.28 In 2013, the COMARE Contaminations Working Group considered the possibility that the *in vitro* measurements might overestimate the mammalian *in vivo* value. It was noted that, owing to the apparent differences in chemical form of the sources found, it would be necessary to test large numbers of animals to resolve this issue. Use of the relatively low mean value from the distribution already makes some allowance for this uncertainty.

5.29 Radiation doses were derived using standard ICRP dose coefficients (ICRP, 1996). Assuming that the radium-226 decay products are in equilibrium, the contributions from radium-226, bismuth-214, lead-214, bismuth-210, lead-210 and polonium-210 are included in the calculation, and bismuth-210 and polonium-210 are assumed to be in equilibrium with lead-210. This is an important assumption as 66% of the estimated dose for an infant under 1 year of age is dominated by polonium-210 against 55% for an adult.

5.30 Tables 5.1 and 5.2 show the results for the mean and 95th percentile solubilities, respectively. Table 5.1 shows that sources which have the mean solubility would require activities of around 100 kBq of radium-226 to deliver a committed effective dose in excess of 100 mSv to a 1-year-old child (age range 1 to 2 years). A little over 10% of the sources tested dissolved sufficient radioactivity to result in a 100 mSv committed effective dose to an infant. If the 95th percentile value is used, sources greater than 40 kBq would result in a dose greater than 100 mSv to a 1-year-old child and for an adult this would be around 250 kBq.

Table 5.1 Doses arising from ingesting a source of given activity with a mean solubility of 5.7%

Original activity (Bq)	Activity in solution (Bq)	Committed effective dose (mSv)					
		3 months	1 year	5 years	10 years	15 years	Adult
1,000	57	2.25	0.75	0.41	0.30	0.29	0.12
10,000	570	22.5	7.5	4.1	3.0	2.9	1.2
100,000	5,700	225	75	41	30	29	12
1,000,000	57,000	2,250	750	410	300	290	120

Table 5.2 Doses arising from ingesting a source with solubility at the 95th percentile of the distribution (20.2%)

Original activity (Bq)	Activity in solution (Bq)	Committed effective dose (mSv)					
		3 months	1 year	5 years	10 years	15 years	Adult
1,000	202	7.9	2.7	1.5	1.1	1.0	0.44
10,000	2,020	79	27	15	11	10	4.4
100,000	20,200	790	270	150	110	100	44
1,000,000	202,000	7,900	2,700	1,500	1,100	1,000	440

5.31 Some of this information, together with further unpublished information, was used in an HPA report on the hazards posed (Brown and Oatway, 2012). In that report, the HPA assumed that the maximum activity which could be ingested was 100 kBq of radium-226, with a physical diameter of 1 mm. Litovitz (1985) reported, however, that batteries of up to 11.9 mm in size have been swallowed by children under 4 years of age; indeed, although most would tend to lodge in the oesophagus, 20 mm batteries can be ingested (Litovitz et al, 2010). Thus it is possible that sources of a few millimetres in diameter would be ingestible and these could have an activity of around 1 MBq. Indeed, sources have been recovered at Dalgety Bay which have multi-megabecquerel activities and physical sizes under 20 mm.

5.32 In the extreme case of ingestion of the highest activity source recovered, the 2012 HPA report stated that the possibility of acute organ damage or bone marrow failure cannot be excluded, but the majority of recovered finds have activities much less than this value (Brown and Oatway, 2012). The HPA report then concluded, however, that the committed effective dose from ingestion of a 100 kBq source could be around 330 mSv to a young child (ie 1 to 2 years old), similar to the values derived above. For an ingestible 1 MBq source this would suggest a dose of a few sievert for a young child, which could lead to the acute consequences outlined above.

5.33 As indicated above, only a few sources of 1 MBq or greater have been found to date and thus the current possibility of this occurring would be remote on the basis of present beach find data, especially as, at present, the known contaminated area is under monthly surveillance. Nevertheless, even the potential radiation doses from sources of 100 kBq are significant.

5.34 The 2012 HPA report (Brown and Oatway, 2012) discusses how the committed effective dose estimates can be appropriately used to derive the resulting radiation-induced cancer risks for exposures at different ages. For ages at exposure of 1 year and 20 years the appropriate lifetime risk estimates are 16% per Sv and 9% per Sv, respectively, the lifetime cancer risks being weighted by detriment to account for the severity of the cancer type (eg the threat to life and the intensity of treatment). Using these risk estimates, a committed effective dose of 100 mSv received by a 1-year-old child would result in a lifetime detriment-weighted cancer risk of around 1.5%, while a dose of 35 mSv to a 20-year-old adult would result in a lifetime cancer risk of around 0.35%. These risk estimates may be adjusted proportionally to take account of different committed effective dose estimates, although the risk per unit dose will be less in later adult life.

5.35 When radium is ingested, the main risk arising is from bone cancer, because radium deposits primarily on the bone surfaces. Consequently, the risk of bone cancer has been examined separately.

5.36 Samartzis et al (2011) investigated bone cancer incidence among the Japanese atomic bomb survivors, who were exposed largely to an external source of gamma radiation. They found an excess incidence of bone cancers among survivors followed to 2001, but only at bone marrow doses estimated to be greater than 0.85 Gy; above this value, the dose-response relationship was linear with an excess relative risk of 7.5 per gray (95% confidence interval: 1.34, 23.14). In its 2006 report, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008) modelled the radiation-induced excess risk of bone cancer incidence among the atomic bomb survivors followed to 1998 and found that the excess risk was best described by a quadratic dose-response – the excess absolute risk (EAR) was best described by $9.33\ 10^{-6} \times D^2$ cases per 10^4 person-year-Sv, where D is the equivalent dose to the skeleton. Follow-up of solid cancer incidence among the atomic bomb survivors, however, only commenced in 1958, 12.5 years after the bombings, so these investigations would have missed any early radiation-induced bone cancers. The work of Nekolla et al (2000), upon which the US Environmental Protection Agency (EPA) bone cancer incidence risk model is largely based, suggests that such early bone cancers would have occurred. The Nekolla et al (2000) study is of patients injected with radium-224, which emits alpha particles that irradiate the bone surfaces (as will occur also when radium-226 is deposited on bone surfaces) and so leads the Committee to base its bone cancer risk estimates upon the EPA bone cancer incidence risk model (EPA, 2011; Pawel and Puskin, 2012). The nominal bone cancer incidence risk estimate used by the ICRP (2007) of $6.5\ 10^{-4}$ cases per person-Sv is also based on studies of the radium-224-injected patients, as is the bone cancer mortality risk estimate of $5\ 10^{-4}$ deaths per person-Sv derived by the then NRPB (NRPB, 1993).

5.37 The EPA bone cancer risk model takes the form

$$\text{EAR} = a\ D\ g(e)\ h(t) \text{ excess cases per } 10^4 \text{ person-Gy}$$

where D = bone surface dose of alpha-particle radiation in gray

$\alpha = 1.7\ 10^{-3}\ \text{Gy}^{-1}$

$g(e) = \exp[-0.0532(e - 30)]$

$h(t) = (2\pi\sigma^2)^{-1/2} \times \exp[-(\ln t - \ln t_0)^2/2\sigma^2] \times 1/t$

e = age at exposure in years

t = time since exposure in years

$\sigma = 0.612$

$t_0 = 12.72$ years

Thus the EPA model describes an excess absolute risk of bone cancer incidence that is linear with the bone surface dose of alpha-particle radiation (and without a threshold dose), and is modified by the age at exposure (greater at younger ages at exposure) and by time since exposure (excess risk is expressed as a 'wave' with time since exposure, peaking at nine years since exposure). The EPA (2011) suggests that this model may be conservative (in that it somewhat overestimates the risk), a position also adopted by the ICRP (2007) for its nominal risk coefficient for bone cancer.

5.38 At the request of COMARE, Public Health England provided estimates of the absorbed doses to various tissues received in each year following the ingestion of 1 Bq of radium-226 at ages 3 months and 1, 5, 10 and 15 years, and by an adult, using the ICRP solubility assumptions. The doses (which take account of burial of radium-226 in the bone volume and of the ingrowth of radioactive decay products) are dominated by the alpha-particle dose, and the dose to the bone surface is substantially greater than that to other tissues (eg the bone surface dose is some 40 times greater than the liver dose). The bone surface doses are highest for an infant aged 3 months, and decrease with time since exposure (as radium-226 becomes buried in the bone volume). For an infant ingesting 100 kBq of radium-226, the bone surface dose from alpha particles received to 1 year of age is 0.66 Gy, and the lifetime dose is 0.84 Gy. Applying the EPA bone cancer risk model to these bone surface doses received following intake in infancy gives a lifetime risk of bone cancer incidence of 0.86%. The ICRP nominal risk coefficient also gives a lifetime risk of around 1%, while the UNSCEAR bone cancer risk model gives a lifetime risk less than that given by the EPA model by a factor of 3.5. As the EPA bone cancer risk model has a linear, no-threshold dose-response, intakes of other activities of radium-226 will result in risks that are directly proportional to that arising from an intake of 100 kBq. The lifetime risk of bone cancer incidence following ingestion of radium-226 at older ages will be less than that for an infant, substantially so for adults.

Skin contact

5.39 The main deterministic effect of importance is ulceration, for which cells at greater depths in the dermis are implicated. For adults, the relevant depth is taken to be 70 µm, at which there is no contribution from alpha radiation.

5.40 Using a standard computer model, Charles and Gow (2010) estimated that the total skin dose rate (at a depth of 70 µm over an area of 1 cm^2) from a radium-226 point source activity of 1 MBq (in equilibrium with all progeny) is approximately 5.5 Gy h^{-1}. A theoretical value of 3.8 Gy h^{-1} has been obtained by PHE (Tanner R, PHE: personal communication, 2013). Taken together, it would be reasonable to assume a maximum dose rate of 5 Gy h^{-1}. For the point sources recovered this is likely to be an overestimate of dose by about 10% because progeny in the chain following radon-222 will be in deficit relative to the equilibrium distribution. The main contributors to the dose are lead-214, bismuth-214 and bismuth-210; the last of these will be in deficit due to the 22-year physical half-life of its precursor, lead-210. These theoretical dose rates will be affected also by source shape and self-absorption characteristics.

5.41 Using radiochromic dye film measurements (Charles and Gow, 2010), experimental estimates of dose were obtained from ten sources. Results from the two highest activity sources are likely to be the most reliable. One showed the dose rate at 70 µm depth to be 1 Gy h^{-1} per MBq, while the other gave a value of 2 Gy h^{-1} per MBq. The latter is consistent with a report from the MoD (Brown, 2008), which estimated the skin contact dose to be 2.7 Gy h^{-1} per MBq.

5.42 The 2012 HPA report recommended the use of a value of 1 Gy h^{-1} from a 1 MBq source on the basis of theoretical calculation (Brown and Oatway, 2012).

5.43 Experimental studies of dose rates from the 76 MBq source, which was recovered at Dalgety Bay in 2011, have been carried out recently (Burgess, 2013). These demonstrated that the measured dose rates around the object varied by at least three orders of magnitude. This would suggest a localised source of paint within a matrix of either inert or much lower level radium contamination substrate. The maximum dose rate equivalent reported at a depth of 70 µm was 1,380 mSv h^{-1} averaged over the 4.5 mm diameter thermoluminescent dosemeter. This would suggest that dose rates of around 1–2 Gy h^{-1} are possible from specific locations, even in such a large source. The measurements were located randomly, so it is possible that higher doses could occur if this location did not yield the highest concentration, but the highest dose is unlikely to be much greater because 22 measurements were made at locations across the surface of the source and the next highest reading was 286 mSv h^{-1}, obtained within a few millimetres of the highest value. However, if the activity being measured is subsurface, then physical breakdown of the source could result in significantly greater dose rates.

5.44 The above values are for adult skin, but in young children reference skins are thinner (45 µm) than in adults (70 µm) (ICRP, 1975, 2002). Theoretical calculations by Charles and Gow (2010) indicated that, for skin depths of less than 70 µm, the predicted depth-dose curves showed a sharp increase due to alpha-particle dose. For depths between 40 and 50 µm, the calculated alpha absorbed dose was more than an order of magnitude greater than the beta/gamma absorbed dose. Their experimental results, however, did not seem to accord with the prediction.

5.45 Overall, the available data indicate that it would be reasonable to assume that physically small sources could give rise to skin doses of 2 Gy h^{-1} per MBq, while physically larger sources of very high activity could yield skin doses of several gray per hour. Given possible residence times of more than an hour, high skin doses (in excess of the threshold of 2 Gy for deterministic effects), from several of the sources that have been recovered, are a definite possibility.

External irradiation

5.46 The external irradiation hazard is due to the gamma radiation emitted from the sources and could arise from passing through the affected area or from lying on the ground near to a source.

5.47 As a result of the COMARE recommendation (see paragraph 4.20), SEPA undertook a gamma survey in order to provide an estimate of the radiation dose that could be received by people walking across the beach. Gamma dose rates were measured at 263 locations across the affected area. The maximum dose rate was found to be 73 nSv h^{-1} (mean 27 and standard deviation 9.7 nSv h^{-1}). Even if a person remained at that location for an entire year they would receive a dose of only 0.6 mSv; a more realistic 1 h per day spent moving through the area would give rise to a dose of 10 μSv over a year using the mean radiation level measured. By comparison, the UK average background dose rate is some 2.7 mSv, with the natural contribution to the total being around 2.2 mSv (Watson et al, 2005).

5.48 Assuming a direct relationship between activity and dose rate (ie neglecting geometrical effects), sources that contain megabecquerel activities could deliver external doses greater than 7.5 μSv h^{-1} if a person came within 0.5 m of such a source. However, the effects of shielding from burial of the source would reduce this significantly. If the maximum residence time for a person on the beach is around 8 hours (due to tides) and a person were to remain static for this period and within 0.5 m of a 70 MBq source on the surface of the beach, they could receive a dose of 1 mSv.

5.49 Given this calculation, the risk from external irradiation is not of major concern.

Groundwater

5.50 There is a theoretical possibility of radium leaching into groundwater from the contaminated material. AMEC Environment and Infrastructure UK Ltd, the MoD contractor, has taken five samples from the area and reported a result of 65 counts per minute (AMEC, 2013a). The import of these data is unclear because no values were given for a control or for the minimum detectable level. Further information has been sought from the contractor.

CHAPTER 6

CANCER EPIDEMIOLOGY

6.1 Exposure to moderate and high levels of ionising radiation is known to cause most types of cancer (IARC, 2012; ICRP, 2007). Not all types of cancer are equally sensitive to induction by radiation, however, and Boice (2006) has categorised cancers into four groupings:

(a) Cancers frequently associated with radiation with authoritative risk estimates

(b) Cancers occasionally associated with radiation with robust risk estimates

(c) Cancers rarely associated with radiation with uncertain risk estimates

(d) Cancers never or sporadically associated with radiation with no risk estimates

By international consensus, the risk estimates obtained from the epidemiological study of groups exposed to moderate and high doses of ionising radiation (such as the Japanese atomic bomb survivors) are assumed, for the purposes of radiological protection, to extend to low doses (ICRP, 2007).

6.2 The risk of cancer posed by exposure to ionising radiation depends on the types of cell that are irradiated, the level of exposure and the sensitivity of the cells to radiation-induced cancer. Penetrating gamma radiation essentially irradiates all tissues, but short-range radiations, such as alpha particles, only irradiate those cells close to the site of deposition of the radioactive material. This is especially so for alpha-emitting material deposited within the body. Therefore, if an alpha emitter is distributed heterogeneously within the body at a high level, a characteristic pattern of radiation-induced cancer sites would be expected, reflecting the particular sensitive cells that have been irradiated by the alpha particles.

Effects of radium

6.3 Radium is an alkaline earth metal and, when taken into the body, it behaves biochemically like calcium, so that it is deposited predominantly in bone, initially with a brief residence on bone surfaces and then in the bone volume. Consequently, any health effects arising from the intake of radioisotopes of radium would be anticipated to be related to its primary site of deposition within the body, bone surfaces, and then bone volume.

6.4 Workers in the past, usually young women, who applied radium-based luminous paint to watch and instrument dials inadvertently ingested radium, mainly through the action of 'tipping', by which they licked the tip of the paintbrush to obtain a fine point. Women in the luminising industry in the USA prior to 1930 were particularly heavily exposed to radium in this way and it has been known for many years that they experienced a substantial excess risk of bone and head cancers as a result of their ingestion of radium (see, for example, Jones and Day, 1945).

6.5 Stebbings et al (1984) examined data on cancer mortality in female radium workers in the USA. In addition to the long-established excess mortality from bone and head cancers, they examined mortality from other cancers and found no clear evidence of an association between these other cancers and exposure to radium. In particular, they noted that 'liver, pancreatic, cervical, and uterine cancers were clearly unrelated to radium exposure'.

6.6 In a comprehensive review of the evidence from studies of the US dial luminisers, Fry (1998) noted the large excess risk of bone cancers resulting from radium deposited in bone. Remarkably, there was also a large excess risk of cancers of the paranasal sinuses and mastoid air cells in the head. This excess was attributed to the decay of radium-226 in the bones of the head into the noble gas, radon-222, that was released into the airways of the head, leading to their irradiation by radon-222 and its radioactive decay products. Fry noted that although increased risks were observed for some other health outcomes, such as breast cancer, 'no significant or unequivocal relationships with prior exposure to radium have been found'. Of some interest is the observation that all of the bone cancers occurred in workers with bone surface doses greater than 5 Gy (of predominantly alpha-particle irradiation), ie very high localised doses.

6.7 During the 1940s and 1950s, patients in Germany suffering from bone disease – primarily bone tuberculosis or ankylosing spondylitis, but including some patients with other medical conditions (eg polyarthritis) – were injected with radium-224 as a treatment. Radium-224 has a relatively short half-life of 3.6 days, decaying through the emission of an alpha particle to produce another isotope of radon, radon-220. Radium-224 occurs naturally on Earth as a component of the radioactive decay chain of thorium-232. Owing to its short half-life, radium-224 decays mainly on the surfaces of bones where it is deposited, rather than in the bone volume.

6.8 Nekolla et al (2010) have reviewed the findings of the study of patients injected with radium-224. They found the anticipated large excess risk of bone cancers, but also reported excesses of a number of other cancers, such as thyroid, liver and breast. The standardised incidence ratio (SIR) for liver cancer was 4.2 (10 cases observed against 2.4 expected). Considerable care has to be exercised when assessing the results of studies of patients who have been treated with radiation as therapy for a disease because of concerns that the disease itself may have increased the risk of future diseases such as cancer. In this respect, it is of interest that the excess of cancers other than bone cancer is confined to those patients with bone tuberculosis, suggesting that this group of patients may be at an increased risk of these other cancers for reasons other than the radium-224 injections. Further, Nekolla et al (2010) noted that pre-existing liver disease (present in 4 of the 10 patients) was likely to be a factor in the reported excess of liver cancers. As radium-224 was administered as a therapy, the doses delivered to bone surfaces, at several gray, were high.

6.9 In addition to being a different radioisotope of radium, the radium-224 administered to the patients was in a different chemical form to that used by the dial painters, being designed to be soluble in the bloodstream and deposited rapidly on bone surfaces. Doses to tissues other than bone surfaces were also high – eg the average dose to the liver was several sievert (Nekolla et al, 2010) – so that a radiation-induced excess of cancers other than bone cancer is plausible. Further, phenylbutazone was administered to patients to relieve the pain associated with bone disease, a drug that may be related to some cancers, such as acute leukaemia.

6.10 In summary, it is clear that the intake of radium leads to an excess risk of bone cancers, but that this occurs after high alpha-particle doses to bone surfaces. Large intakes of radium-226 also lead to an excess risk of rare head cancers due to the production of radon-222 from the decay of radium-226 in the bones of the head.

6.11 The risk of other cancers from exposure to radium-226 is not well established and, for liver cancer in particular, the small number of excess cases reported from the patients injected with radium-224 could well be due to other causes. An excess of liver cancer in the dial luminisers with high intakes of radium-226 has not been found.

6.12 No papers have been found in the peer-reviewed literature that reliably link the risk of non-Hodgkin lymphoma (NHL) to radium exposure.

ISD reports

6.13 Following receipt of the 1991 NRPB report (Milton, 1991), COMARE first commissioned a report from the ISD on cancers in the Dalgety Bay area in 1992, which covered the period 1975–1990 and was subsequently published in 1994 (Black et al, 1994). The ISD study was extended in 2005 to cover 1975–2002. The most recent report for COMARE covered 2000–2009. COMARE had requested consideration of all sites of cancer in this report, which led to a large number of statistical tests comparing expected and observed numbers. For this reason, a higher than usual threshold was used to determine statistical significance, thus reducing the likelihood of finding a nominally positive statistical association by chance alone and significance tests were conducted at the 1% level. Also, because half of the postcodes involved are in the least deprived 10% of the Scottish population and all are within the least deprived 40%, the two least deprived deciles of the Scottish population were used to calculate the expected cancer rates. This partially corrects for known socioeconomic effects on cancer incidence rates (COMARE, 2006).

6.14 Data from the 1975–1990, 1975–2002 and 2000–2009 reports are shown in Table 6.1. It will be seen immediately that, for most sites of cancer, the average annual expected numbers of cases are substantially higher in the later periods. This could merely reflect the fact that the population was predominantly younger in the last quarter of the 20th century, consisting as it did of incoming workers with young families (Black et al, 1994).

6.15 A statistically significant ($p < 0.01$) excess of liver cancer incidence was present in 2000–2009, but not during 1975–2002, when there was a (statistically non-significant) deficit of cases. Liver cancer is not among the 10 most common cancers for either men or women in Scotland, but the annual number of cases rose from 151 to 258 between 2000 and 2009 for men, although remaining at 112 per year for women over this period.

6.16 There was also a statistically significant ($p < 0.01$) excess of cases of NHL during 2000–2009, but not in 1975–2002. The excess of cases of non-melanoma skin cancer (NMSC) during 1975–2002 is statistically significant ($p < 0.01$), but the observed number of cases of NMSC is similar to the expected number during 2000–2009. The excess of cases of pancreatic cancer during 1975–1990 approaches statistical significance at the $p = 0.01$ level, but over the period 1991–2009 the observed number of cases is about the same as the expected number.

6.17 These nominally statistically significant excesses of particular sites of cancer must be set against what is known about their causes and how they might be related to exposure to radium-226 at Dalgety Bay. The absence of any case of bone cancer during any period is notable because bone cancer (and rare head cancers) is the only type of cancer firmly associated with exposure to radium-226; the pattern of cancers shown in Table 6.1 must be viewed in this light.

6.18 The excess of cases of Hodgkin's lymphoma during 2000–2009, which approaches statistical significance at the $p = 0.01$ level, may suggest that there is a common cause for Hodgkin's lymphoma and NHL. Hodgkin's lymphoma is considered to have a very low sensitivity to induction by radiation, if it can be induced by radiation at all (Boice, 2006).

Table 6.1 Cancer incidence figures for 1975–1990, 1975–2002 and 2000–2009 in the Dalgety Bay area

Figures in italic font are statistically significant increases in the observed number of cases over those expected, using a one-sided test at the 0.01 significance level

	1975–1990*		1975–2002			2000–2009		
	Obs	**O/E**	**Obs**	**Exp**	**O/E**	**Obs**	**Exp**	**O/E**
Frequently associated with radiation								
Myeloid leukaemia (C92)						6	4.9	1.23
Leukaemia (C91–C95)	5	1.02	15	15.32	0.98			
Thyroid (C73)	3	2.4	6	3.76	1.6	3	2.9	1.03
Female breast (C50)	31	1.19	92	84.6	1.09	61	73.8	0.83
Occasionally associated with radiation								
Lung (C34) (C33–C34)	25	0.65	74	113	0.65	41	43.9	0.93
Stomach (C16)	4	0.4	10	27.04	0.37	6	10	0.6
Colon (C18)	15	1.06	44	46.61	0.94	34	38.9	0.87
Oesophagus (C15)			7	15.3	0.46	6	10.4	0.58
Bladder (C67)	8	0.86	22	26.97	0.82	9	10.4	0.86
Ovary (C56)			12	14.87	0.81	9	10.7	0.84
Brain and nervous system (C71–C72) (C70–72)			11	11.46	0.96	6	7.7	0.78
Liver (C22)	0	0	2	4.55	0.44	***10***	***4***	***2.47***
Rarely associated with radiation								
Kidney (C64) (C64–C65)	3	0.78	7	12.01	0.58	8	10.2	0.78
Salivary glands (C07–C08)			2	1.57	1.27	2	0.5	3.65
NHL (C82–C85)	4	0.75	18	17.33	1.04	***27***	***15.8***	***1.71***
Myeloma (C90) (C88+C90)	2	1.08	8	6.51	1.23	5	6.1	0.82
Malignant melanoma (C43)			21	15.94	1.32	20	22.7	0.88
NMSC (C44)	36	1.5	***129***	***101.6***	***1.27***	169	163.2	1.04
Rectum (C19–C20)	10	1.36	32	23.78	1.35	18	19.9	0.9
Uterus (C54–C55) (C54)			16	9.06	1.77	12	9.7	1.23
Bone (C40–41)	0	0	0	1.59	0	0	0.4	0
Connective tissues (C47+C49)			3	3.43	0.88	2	2.9	0.69
Never or sporadically associated with radiation								
Chronic lymphocytic leukaemia (C91.1)						7	4.6	1.51
Pancreas (C25)	11	2.28	18	14.42	1.25	12	9.3	1.28
Hodgkin's disease (C81)	1	0.45				7	2.6	2.68
Prostate (C61)	5	0.68				61	52.4	1.17
Testis (C62)						3	4.2	0.71
Cervix (C53)						3	3.6	0.83
Selected childhood cancers (0–14 years age range)†						0	0.4	0
Childhood leukaemia			4	2.12	1.89			
Other sites	48	0.93						
Total figures for cancers shown	**Obs 211**	**Exp 214.2**	**Obs 553**	**Exp 572.8**		**Obs 547**	**Exp 546.1**	

* Black et al (1994).

† Sites for which radiation-induced cancers have not yet been reported or confirmed: retinoblastoma, Wilms' tumour, neuroblastoma, and others of embryonic origin (Boice, 2006).

6.19 The excess of NMSC during 1975–2002 is comparable to that seen during the same period for melanoma skin cancer, a cancer with a very low sensitivity to induction by radiation (Boice, 2006). The excess incidence of melanoma and non-melanoma skin cancers may indicate a link to ultraviolet radiation exposure, which is an established cause of skin cancer of both forms. The age distribution of the population at this early period is consistent with uptake of package holidays which could have led to excessive exposure to sunshine, although the incidence of both types of skin cancer returned to expected levels during 2000–2009.

6.20 The generally low ratios of observed to expected cases presented in Table 6.1 for those sites of cancer most strongly associated with radiation exposure in previous epidemiological studies (eg lung and oesophagus) are notable. The low rate of lung cancer argues against any significant exposure through inhalation of airborne sources.

Postcode analysis

6.21 The liver cancer and NHL incidence data from the ISD demonstrate statistically significant increases in incidence, so COMARE undertook a further analysis using areal counts in each of the 13 data zones surrounding the site, supplied by the ISD. These zones are bounded by the Firth of Forth and the A921 on the south and north, by Letham Hill to the west and the fields above Braefoot Point to the east.

6.22 Having first confirmed through a test allowing for the large number of cancer sites examined that the excess in incidence of both diseases was unlikely to be due solely to this multiplicity, the data were subjected to the 'linear risk score' distance test, found previously (COMARE, 2005) to be well suited to datasets involving small numbers. In effect, the procedure tests whether the cases observed are distributed closer to a specific point – in this case, the headland, where the contamination has been confirmed – than would be expected by chance alone.

6.23 There are two forms of this test, conditional and unconditional. The conditional test is used to assess whether there is a significant association between incidence and distance from the hypothetical source, taking no account of the overall incidence rate, while the unconditional test integrates the spatial evidence with the overall incidence rate.

6.24 For the liver cancer data, the conditional test yielded a positive result significant at the $0.01 < p < 0.05$ level, implying that residence near the headland is associated with an increase in the risk of liver cancer. It is important, however, to note that there may be factors other than the radioactive contamination associated with residence near the headland.

6.25 No such association was found for NHL using the conditional test, indicating that the excess incidence of NHL is not associated with proximity of residence to the headland.

NHS Fife report

6.26 At COMARE's request, a review of the medical records of each of the liver cancer patients was undertaken by NHS Fife; prior approval was obtained from the Caldicott guardians for NHS ISD, NHS Fife and NHS Lothian. Only eight records were available for review and, of these, one did not meet the definition of primary liver cancer. The remaining seven had pathologically proven or clinical and radiological evidence of primary liver cancer (ICD-10 codes C22.0–22.8).

6.27 It should be noted that the cases from elsewhere in Scotland used to generate the expected number were not reviewed and so it is not known whether any of these may have been misclassified also, which would then affect the SIR (by increasing it). If it is assumed that the two patients for whom the records were unavailable were classified correctly, this would give the observed number of cases as nine. The corresponding SIR is 2.22, which is no longer statistically significant at the $p=0.01$ level if the expected number of cases is assumed to be unaltered (although statistically significant at the $0.01<p<0.05$ level).

6.28 In addition, the review examined the records for known risk factors for liver cancer, the major ones being infection with hepatitis B or C, evidence of heavy alcohol consumption or alcoholic liver disease and non-alcoholic steato-hepatitis. Less common causes include genetic haemochromatosis, alpha-1 antitrypsin deficiency and autoimmune hepatitis (El-Serag, 2011). Of the seven cases, all had some record of having known risk factors; in six cases, these were was well established. The presence of these known risk factors in the majority of the liver cancer cases is likely to have played a significant causative role.

Conclusions

6.29 The recent ISD analysis for the period 2000–2009 shows two types of cancer, which have been linked with exposure to radiation to some degree in previous epidemiological studies, to have statistically significantly raised incidences in the area around Dalgety Bay. The raised incidence rates have been confirmed by independent analysis.

6.30 It is not possible to be definitive about the cause of any particular case of cancer. Although liver cancer is classed only as ‘occasionally associated with radiation’ (Boice, 2006), a statistical association with residential proximity to the headland exists and so a link with radiation cannot be excluded completely. This statistical evidence must be assessed in the light of all available information.

6.31 Given it is known that the potential hazard relating to radioactive contamination at Dalgety Bay is due to the intake of radium-226, a particular pattern of cancers would be expected from epidemiological studies of those who have been exposed to radium-226, namely bone and head cancers. This signature of exposure has not been found in the cancer incidence data for Dalgety Bay, while there are indications that other (non-radiation) factors are responsible for the excess cases that have been found, and this is so for liver cancer particularly. It is thus very unlikely that the excess cases of liver cancer or of NHL during 2000–2009, or of NMSC during 1975–2002, are due to the presence of radium-226 in the area.

6.32 It should be noted that there is a time-lag between an individual being irradiated and the development of any consequent cancer (the latent period), which depends on the type of cancer. The above analysis, therefore, would not reflect any consequences of recent finds.

CHAPTER 7

CONCEPTUAL MODEL AND RECENT INVESTIGATIONS

7.1 The history of land use and activity on the site in the Dalgety Bay area is reviewed in Chapter 2 of this report, and the history of the discovery of the contamination, radiological surveys and investigations of the site is detailed in Chapter 4. This chapter presents a review of the current state of the site and the environmental processes affecting it, with particular attention on coastal processes that may be mobilising and transporting radium sources in contaminated material from the shore on to beaches.

7.2 A review of the potential for radium from luminising activities to migrate in the environment was undertaken on behalf of the MoD by Baker and Toque (2005). They identified soil erosion by surface water and the subsequent movement of radium-bearing particulates in surface waters as the principal means by which migration might occur, and concluded that:

> 'The extent to which radium will migrate in surface water from a former burial or burning site relates to a number of site-specific parameters including the accessibility of the contaminant to the surface water, the extent of vegetative cover, the intensity of rainfall and the slope of ground surface. The most likely scenario for the migration of radium in surface water would be if surface disposal of luminising ash had occurred on a poorly vegetated slope.'

7.3 Unfortunately, Baker and Toque did not consider erosion of coastal land by the sea as a potential scenario for mobilisation of particulate radium. That appears to be the principal mechanism at Dalgety Bay where made ground along the coastline, in which radium-bearing sources have been buried, has been eroded by waves and redistributed on to beaches and in some cases subsequently re-excavated. Exposed sources have been transported along the coastline, away from the area of the original release, by waves and tidal currents as part of the natural sediment transport process.

7.4 The distribution pattern of radium-bearing sources that have been recovered from beaches and the foreshore at Dalgety Bay supports this interpretation. Figure 4.1 (page 21) shows the distribution of items of radium-bearing materials recovered during surveys by AMEC Environment and Infrastructure UK Ltd (on behalf of the MoD) and SEPA during 2011 and 2012. No definitive map exists of finds made before this date, but it is believed that the extent of contamination found by the 2011–12 surveys is broadly similar to that of previous efforts. The 2011–12 surveys followed more thorough procedures than previously, and the much increased find rates compared with previous years may be due to this. The areas searched were mostly on the beaches, but included adjacent areas on land in some places along the coastal paths.

7.5 From Figure 4.1 it is immediately apparent that the distribution of finds is most dense in the area around the jetties, in the small bay marked 'Mud' immediately north of the 'IRB Sta', and westwards from the western promontory of this bay to the point marked ‘X’ (at E316360, N683320). To the west of these areas the spatial density of finds on the beach is lower, but a scatter occurs as far west as the ‘Outfall’ in the inner, western corner of the main bay. Only a few surveys have extended beyond the Outfall. Some isolated evidence of contamination was found in the form of count rates higher than background, but no sources have been located along the coastline beyond this point. At the other extreme of the most heavily contaminated area, the density of sources on the beach declined immediately west of the jetty area. A scatter of finds occurred on the sandy beach that is exposed at low tide off the headland. Two sources found in the sediments of the New Harbour were the most distant from the main contamination in this direction.

7.6 Many of the sources found in 2011–2012 were buried within the beach sediments, some down to 0.6 m below the surface (deeper in a few cases). The search protocols introduced in 2011 were designed to locate high activity sources buried relatively deeply as well as those on or near the surface. The find with the highest activity, 76 MBq, was buried at a depth of approximately 0.85 m, consistent with the source finds in 1990–1991.

7.7 The pattern of finds may be conceptualised as having arisen through the erosion of the shoreline by storm waves that released material from the parts of the coast where formerly made ground is still unprotected. As will be shown below, this includes the jetty area and the ‘Mud’ bay to the north, whereas since 1990 the radium-bearing made ground in the headland has been protected by a series of placements of rock materials culminating in the ‘armour’ of large blocks forming the present coastline. Thus, the densest part of the find distribution is on beaches in front of the area where radium-bearing made ground is exposed to wave attack. The peripheral part of the distribution west of point X is most likely made up of materials that have been transported along the coast by the action of waves and tidal currents. The beach finds between point X and the western headland of the Mud bay may also result from such transport, as it is not known exactly how far west the original infilling of the coast extended. The thin scatter of finds off the headland southwest of the jetty area may similarly have resulted from wave and tidal transport, although it is likely that some material is being washed out from the interstices of the rock armour where this directly covers radium-bearing made ground. Westwards transport on this section of coast is suggested by the two finds in the New Harbour. However, the overall distribution indicates that the dominant transport direction across the headland is likely to have been eastwards, and that the debris from the jetty area is being carried around the rocky promontory at the tip of the peninsula into the Mud bay, from which transport is in turn westwards into the inner recess of the main bay.

Recent investigations

7.8 In 2012, a ground penetrating radar (GPR) survey of the site was carried out by the universities of Stirling and Belfast (Ruffell and Tyler, 2012). This identified areas of made ground, between 1 and 2 m thick, across the site. Subsequently, a similar survey was completed by a MoD sub-contractor (Zetica Ltd, 2012).

7.9 On the basis of the information from both GPR surveys, the MoD commissioned a contractor to undertake intrusive investigations and these were carried out in early 2013. The results were detailed in a report prepared by AMEC for the MoD (AMEC, 2013a). Figure 7.1 shows the distribution of boreholes and trial pits, together with the lines of cross-sections illustrated in the AMEC report.

7.10 The work confirmed that there was a large volume of made ground containing ash and clinker behind the current rock armoured headland. On the land at the head of the jetties the made ground material was over 1 m thick. On the landward side of the Mud bay coastline the made ground deposits were 1.5 to 2.2 m thick. On the land at point X there was 1.5 m of made ground, thinning inland to 0.5 m. Much of the made ground material in these areas contained clinker and

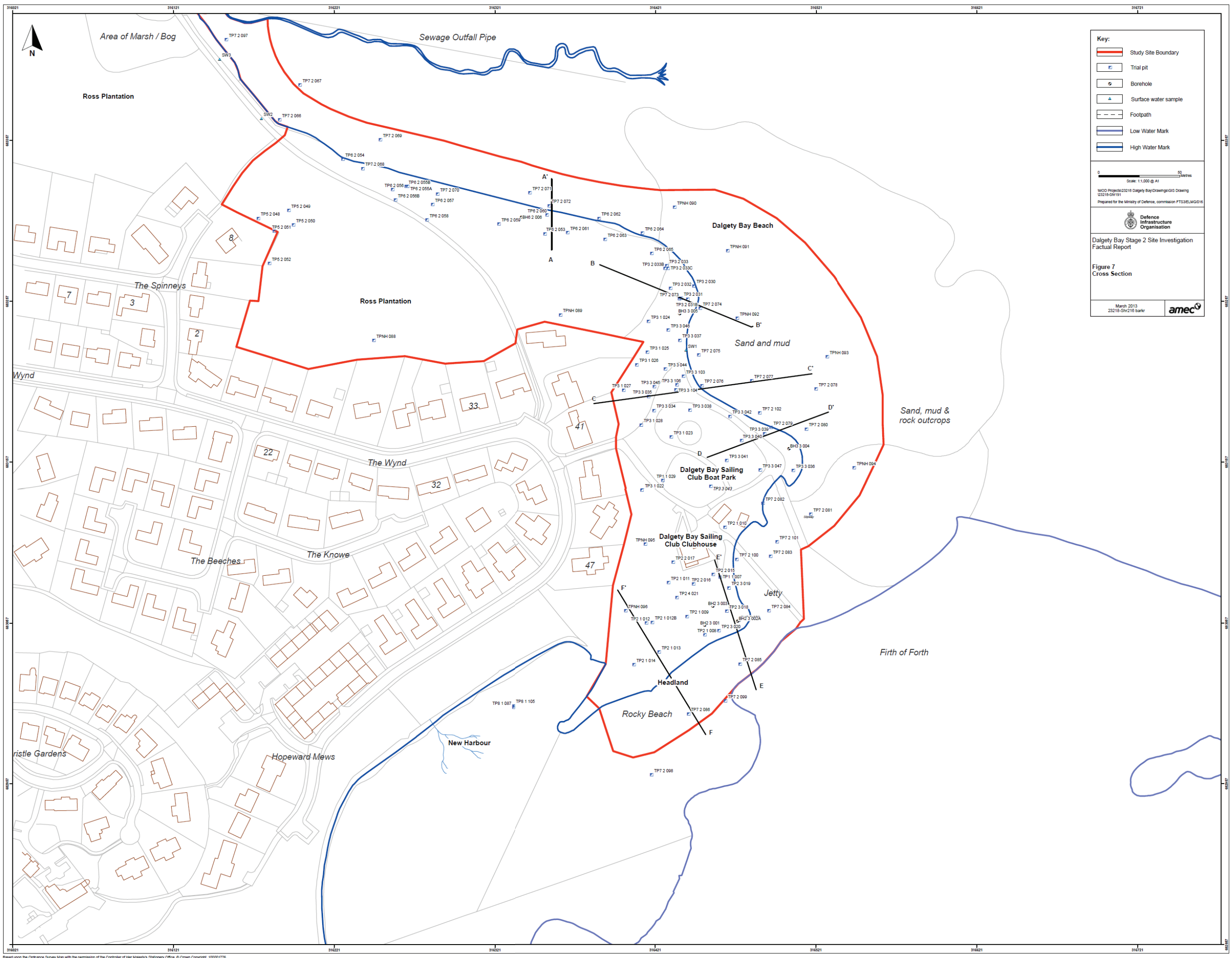


Figure 7.1 Map (taken from AMEC 2013a) showing the locations of trial pits made in 2013, with Figure 7.7 lines of cross-sections shown (note that cross-sections along lines EE′ and FF′ are not included in this report)

ash with heterogeneously distributed radium contamination. From the presence of marine shells, there was evidence that some of the material either had been in a marine environment or had become admixed with marine sediments such as beach sand, while the presence of burnt sand under some deposits suggested some direct burning on the beach.

7.11 The made ground deposits on land either currently on or within 5 m of the coastal frontage of the peninsula have a volume of about 3,000 m^3 (450 m of coastline of average thickness 1.5 m) and represent a significant potential future supply of contaminated material to the beach and marine environment. At present the deposits are not adequately protected from marine action and, as a result, will erode over time to repopulate the foreshore and feed further spreading of the contamination along the beaches surrounding the peninsula. Although the rock armour at the headland does offer limited protection from the most energetic incident waves, it is not fully engineered and no membrane and/or rock filter layer has been installed to prevent wash-out by waves and migration of material from within the headland on to the beach via the interstices in the rock armour. Thus, without isolation or removal, contamination will continue to be deposited on the foreshore as the coastal areas erode.

7.12 Figure 7.1 shows that in addition to the investigations on land, a number of trial pits were dug in the beach. The upper part of the beaches around the peninsula are mostly composed of sandy gravel containing numerous man-made objects such as fragments of brick, concrete and pottery, as well as natural stones and sand. This coarse material forms a slope down to seaward, usually 1 or 2 m in height, with an abrupt change of grain size to sandy mud and/or silty clay at its foot. Trial pits in the upper part of the beach slope on the coast between point X and the jetty area typically showed 0.5–1 m of made ground. Within the Mud bay, the made ground layer in one trial pit contained a fragment of china marked 'ER 1954', indicating its deposition after that date. Towards the foot of the slope the layer reported as made ground was thinner, 0.1–0.2 m, and overlaid marine silt and clay. This distribution is consistent with marine erosion having cut into a layer of made ground that extended some metres to seaward of the present coastline and was formerly as thick as that on the adjacent land (ie 1–2 m, as described in paragraph 7.10), and having bevelled a new beach surface across it. The surface layer of the new beach profile would have been reworked by waves, but the deeper parts (below about 0.3 m) may represent undisturbed made ground. Some of the eroded material has been transported seawards and now forms the thinner layer resting on normal marine mud seen in the offshore trial pits.

7.13 West of point X, the grain size of the upper beach sediments changes fairly abruptly, the gravel component becoming finer over a distance of a few metres along the beach. Trial pits in the beach between point X and the Outfall recorded only 0.2–0.3 m of made ground, and in some pits none was present. It seems likely that the material recorded as made ground in these pits is a reworked deposit that is rich in anthropogenic material that has been eroded from the coastline east of point X and transported westwards by waves and tidal currents.

7.14 The distribution of made ground and radium-contaminated materials in the trial pits suggests that there may have been deposition of anthropogenic material along the whole length of coastline between point X and the headland. Subsequent marine action has eroded this material, causing recession of the coastline, with the eroded material being both re-deposited on the lower beach slope and transported along the upper beach into the inner part of the main bay (ie the topographical feature known as Dalgety Bay, as opposed to the town of that name). Figure 7.2 is a sketch cross-section that illustrates this concept.

Historical changes

7.15 The historical changes in the position of the coastline outlined in Chapter 2 are consistent with the concept of the current state of the site outlined in the preceding section. Historical evidence regarding the site use including aerial photographs of the coastline were reviewed by Enviros Consulting Ltd for the MoD (Enviros Consulting, 2007). These demonstrated that significant changes occurred to the coastline during the 1950s, but exact documentation of the coastline changes was not attempted. Ordnance Survey maps normally indicate the coastline as two contour lines, for mean high water spring tide and mean low water spring tide, respectively. Neither of these corresponds exactly to the coastline as a person might regard it when standing near a point where the

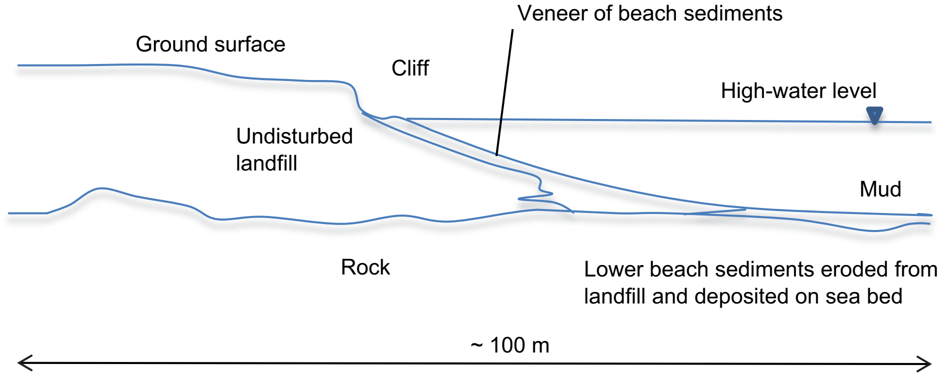


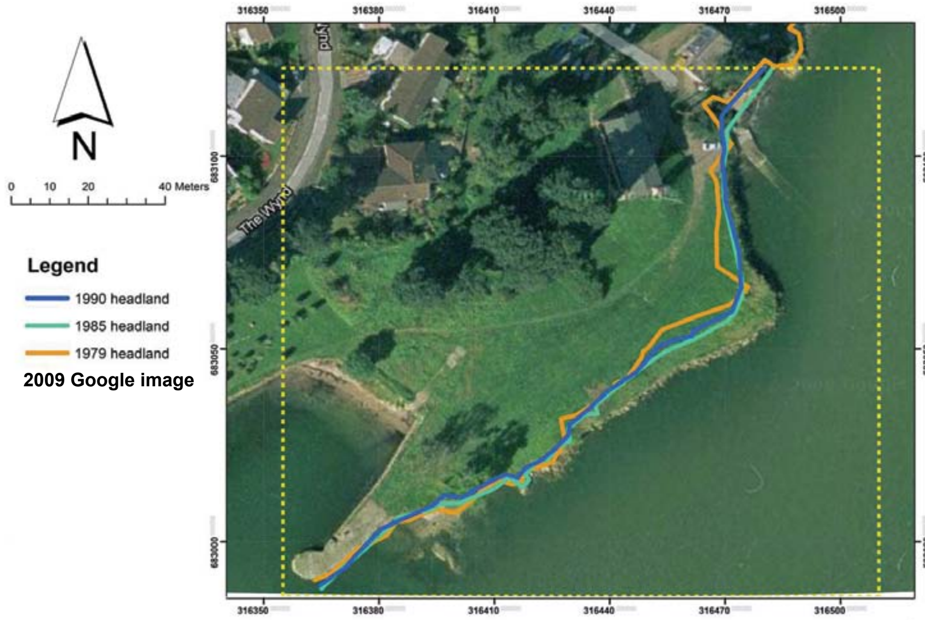
Figure 7.2 Conceptual cross-section of part of the landfill and adjacent beach (not to scale)

land ends and the beach begins. This latter 'morphological coastline' is usually quite obvious when a person is present on the ground, but is not always easy to define as a precise line where there is a transitional zone between the land and the uppermost part of a beach above high tide levels. Exact interpretation from aerial photographs can be even more problematic because what is seen on the photograph as ground uncovered by water depends on the state of the tide, weather and lighting, as well as on the height of the aircraft and quality of the photograph itself. In order to document changes over time, a series of photographic images taken many years apart must be corrected for parallax distortions and geo-referenced to a common base grid. The accuracy of this process may lead to discrepancies of several metres between different photographs in the series.

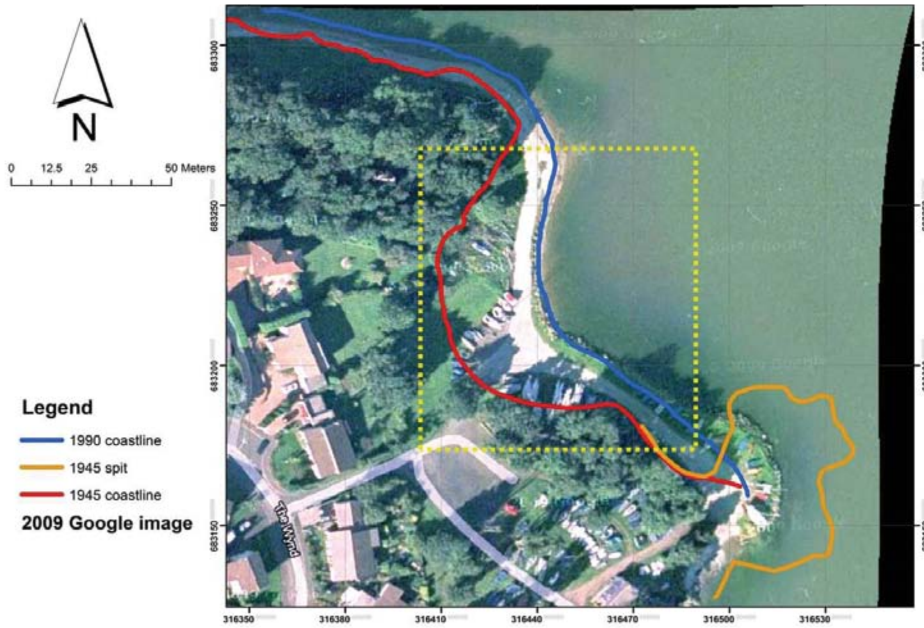
7.16 A study made for SEPA by the University of Stirling (Sneddon et al, 2013) has addressed these issues as far as is feasible, and presents its findings as a series of dated coastlines from 1949 to 1990. In order to minimise errors, the study treated the headland area separately from the Mud bay that lies on the north-east side of the peninsula. For both areas the results were presented as a series of dated lines superimposed on a Google Maps™ satellite image from 2009, taken at a time of high tide, and in some cases on contemporary aerial photographs also. The interpreted coastlines for 1949 and 1990 were taken as reference lines against which changes at other times could be compared. There was no significant change in the coastline of either area between 1945 and 1949, but there were substantial changes between the latter date and 1990. Since 1990 the coastline has been built outwards by emplacement of rock armour to prevent erosion of the headland and boatyard areas, with infilling behind a boulder screen. This has advanced the coastline by a maximum of around 8 m in each area, as shown by a comparison of the 1990 coastline with the 2009 Google image (Figures 7.3a and 7.3b). These changes were made by the Dalgety Bay Sailing Club (see paragraph 2.19). Other parts of the coastline have not changed significantly since 1990.

7.17 Between 1949 and 1955, substantial changes in the coastline occurred. For the headland area, comparison of the aerial photographs in Figures 7.4a and 7.4b shows that part of the coastline was built outwards in the triangular area to the right of the arrow in the 1949 image. In 1949 the seaward edge of this area appears to form a cliff, the line of which can still be discerned as a faint tonal change in the 1955 image. The coastline changes are directly compared in Figure 7.4c, in which the two interpreted coastlines are superimposed on the 2009 Google image. This extension of the coastline is clear evidence that landfilling took place between 1949 and 1955.

7.18 The changes in the Mud bay area are more dramatic. The coastlines shown in Figure 7.3b indicate that this bay underwent substantial infilling between 1945 and 1990. Figures 7.5a–c compare the 1949, 1955, 1959 and 1990 coastlines. In 1955 a hook-shaped feature referred to by Sneddon et al (2013) as a 'spit' has developed across part of the bay. This is an unfortunate choice of terminology as it is not clear whether the feature was formed by natural processes or is wholly or partly man-made. A spit is a coastal feature that is formed naturally where a large flux of sediment is being transported along a coastline and is deposited in deeper water where the coast changes direction. The spit builds progressively outwards from the point where the original coast changed direction. The distal ends of natural spits show a characteristic curvature of beach ridges around their tip. This pattern might be represented by the curvature of lineations on the hook-like feature in Figure 7.5a, but it is hard to be sure. The tip of the feature appears to be topographically above the surrounding areas and the truncations of the lineations do not look natural. If the construction of the feature was from naturally transported sediment, it must have been deposited by currents passing through a gap between the area of rocks and sediment that lies to the east, and the tip of the land forming the main peninsula. Some of the lineations clearly pass



a Coastline changes in the headland area since 1979



b Coastline changes in the boatyard and 'Mud' bay area since 1945

Figure 7.3 Coastline changes in two parts of the Dalgety Bay peninsula (modified from Sneddon et al, 2013)

through this gap, but the outermost ones, right at the base of the photograph, abut against the area of rocks.

7.19 An alternative explanation for the origin of the hook-like feature is that it was formed by deliberate dumping of material into the bay. If that were the case then the feature would have been constructed from material brought along the beach and the lineations might be interpreted as vehicle tracks. This interpretation also has problems, especially the abutment of the outermost 'tracks' with the area of rocks at the base of Figure 7.5a.

7.20 A third possibility, and on balance the most likely, is that the hook-like feature was deposited naturally as a response of the marine system to an artificially increased supply of sediment. The photographs for the period between 1945 and 1949 all show a small peninsula apparently formed of sediment-covered rocks at the extreme east of the area now forming the boatyard. The interpreted coastlines for those years show this feature as fluctuating in outline, though always of much the same general size and position. It may be that the feature represents a Coastline in the headland area in 1949

b Coastline in the headland area in 1955

c Comparison of the 1949 and 1955 coastlines with the headland in 2009

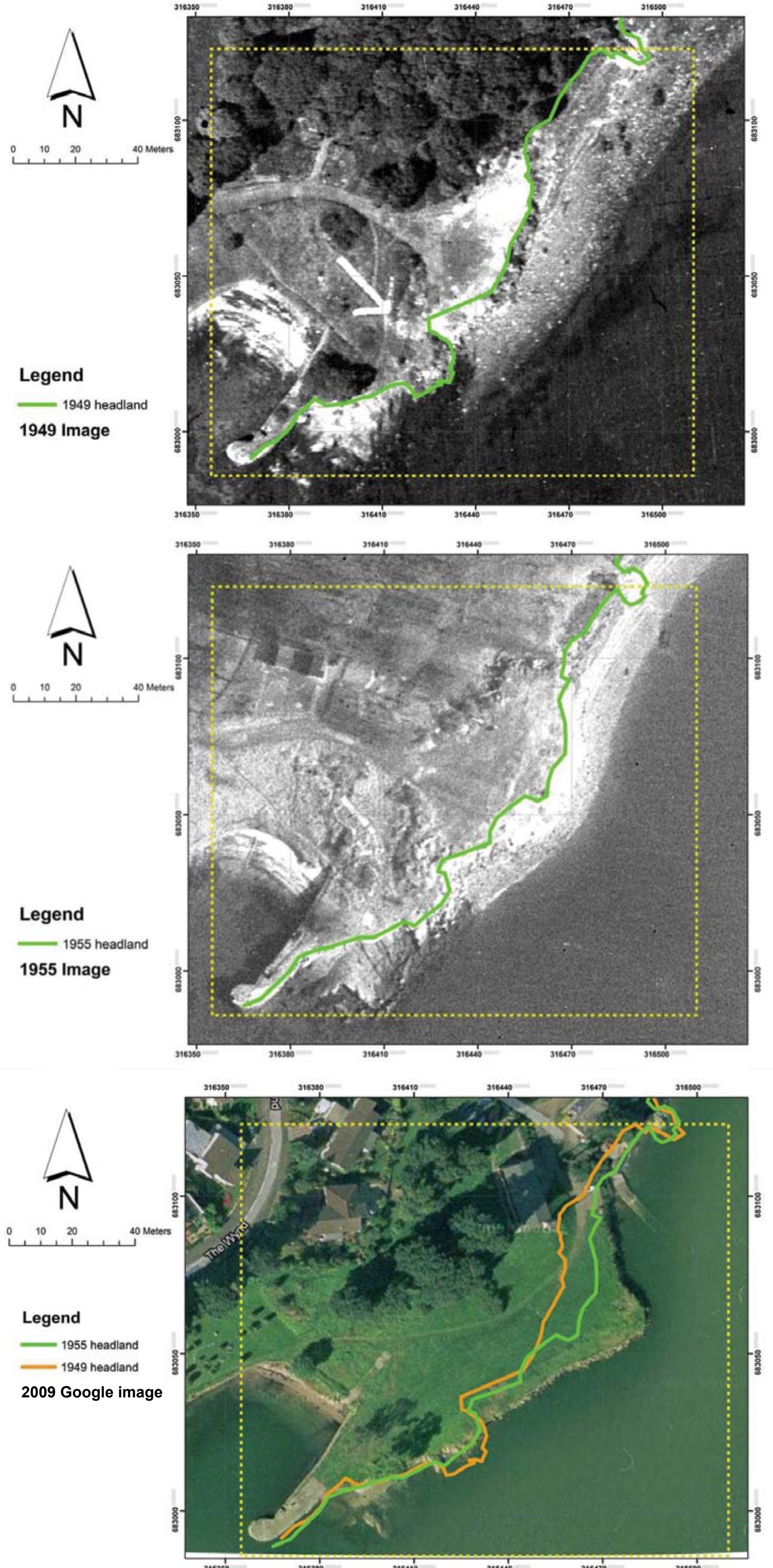
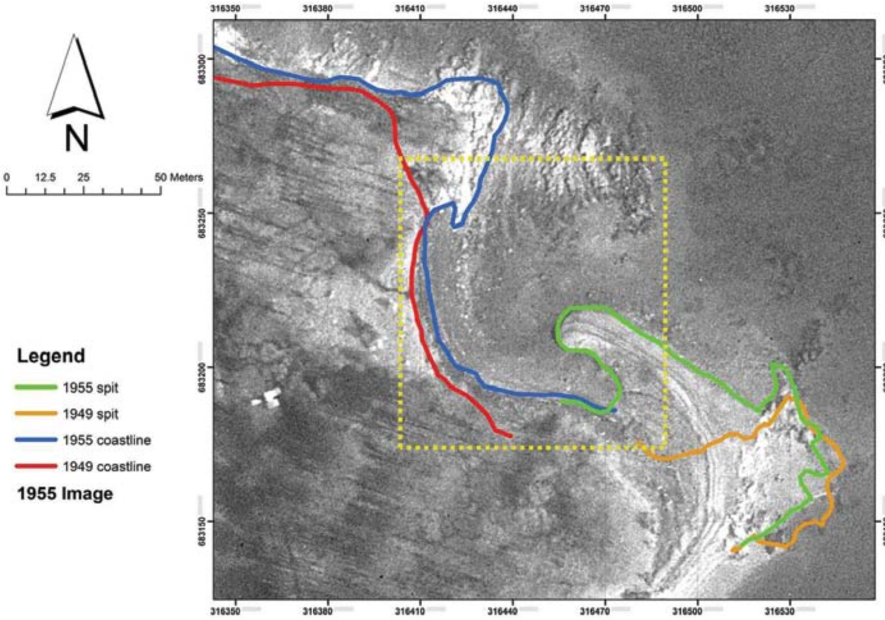
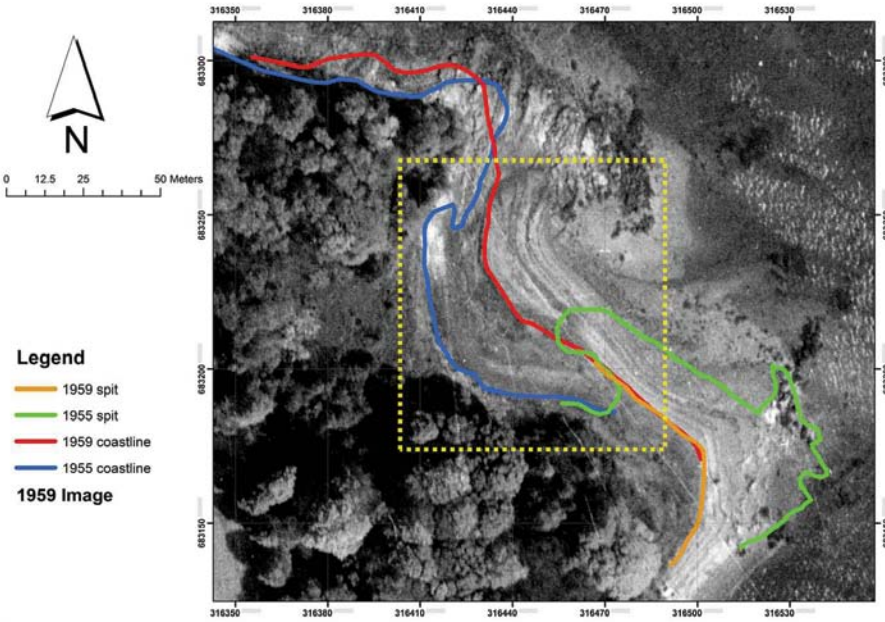


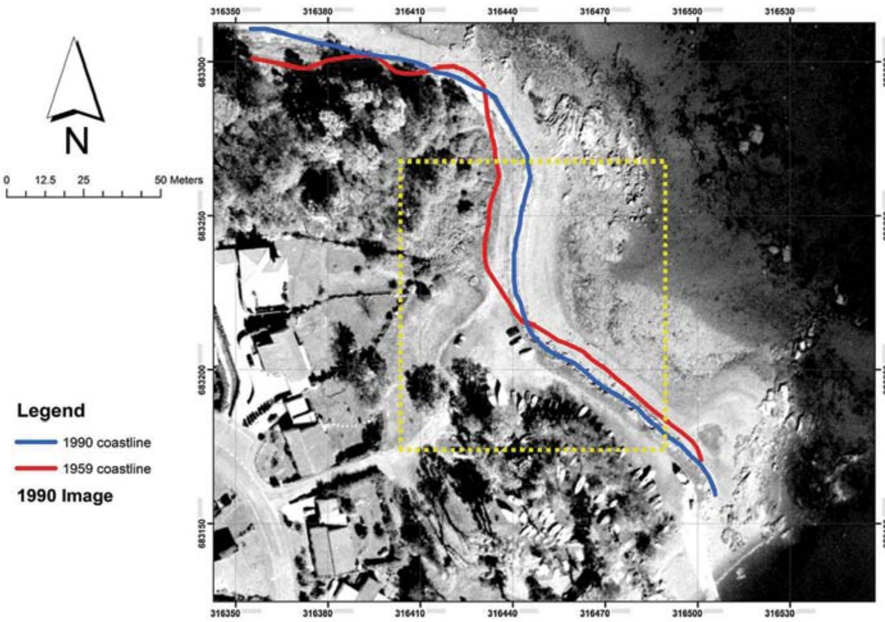
Figure 7.4 Coastline changes in the headland area (modified from Sneddon et al, 2013)



a Coastline changes in the boatyard and Mud bay area, 1949 to 1955



b Coastline changes in the boatyard and Mud bay area, 1955 to 1959



c Coastline changes in the boatyard and Mud bay area, 1955 to 1990

Figure 7.5 Coastline changes in the boatyard and Mud bay area (modified from Sneddon et al, 2013)

an embryonic spit forming where the coastline turns to the north, and that the sediment needed to build and maintain it was supplied by material dumped on to the outer edge of the triangular area visible on the headland in Figures 7.4a and 7.4b, or dumped directly on to the beach.

7.21 What is certain is that the hook-like feature could not have been constructed naturally without an increased supply of sediment, the likely source of which is discussed in paragraph 7.29. The northwards direction of transport implied by this is the same as that suggested by features of the present day situation on the site, namely the distribution of radioactive sources, and also the piling-up of sediment on the western sides of the jetties, with relatively lower sediment surfaces on their eastern sides.

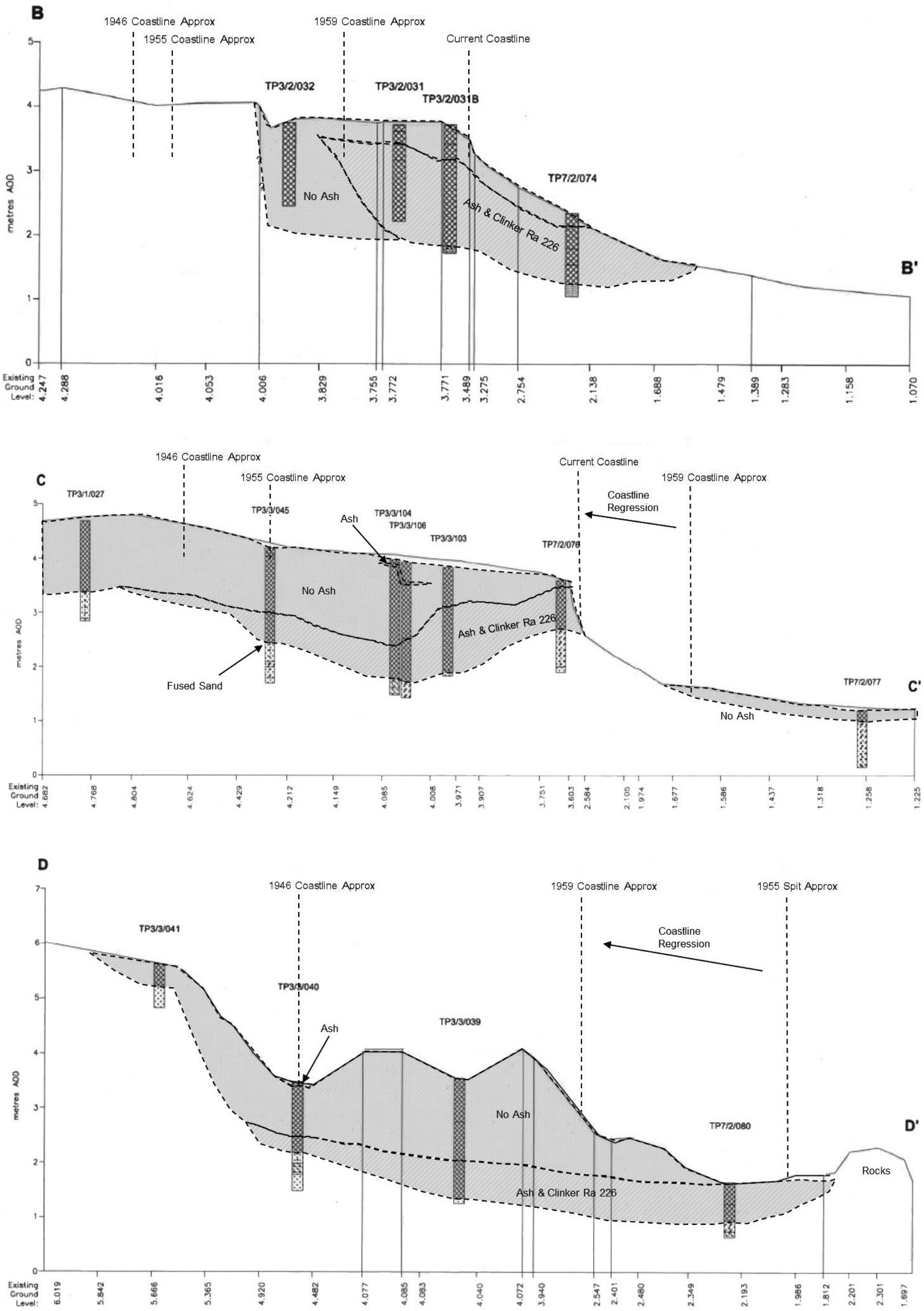
7.22 Between 1955 and 1959, there were further, equally important changes in the Mud bay area, illustrated by Figure 7.5b. The hook-shaped feature had completely disappeared by 1959, whereas the coastline of the inner part of the Mud bay had advanced seawards by 25 m. The area of new land in the inner bay was estimated by Sneddon et al (2013) as 3,100 m^2. It appears to be roughly equal to the area of the former hook-shaped feature. If these changes occurred naturally, they would have involved a major reduction or cessation of the sediment supply to the hook-shaped feature. This feature, as noted above, could have been produced by an enhanced supply of material from the headland and jetty areas to the south. If the supply of sediment were cut off then the hook-like feature would have been unable to grow further. The same patterns of waves and tidal currents that produced the hook-like feature may then have transported the sediment westwards, depositing it against the inner coastline.

7.23 The changes to the Mud bay from 1959 to 1990 were comparatively slight. They are illustrated in Figure 7.5c. The coastline in the southern part of the bay has retreated a few metres landward, whereas in the north of the bay there was a slight accretion. During the same period there were some relatively minor changes to the coastline of the headland (see paragraph 7.30).

7.24 A series of cross-sections based on the results of trial pit investigations made by AMEC in 2013 throw some further light on the uncertainties regarding the formation and destruction of the hook-shaped feature. Figure 7.6 shows interpolated cross-sections interpreted by Nina Patton of SEPA, from the trial pit logs in the AMEC report (AMEC, 2013a), highlighting the presence or absence of radium-contaminated ash and clinker in the made ground. The lines of these cross-sections are shown in Figure 7.1. Figure 7.6a shows cross-section BB′ in the northern part of the Mud bay (Figure 7.1). The approximate positions of the coastline at different dates are marked and the material that accreted to this part of the coast between 1959 and 1990 was described as ‘ash and clinker’ and was contaminated by radium. No ash was present in the pit to landward of the 1959 coastline, but this was in made ground. Unfortunately, this was the only pit in this cross-section that lay in the land that was accreted between 1955 and 1959. However, it seems likely from the elevations of the deposits that the ash-free made ground in this pit was deposited before 1959.

7.25 Moving southwards, Figure 7.6b shows the cross-section CC′ through the central part of the bay. Between this cross-section and the previous one lies the trial pit from which pottery dated from 1954 was recovered from made ground beneath the beach without radium contamination (see paragraph 7.10). If this layer of ash-free made ground was deposited at the same time as that discussed in the last paragraph, the date of deposition must have been after 1954, but before 1959.

7.26 Every trial pit between the 1946 coastline and the current coast in cross-section CC′ shows a layer of radium-contaminated ash and clinker, overlain by



a Cross-section through the coastline and beach along line BB′ in Figure 7.1

b Cross-section through the coastline and beach along line CC′ in Figure 7.1

c Cross-section through the coastline and beach along line DD′ in Figure 7.1

Figure 7.6 Cross-sections along the lines shown in Figure 7.1, based on the results from trial pits reported by AMEC (2013a) and reproduced from diagrams prepared by Nina Patton (SEPA) in June 2013

ash-free made ground (Figure 7.6b). The layer of ash and clinker is exposed at the current coastline where it forms a cliff about 0.6 m high capped by a thin layer of ash-free material. It seems probable that the layers of both materials are laterally continuous. The upper, ash-free, layer of made ground overlaps the ash layer on to the land to the west. In pit TP3/3/045 the ash layer rests on fused sand. This strongly suggests that burning took place at, or very close to, this point and makes it seem unlikely that the ash layer at this location was deposited from the sea. The pit is located close to the estimated position of the 1955 coastline and so would have been on the beach at that time, but in the sea in 1946. Thus, there is evidence of a layer of ash and clinker that stretches from the 1946 coastline to at least the position of the present coastline, with further evidence of burning taking place on exposed beach sand, suggesting that some of the ash at least was produced *in situ* in the vicinity of the 1955 coastline. If the ash to seaward of this represents the transported material from the hook-shaped feature on the 1955 photograph, it implies that the feature itself must have been almost entirely composed of ashy materials, and that the ash in section CC′ was deposited not as a single layer, but as two abutting layers, one *in situ*, the other from the sea.

7.27 Since 1959, the coast at section CC′ (Figure 7.6b) has experienced erosion, which appears to have cut into the ash layer. This erosion may have been a source for the ashy material which has accreted to the coast in section BB′ (Figure 7.6a).

7.28 Section DD′ (Figure 7.6c) has a similar stratigraphy to section CC′ with a layer of ash and clinker with radium contamination that is overlain by ash and radium-free made ground. This section cuts through the root zone of the hook-shaped feature of 1955 (the seaward side of which is shown as '1955 spit approx'). It can be seen that this feature was probably underlain by the layer of ash and clinker. The upper layer of ash-free made ground is absent from the root zone of the hook-shaped feature, but present to landward of the 1959 coastline, where it extends on to relatively high ground around 2.5 m above the present coastline at the west end of the section. This makes it very unlikely that the ash-free made ground was deposited from the sea.

7.29 The evidence from the cross-sections, together with that from the aerial photographs already discussed, are consistent with the following scenario. Radium-contaminated ash and clinker was produced in the headland area at some time before 1955 and added to the seaward edge of the triangular area visible on the 1949 photograph, as well as possibly being dumped on the beach or burned *in situ* there. Aircraft repair and reclamation commenced on the site in 1939 (paragraph 2.5), so feeding of radium-contaminated ash on to the coastline and beach may have occurred at any time during the decade prior to 1949. It is certain that some additions of material were also made between 1949 and 1955 as photographs show an accretion of land on the headland coastline between those dates. As it was added to the beach area, the ash was entrained by coastal transport processes and carried northwards. The small peninsula or 'spit' interpreted as being present on the eastern tip of the main site from 1946 to 1950 is likely to have been composed of sands contaminated by this ash, its form being a natural response to the extra supply of artificial sediment that was added to the coastal system. Sometime between 1949/50 and 1955 the supply of sediment-bearing radium-contaminated ash and clinker was increased. In the same period the coastline of the headland was extended to seawards and the hook-like spit feature developed across the Mud bay. On the evidence of section DD′ (Figure 7.6c), the hook-like feature seems mainly to have been composed of ashy material. Between 1946 and 1955 some burning to produce ashy material *in situ* took place on a beach that then formed the back of the bay, but now lies 20–25 m to landward of the coast (cf section CC′ in Figure 7.6b). In or about 1955, the supply of sediment to the hook-like feature ceased or was greatly diminished and the material composing it was washed by wave action into the bay, where it formed a layer containing radium-contaminated ash and clinker that covered the bay floor and piled up to 1 m thick against the 1955 coastline (section CC′). After this, but before 1959, a layer of ash-free made ground containing domestic artefacts dating from 1954 was deposited on the land areas adjoining the then coastline and in the bay itself. This layer was up to 2 m thick. By 1959, marine erosion had reworked some of this layer and produced beach ridges that are visible on the aerial photograph in Figure 7.5c, suggesting that the ash-free landfilling took place long enough before the 1959 photograph was taken for some wave and tide action to have accomplished this.

7.30 Little change occurred to the headland coastline between 1955 and 1960. After 1960 there were further changes. By 1973 small spits of land had extended into the sea in the area now grassed over in the headland, and the coastline had

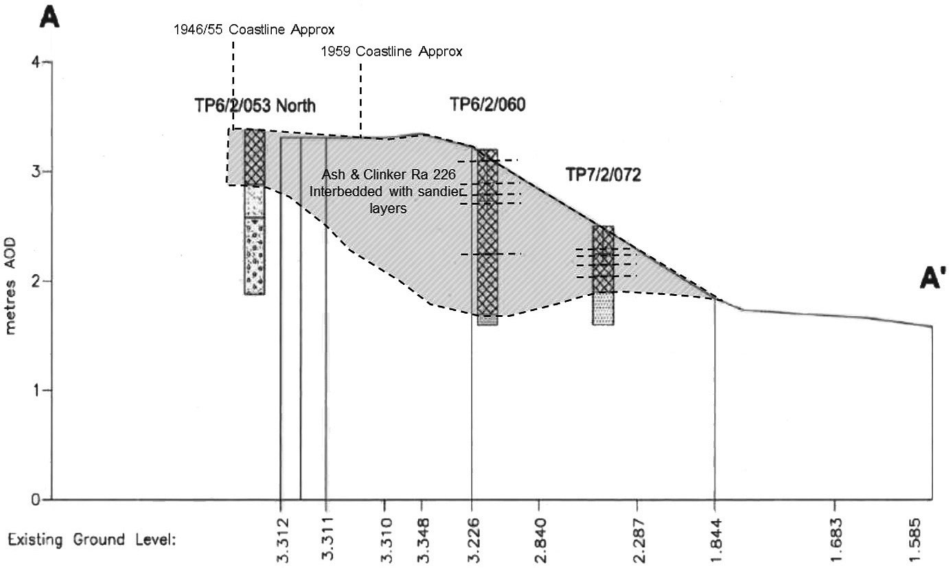


Figure 7.7 Cross-section through the coastline and beach along line AA′ in Figure 7.1

accreted seawards in the jetty area. The 1973 photograph, given in the report by Sneddon et al (2013), is the first to show the east jetty, the west jetty being added between 1976 and 1979. By 1979 the coastline had receded and the small spits had shifted position slightly and been reduced in size. By 1985 the first rock armour composed of large blocks had been added to the headland and there was little change thereafter until 1990 (Figure 7.3a). As noted above (paragraph 7.16), material and rock armour has been added to both the headland and the boatyard areas in the period since 1990.

7.31 On the coastal segment to the north of the main site, adjoining Ross Plantation, a cross-section was made by SEPA using AMEC data (Patton N, SEPA: personal communication, 2013). This is shown in Figures 7.1 and 7.7 as section AA′. It is adjacent to point X on Figure 4.1. It shows that the shoreface and upper beach at this point are underlain by interbedded layers of sand mixed with ash and clinker containing radium contamination. This suite of materials has probably been derived from the ashy layer in the back of the Mud bay, where coastal erosion has cut into it. Some of the material may derive also from further south, as investigations by SEPA and the MoD demonstrated that ashy material underlies the jetty area and is exposed to active erosion and re-deposition by waves. As already noted, in the long term over a period of years the material released into the coastal system from this area is likely to undergo transport into the Mud bay and then to be carried further west into the inner part of Dalgety Bay.

Coastal processes

7.32 So far in this chapter only the current state of the site has been considered; the pattern of radioactive finds along beaches, the AMEC investigations of 2013 and the historical evidence of coastline changes have been used as the basis for the conceptual model of current processes and past events outlined in paragraphs 7.7, 7.14 and 7.29 and in Figure 7.2. Before drawing the evidence together it is important to consider what is known of current coastal processes on the site, and to examine the compatibility of these processes with the transport and deposition of materials that have been inferred from the evidence above.

7.33 The MoD commissioned AMEC Environment and Infrastructure UK Ltd to conduct a desk study of coastal processes. That report (AMEC, 2013b) draws the following conclusions:

(a) Waves breaking in shallow water are likely to be the main mechanism for transporting the wide range of sediment grains, from coarse sand up to small boulders, that have been observed on the beaches

(b) While the fetch for generating waves is greatest from the direction of the North Sea, the islands and rocks around Inchcolm that lie between due east and east-south-east of the site will provide shelter and refract the easterly waves round so that they approach the shore from the south to south-east

(c) The largest waves generated within the Firth of Forth will impact the shore from the south-west to east-south-east directions

(d) Shallow-water waves with significant wave heights* of 1 to 1.25 m can be generated from time to time by the wind speeds observed in the region

(e) Such waves will move material of most sizes observed on the beach, but the larger pebbles and boulders would be moved only momentarily as waves plunged and broke over them

(f) The net direction of sediment movement along this part of the coast is from west to east

(g) There is evidence from sedimentary structures of sediment transport from the IRB Sta (see Figure 4.1) (called promontory 2 in the AMEC report) north-westwards across the mouth of Mud bay (Boatyard bay in the AMEC report)

7.34 Building on these conclusions regarding processes, the AMEC coastal processes report (AMEC, 2013b) states that the source of coarse debris – ie material up to small boulder size, including bricks or fragments of bricks and other building materials, as well as rock particles – is likely to have been erosion of the tipped debris that formed the headland (called promontory 1 in the AMEC report) prior to the emplacement of rock armour. The report points to the disparity in beach levels across the jetties (the 'groyne effect') as further evidence for this conclusion.

7.35 These conclusions are in broad agreement with the evidence already considered, and do not contradict those conclusions that have already been reached from the foregoing synthesis of conceptual model and site data. It should be noted that the AMEC coastal processes report omits detail on some aspects. Conclusion (c) that the largest waves may approach from the south-west to south-east quadrant is reasonable, but considers only the fetch available and neglects to take into account how this will combine with wind direction or the relative frequency distributions of wind speeds from different directions. The refracting effect of islands is undeniable – conclusion (b) – but in drawing conclusion (c) the report omits the fact that the gaps between the islands are substantial and that there is 2.5–3 km of fetch (across shallow water) from the islands to the site. This gives an opportunity for waves generated by easterlies to pass between the islands and undergo regeneration before hitting the east-facing coasts of the site. Another omission from the report is any mention of surges, which are an important feature of the water level regime on the east coast of Britain and could influence wave heights and the areas of the Dalgety Bay peninsula directly exposed to wave action during a surge. The impacts of these omissions are difficult to assess currently, but they may have important implications when considering the likelihood of storm wave erosion of the radium-contaminated deposits in Mud bay (ie Boatyard bay in the AMEC report).

* 'Significant' wave height is defined as the average height of the highest third of all waves. It is close to the height an observer would estimate as average wave height when looking at a stormy sea from a ship's deck. It differs from average wave height because it does not take into account the full spectrum of the waves, but is the measure most relevant to sediment transport because it does represent a broad band of the more energetic part of the wave spectrum.

7.36 Further work on coastal processes, possibly including a full-scale modelling exercise, may be needed to generate valid engineering criteria for future coastal protection at the site. The nature of such protection, and of the strategy that should guide remediation, are issues yet to be decided (see paragraphs 7.45 and 7.46).

Conceptual model of the site and implications for remediation and long-term protection of the public

7.37 Much of the area between the modern shoreline and the 1949 coastline was filled with debris that contained radioactive sources, ash and clinker. Some of the infill was artificially deposited directly on to beaches or adjacent land areas. In some areas marine action may have been an agent in the process of infilling, following transport of materials that were dumped on to the beach within the area now designated as the headland. However, even where marine action may have been involved, there was subsequent direct deposition of landfill materials to form a surface layer. The areas on which radium-contaminated materials were deposited by one agency or another extend from the rock outcrops on the coast immediately east of the New Harbour, across the interior of the headland, across the exposed beaches of the jetty area, around the point at the eastern extremity of the site and across the Mud (or Boatyard) bay, probably as far as the point marked X on Figure 4.1.

7.38 Erosion by waves has trimmed the seaward edges of the original landfilled area, causing the high-tide waterline to recede landwards, probably by a distance of several metres in places. Material removed by waves has been deposited lower down in the area exposed at low tide, the net effect being the creation of a pebble and coarse sand beach with a profile that in some places has its upper part bevelled across radium-contaminated made ground, but in other places across made ground that lacks radium contamination. This concept is illustrated in profile in Figure 7.2.

7.39 It follows from this, and from the profiles in Figures 7.6 and 7.7, that radium-contaminated material is likely to be present on beaches as a veneer of reworked beach sediments less than a metre thick which in places overlies radium-contaminated material that variously represents undisturbed landfill, former beach sediments containing large amounts of ash and clinker that were dumped on to the beach, or reworked materials from the hook-shaped feature visible in Mud bay in 1955. Waves will disturb this veneer to varying depths depending on their direction, energy and height. Large waves coming on to a beach will tend to remove material from the upper part and deposit it further down. Storms cause erosion of the upper beach and an episodic, but progressive, erosion of the land's edge. Thus, over time the whole beach system probably increases in width at the expense of the land. Undisturbed made ground to landward of the present coastline has a volume of several thousand cubic metres and is a reservoir of contamination that in the long term is vulnerable to erosion by marine action. Such erosion would spread the contamination on to beaches and shorelines and into the marine environment, in the same manner as has already occurred.

7.40 The disturbance and reworking of the beach materials from time to time exposes radioactive sources at the surface, or deposits them at shallow depth where they can be detected. It is an established fact that if such sources are removed they are eventually replaced by new sources. This repopulation of the near-surface occurs when:

(a) Waves of all sizes and frequencies of occurrence rework the veneer of beach material and bring new sources to the surface

(b) Larger storms excavate into previously the deeper layers of undisturbed radium-contaminated material either beneath the beach veneer or at the edge of the land

7.41 Parts of the coastline have been armoured with large rocks as an attempt to slow down the erosion of the land's edge. Waves may excavate finer materials from between these, and cavities have been detected in the area of landfill in front of the clubhouse of the Dalgety Bay Sailing Club that may be due to this process. Radioactive sources within the landfill materials behind the armour may thus be transported on to the beach in front of it.

7.42 Once a radioactive source has been incorporated into the beach sediments, it may be periodically buried and exposed, and then reburied and re-exposed, unless eventually detected and removed. Some sources may break up into finer particles. On the beaches north of Ross Plantation the sediments become finer westwards from the point marked X on Figure 4.1 towards the inner corner of the main bay. The more westerly part of this section of coast was not landfilled, but radioactive sources have been found in the sediments of the upper beach there. These probably result from transport along the coast of the finer fractions of the sediments that have been eroded from the landfill-backed beaches near the headland. These finer sediments have been added to the beach profiles of the inner parts of the bay.

7.43 All of these natural geomorphological processes are certain to continue into the future. Waves will continue to rework existing beaches, bringing radioactive sources to the surface from time to time. Larger storms will sometimes excavate down into the sub-beach landfill material, or eat laterally into the land at the top of the beaches. Even on the armoured sections of coast, erosion by waves may continue to remove material from behind the armour. Finer sediment will be winnowed and added to beach profiles on the more sheltered coast in the inner bay. These processes may proceed episodically and fitfully; erosion on parts of the coast may even be replaced by deposition for periods of time. But the overall trend almost certainly will be that the landfill will be relentlessly eroded in the long term. As it is already known to contain numerous radioactive sources, these will eventually be added to those already on beaches, and over time they may become dispersed over a wider area than at present. Corrosion and attrition of sources exposed to the waves will reduce their average size in the long term, and this will lead to greater transport and dispersal, as well as creating a future supply of radioactive sources small enough to be ingested should members of the public and users of the headland come into close proximity with them.

7.44 The circumstances at Dalgety Bay exactly match those identified by Baker and Toque (2005) as most likely to lead to migration of radium contamination, in all respects except one. Unvegetated surface deposits of luminising ash have been, and continue to be, exposed to erosion by surface waters and subsequent transport by moving water. The only mismatch between the circumstances envisaged by Baker and Toque and those at Dalgety Bay is that the surface water concerned is the sea, rather than rainfall or streams. Of these three agents, the sea is the most powerful and persistent.

Implications for remediation strategies

7.45 The present distribution of contamination and the near certainty that the processes of erosion and re-deposition that have operated in the past will continue to spread the radioactive contamination if nothing is done, both have important implications for the design of remedial actions. Strategies for intervention are likely to fit into one of five generic categories:

(a) Do nothing apart from placing notices asking members of the public to take precautions by not entering certain areas, not digging, etc

(b) Option (a) above plus continue to monitor beaches and land and remove sources as they are detected

(c) Attempt to remove the source of the contamination. Ultimately, this is the undisturbed landfill material that is present beneath land areas and beaches

(d) Impose barriers to migration of the sources to the beach veneer. A particular drawback to this option is that parts of the contaminated materials may be left on the seaward side of the barrier, and might have to be removed

(e) Create engineered structures such as breakwaters off shore with the aim of reducing incident wave energy below that required for further erosion and transport. It is highly likely, however, that such an approach would carry much greater uncertainty in its design and performance than either option (c) or (d), although in principle it could be combined with either of these

7.46 Strategies (a) and (b) do not address the root of the problem, but seek merely to manage (ie reduce) the risk to the public, either by modifying their behaviour or by keeping down the numbers of sources that might be encountered. Both strategies have a time dimension because they would have to continue for as long as the occurrence of sources on beaches persisted. It should be recognised that the overall risk of at least one member of the public experiencing harm depends on how long the situation lasts. The overall cost of strategies such as (b) that involve continued active management of the situation indefinitely will also depend on how long the situation persists. Paragraph 7.43 makes clear that this may be assumed to be without end in the foreseeable future unless remedial action is taken.

7.47 Strategies (c) and (d) and, to some extent, (e) are more radical, engineered solutions to the problems presented by the current situation. Strategy (c) involves complete removal of the contaminated materials that underlie the land area as well as those that are beneath beaches. Wholesale removal of buried contamination from land areas would be disruptive and would not greatly decrease the risks to users or to the general public, if there were to be no excavation within the contaminated areas. This factor makes strategy (d) appear attractive. However, an engineered barrier just landward of the present coastline would not enclose the contaminated made ground deposits that lie beneath the beaches. These would then form a reservoir of contaminated materials that could perpetuate the problem. If a 'hard' barrier were to contain the entire extent of the contamination it would have to be built between 25 and 50 m offshore, and would have to resist marine erosion indefinitely. An alternative that was simpler to implement would be to remove any contaminated material that lay to seaward of an engineered barrier. As this would most likely involve removal of the beach down to its original natural surface prior to contamination, it would be essential to replace it with a suitably stable profile of uncontaminated materials. Failure to do so would be to invite marine erosion of the engineered barrier where it was unprotected because of the removal of the beach. Precise design of an engineered barrier and stable artificial beach profile would require further study and modelling of the site and its surroundings. Such study would be essential also if strategy (e) was adopted, on its own or in conjunction with (c) or (d). Though off-shore breakwaters might conceivably remove enough energy from the largest storm waves to prevent ongoing migration of the present coastline towards the land, this would be difficult to achieve with certainty. It is most unlikely that breakwaters could prevent reworking of beach materials and transport of exposed material along the shore, so the presently contaminated beaches would continue to act as a reservoir for the future supply of radioactive sources that might spread beyond the bounds of the present site. No matter which combination of strategies (c), (d) or (e) might ultimately be adopted, it is most important to understand that failure to take action to produce and implement an engineered solution will simply prolong the present situation and its attendant risks to the public, while also incurring ongoing costs for an indefinite period into the future.

CHAPTER 8

IMPLICATIONS FOR OTHER SITES

8.1 It is known that there are several other sites potentially contaminated with luminising residues, some of which have been remediated.

8.2 Experience from previous remediation actions and the work reported above can be used to establish a set of principles for dealing with such sites.

8.3 If records are available, the potential amount of radium contamination and its form can be established. Of particular importance is whether luminising activities were carried out on the site, in which case it is possible that raw paint residues of potentially high radioactive content could be encountered.

8.4 In accordance with the recommendation of the COMARE Contaminations Working Group, surveys of the area should be carried out using a detector system with a detection limit of, or better than, 20 kBq of radium to a depth of 100 mm with a 95% probability of detection.

8.5 If radium contamination is detected, it should be established whether this is on or near the surface or is buried at depth. If the latter, a further consideration will be whether or not the site could be subject to erosion (as at Dalgety Bay) which could lead to unpredictable source exposure. Sites found to contain surface contamination or to be subject to erosion should be given priority.

8.6 Even if contamination is found to be present on a particular site, there may be no need for further action provided that it is present in a form for which there is no plausible exposure pathway for a member of the public. As an example, a concrete-covered, deeply buried cache whose extent is well defined, and for which planning constraints to prevent excavation or building are in place, would not give rise to concern.

8.7 Where there are credible pathways for exposure, the associated risks and hazards should be assessed and a judgement made of the necessity for further investigation and/or remediation. Radon measurements should be made if radium contamination is suspected to lie beneath, or in close proximity to, buildings.

8.8 Should the circumstances make it appropriate, epidemiological studies of the locality should be instituted; particular attention should be paid to bone cancers.

CHAPTER 9

CONCLUSIONS

9.1 At present, there does not seem to be any comprehensive list available of sites in the UK potentially contaminated with radium. COMARE deems this to be unacceptable as it implies an unknown risk to the general population. There are instances (apparently including Dalgety Bay) where no records have been passed to purchasers of contaminated sites.

9.2 The radioactive contamination at Dalgety Bay appears to have arisen as a result of the luminising works carried out at RNAS Donibristle and/or the destruction of radioactive aircraft instruments on the site.

9.3 Despite a letter suggesting that over 800 aircraft were dismantled on the site in 1946 alone (Wright, 1990), no records of the amount of radioactivity brought on to the site are available. It is not possible, therefore, to determine the radioactivity remaining or to estimate the longevity or magnitude of the associated hazard.

9.4 Monthly monitoring of the foreshore area to specific criteria (paragraph 4.26) has been in place since 2012 and is carried out by contractors on behalf of the MoD. Given that source repopulation occurs (paragraph 4.21), the monitoring and recovery programme is not preventing an encounter, but is lowering the possibility that such an encounter will occur. This is further compounded by the fact that the MoD contractor cannot achieve the required limit of detection with current equipment on part of the beach as the local background is too high for the technique used (ie lower activity sources may not be detected and, hence, not removed). It is likely also that compliance with the advice given in signage, etc, will reduce in the coming years and this will result in an increase in the probability of an encounter. The monitoring programme covers a fixed area, but it could be expected that, as in the past, the contaminated area may spread outside that currently delineated. For these reasons, the monitoring and removal programme could be argued not to be consistent with the principle that radiation doses should be kept as low as reasonably achievable (ALARA) in the medium and longer term.

9.5 The current monitoring programme occupies three weeks each month, requiring both capital equipment and staffing. There are associated costs for storage and disposal of the sources found because the Radioactive Substances Act 1993 (UK Parliament, 1993a,b) restricts the disposal of such sources to unauthorised landfill sites to a maximum activity of 40 kBq per item. In addition, there are socioeconomic costs that the continuing presence of signage and monitoring teams is having on the local community. Thus the programme is deemed not to be cost effective or sustainable in the longer term.

9.6 The undisturbed made ground to landward of the present coastline identified by the intrusive investigations has a volume of several thousand cubic metres and is a reservoir of contamination that in the long term is vulnerable to erosion by marine action.

9.7 The combination of soil erosion by surface water and erosion of coastal land by the sea results in a dynamic and changing environment for the release of radioactive sources. Without remediation it could be expected that this erosion will continue in the long term and may result in a wider dispersion of sources.

9.8 Importantly, because of the heterogeneity of the radium contamination in terms of activity, solubility, size and distribution of sources within the made ground, a retrospective risk assessment based solely on previous surface finds may not provide a suitable indication of future risks. This was clearly demonstrated in 2011 when many more sources, some with far greater activity than had previously been known, were found on the beach at Dalgety Bay.

9.9 Based on concordant data from SEPA, the University of Stirling and Public Health England, taken in conjunction with data from the habits survey, it is concluded that the sources present at Dalgety Bay pose a potential risk to public health in terms of committed effective dose estimates.

9.10 Further work is necessary to determine the significance of such a risk resulting from skin contact, particularly for young children.

9.11 It is unlikely that there is a current significant risk posed by airborne contamination.

9.12 There does not appear to be a current risk from external radiation exposure. Periodic (eg biennial) confirmatory monitoring should be carried out.

9.13 It is very unlikely that the excess cases of liver cancer or of NHL during 2000–2009, or of NMSC during 1975–2002, are due to the presence of radium-226 in the area.

9.14 There are three main options for remediation – removal, containment or a combination of these. In the past, for the terrestrial contamination found at Dalgety Bay, removal has been the option of choice. The current contamination, however, is more widespread and is not fixed. COMARE tends to the view that a combination of methods may be the most effective solution, but this should be subject to an evaluation process, with the required endpoint being set by the regulator.

CHAPTER 10

RECOMMENDATIONS

Recommendation 1

Given the dynamic nature of the contamination, the indefinite continuation of a monitoring and recovery programme allied to demarcation of affected areas is not regarded as best practice and may well not be in compliance with ALARA; it would be undesirable also on economic grounds. We therefore recommend that the present monitoring and recovery programme being carried out by the MoD at Dalgety Bay should continue in the interim only until remediation can be undertaken, with the coverage and frequency to be determined by the regulator. The monitoring and recovery programme should be carried out to at least the standard specified by the COMARE Contaminations Working Group.

Recommendation 2

Given the long half-life of radium-226, the dynamic nature of the contamination, the number and activity of the sources being found, and the unknown quantity of radium remaining, we recommend that the Scottish Government should take steps to ensure that effective remediation of the affected area is undertaken as soon as is possible.

Recommendation 3

We recommend also that, in conjunction with all stakeholders, an evaluation of the means of remediation should be instituted immediately, considering efficacy, practicability and cost.

Recommendation 4

In the interim period, since the area found to be contaminated with ash is extensive, parents should be recommended not to allow their children to dig. We recommend that this should be added to the warning signs.

Recommendation 5

We acknowledge that the circumstances relevant to risk change over time and that periodic reviews should be undertaken. We recommend that these should include periodic re-monitoring of the external gamma dose rate of the affected areas and that a review of the epidemiological survey of cancer rates in the area should be carried out in five to ten years' time to allow for a latent period following the recent potential exposure to large numbers of sources.

Recommendation 6

We should seek authority from government and the devolved administrations to require information from appropriate bodies to create a UK-wide list of sites which are known to have been, or thought to be potentially, contaminated with radium. This should incorporate details of any monitoring and/or remediation known to have been carried out. The information available for each site should be evaluated and, where deemed necessary, investigation and/or remediation instituted.

Recommendation 7

We recommend that an accredited, UK-based measurement capability for the absolute quantification of high activity sources should be established.

Recommendation 8

In the course of our investigations, it has become clear that further experimental work on skin doses should be undertaken. We recommend continued research into this issue, with particular reference to young children.

NOTE

During the prolonged delay between completion of the report and its publication, further work has been carried out by SEPA and the MoD. In particular, the MoD commissioned a report (AMEC, 2014) entitled Outline Management Options Appraisal Report. The Committee is pleased to note from this that the MoD conceptual site model has been updated along the lines of the model described in Chapter 7 and that the dynamic nature of the contamination caused by natural coastal processes has now been recognised.

Concerns have been raised by SEPA over the monitoring programme, which may lead to an upwards revision of the number of particles on the beach, while PHE is revising upwards its skin dose estimates.

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THE APPENDICES

APPENDIX A

GLOSSARY

ACCRETION	Increase in size – particularly of an area of land as a result of deposition of material from the sea
ALIENATED SITE	Area of land which was previously owned by, occupied by or the responsibility of the Ministry of Defence
BACKGROUND RADIATION	Radiation that comes from naturally occurring radioactive material in the ground and from cosmic rays irradiating the Earth from outer space. The UK average dose from natural background radiation is 2.2 mSv per year: regional averages range from 1.5–7.5 mSv per year
BECQUEREL (Bq)	Unit of radiation equal to one disintegration per second. Discharges are normally expressed in: megabecquerel (MBq) – one million Bq gigabecquerel (GBq) – one thousand million Bq terabecquerel (TBq) – one million million Bq
COMBUSTIBLE	Capable of being burnt
EPIDEMIOLOGY	Study of death or illness in a population and their relation to factors regarded as possible causes
EROSION	Removal of solid material on the coastline by the action of the sea
GRAY (Gy)	International (SI) unit of absorbed dose: one gray is equivalent to one joule of energy absorbed per kilogram of matter such as body tissue
HALF-LIFE	Time that a given quantity of radioactive substance takes to lose half its radioactivity through decay. It is a consequence of the independence of atomic disintegrations that this quantity does not depend on the initial quantity, leading to exponential decay
HAZARD	Property that in particular circumstances could lead to harm, eg exposure to radiation leading to damage to an individual's health
INCIDENCE	Number of instances of illness commencing, or of people falling ill, during a given period in a specified population. More generally, the number of new events, eg new cases of disease in a defined population, within a specified period of time. The term incidence is sometimes used to denote 'incidence rate', ie the number of cases divided by the (average) number at risk in the relevant time period
INFILL	Filling of existing spaces, eg with material deposited by the sea or placed to reinforce a barrier
INGESTION	Intake of food or drink into the body
INHALATION	Breathing in of vapours or gases

IONISING RADIATION	Radiation that is sufficiently energetic to remove electrons from atoms in its path. In human or animal exposures ionising radiation can result in the formation of highly reactive particles in the body which can cause damage to individual components of living cells and tissues
ISOTOPE	One of a number of alternative forms of a given chemical element with the same atomic number but different numbers of neutrons
LUMINISING	Making something luminous, particularly painting instruments with light-emitting paint
MADE GROUND	Land or ground created by filling in a low area with rubbish or other fill material
MEAN LOW WATER SPRING (MLWS)	Average height of low waters occurring at the time of the spring tides
NON-HODGKIN LYMPHOMA (NHL)	Group of lymphomas that differ in important ways from Hodgkin's lymphoma and are classified according to the microscopic appearance of the cancer cells. In children, NHL and leukaemias are often combined due to historical difficulties in making diagnostic distinctions
RADIATION	Emission and propagation of energy by means of rays or waves or subatomic particles
RADIOISOTOPE	Radionuclide that is also one of a number of isotopes of a given element
RADIONUCLIDE	Type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation (usually alpha, beta or gamma)
RAMSAR SITES	International important wetland sites, including some tidal waters, designated under the Ramsar Convention signed in Ramsar, Iran, in 1971
RELATIVE RISK (RR)	Ratio of the risk of disease or death among those exposed to a potential hazard to the risk among those not exposed to the hazard
RISK	Combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence *(See **HAZARD** and **RELATIVE RISK**)* Risk is sometimes taken to mean the probability that an event will occur, eg that an individual will become ill or die within a stated period of time or age. Risk is also used as a non-technical term encompassing a variety of measures of the probability of a (generally) unfavourable outcome
ROCK ARMOUR	Rocks and other material used to protect a shoreline from erosion, usually of an irregular form that dissipates the energy of the sea by permitting some permeability
SIEVERT (Sv)	International (SI) unit of effective dose obtained by weighting the equivalent dose in each tissue in the body with ICRP-recommended tissue weighting factors and summing over all tissues. Because the sievert is a large unit, effective dose is commonly expressed in millisievert (mSv) – ie one-thousandth of one sievert. The average annual radiation dose received by members of the public in the UK is around 2.7 mSv
STANDARDISED INCIDENCE RATIO (SIR)	Ratio of the actual number of cases in a study group or population to the expected number. The expected number is calculated using the age- and sex-specific incidence rates for a reference population. These 'reference rates' will often be those of the national population but may also be taken from a smaller area

APPENDIX B

REPORTS OF THE COMMITTEE ON MEDICAL ASPECTS OF RADIATION IN THE ENVIRONMENT

COMARE Fourteenth Report	Further consideration of the incidence of childhood leukaemia around nuclear power plants in Great Britain. HPA, Chilton, May 2011
COMARE Thirteenth Report	The health effects and risks arising from exposure to ultraviolet radiation from artificial tanning devices. HPA, Chilton, June 2009
COMARE Twelfth Report	The impact of personally initiated X-ray computed tomography scanning for the health assessment of asymptomatic individuals. HPA, Chilton, December 2007
COMARE Eleventh Report	The distribution of childhood leukaemia and other childhood cancer in Great Britain 1969–1993. HPA, Chilton, July 2006
COMARE Tenth Report	The incidence of childhood cancer around nuclear installations in Great Britain. HPA, Chilton, June 2005
COMARE Ninth Report	Advice to Government on the review of radiation risks from radioactive internal emitters carried out and published by the Committee Examining Radiation Risks of Internal Emitters (CERRIE). NRPB, Chilton, October 2004
COMARE Eighth Report	A review of pregnancy outcomes following preconceptional exposure to radiation. NRPB, Chilton, February 2004
COMARE Seventh Report	Parents occupationally exposed to radiation prior to the conception of their children. A review of the evidence concerning the incidence of cancer in their children. NRPB, Chilton, August 2002
COMARE and RWMAC* Joint Report	Radioactive contamination at a property in Seascale, Cumbria. NRPB, Chilton, June 1999
COMARE Sixth Report	A reconsideration of the possible health implications of the radioactive particles found in the general environment around the Dounreay nuclear establishment in the light of the work undertaken since 1995 to locate their source. NRPB, Chilton, March 1999
COMARE Fifth Report	The incidence of cancer and leukaemia in the area around the former Greenham Common Airbase. An investigation of a possible association with measured environmental radiation levels. NRPB, Chilton, March 1998
COMARE Fourth Report	The incidence of cancer and leukaemia in young people in the vicinity of the Sellafield site, West Cumbria: further studies and an update of the situation since the publication of the report of the Black Advisory Group in 1984. Department of Health, London, March 1996
COMARE and RWMAC* Joint Report	Potential health effects and possible sources of radioactive particles found in the vicinity of the Dounreay nuclear establishment. HMSO, London, May 1995

* Radioactive Waste Management Advisory Committee.

COMARE Third Report	Report on the incidence of childhood cancer in the West Berkshire and North Hampshire area, in which are situated the Atomic Weapons Research Establishment, Aldermaston and the Royal Ordnance Factory, Burghfield. HMSO, London, June 1989
COMARE Second Report	Investigation of the possible increased incidence of leukaemia in young people near the Dounreay nuclear establishment, Caithness, Scotland. HMSO, London, June 1988
COMARE First Report	The implications of the new data on the releases from Sellafield in the 1950s for the conclusions of the Report on the Investigation of the Possible Increased Incidence of Cancer in West Cumbria. HMSO, London, July 1986

APPENDIX C

COMMITTEE ON MEDICAL ASPECTS OF RADIATION IN THE ENVIRONMENT

CHAIRMAN

Professor A Elliott BA PhD DSc CPhys FInstP FIPEM
University of Glasgow

MEMBERS

Dr J Bithell BA MA DPhil
Childhood Cancer Research Group, Oxford

Dr P Darragh MD PhD MSc FRCP FFPHM
Public Health Agency for Northern Ireland, Belfast

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Professor P Hoskin
Mount Vernon Cancer Centre, Northwood

Dr B Howard MBE
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Professor P Marsden MSc PhD FSRP MIPEM MInstP CRadP
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Dr T Nunan MD FRCP FRCR
Nuclear Medicine Physician

Dr M Pearce BSc MSc PhD
Institute of Health and Society, Newcastle University, Newcastle upon Tyne

Mr I Robinson BSc CRadP FSRP FNucI
Consultant on Nuclear and Radiation Safety (formerly HM Superintending Inspector of Nuclear Installation, Office for Nuclear Regulation)

Professor R Taylor MA FRCPE FRCP FRCR
School of Medicine, Swansea University

Professor R Wakeford BSc PhD CSci CPhys FInstP CStat CEng MINucE CRadP FSRP
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Professor P Warwick BA MSc PhD DSc CChem FRSC
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Professor Catharine West BA PhD
University of Manchester

SECRETARIAT

Mr S Ebdon-Jackson BSc MSc FRCR HonFRCP (Scientific)

Dr E Petty BSc PhD (Scientific)

Dr K Broom BSc DPhil CBiol FSB (Scientific)

Ms K Stonell (Minutes)

Ms J Humphries (Administrative)

ASSESSORS IN ATTENDANCE REPRESENTING THE FOLLOWING ORGANISATIONS

Department for Education

Department for Communities and Local Government

Department of Energy and Climate Change

Department of the Environment, Food and Rural Affairs

Department of Health

Department of Health, Social Services and Public Safety (Northern Ireland)

Department for Innovation, Universities and Skills

Environment Agency

Food Standards Agency

Health and Safety Executive

Medical Research Council

Ministry of Defence

Nuclear Decommissioning Authority

Office for National Statistics

Public Health England

Public Health and Intelligence, NHS National Services Scotland

Scottish Environment Protection Agency

Scottish Government

Welsh Government

WRITING GROUP MEMBERSHIP

Professor A Elliott BA PhD DSc CPhys FInstP FIPEM
University of Glasgow

Professor T C Atkinson BSc PhD
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Dr J Bithell BA MA DPhil
Childhood Cancer Research Group, Oxford

Mr R Black MA
National Information and Intelligence, NHS National Services Scotland

Dr T Bruce BSc MSc PhD
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Dalton Nuclear Institute, University of Manchester

APPENDIX D

DECLARATION OF MEMBERS' INTERESTS CODE OF PRACTICE

1 Introduction

This code of practice guides members of COMARE as to the circumstances in which they should declare an interest in the course of the Committee's work. To avoid any public concern that commercial interests of members might affect their advice to Government, Ministers have decided that information on significant and relevant interests of members of its advisory committees should be on the public record. The advice of the Committee frequently relates to matters which are connected with the radiation industry generally and, less frequently, to commercial interests involving radioactivity. It is therefore essential that members should comply with the code of practice which is set out below.

2 Scope and definitions

This code applies to members of COMARE and its subcommittees, subgroups, working groups and working parties which may be formed.

For the purposes of this code of practice, the 'radiation industry' means:

(a) companies, partnerships or individuals who are involved with the manufacture, sale or supply of products processes or services which are the subject of the Committee's business. This will include nuclear power generation, the nuclear fuel reprocessing industry and associated isotope producing industries, both military and civil, and also medical service industries

(b) trade associations representing companies involved with such products

(c) companies, partnerships or individuals who are directly concerned with research or development in related areas

(d) interest groups or environmental organisations with a known interest in radiation matters

This excludes government departments, professional bodies, and international organisations and agencies.

It is recognised that an interest in a particular company or group may, because of the course of the Committee's work, become relevant when the member had no prior expectation this would be the case. In such cases, the member should declare that interest to the Chairman of the meeting and thereafter to the Secretariat.

In this code, 'the Department' means the Department of Health, and 'the Secretariat' means the secretariat of COMARE.

3 Different types of interest – definitions

The following is intended as a guide to the kinds of interests which should be declared. Where a member is uncertain as to whether an interest should be declared they should seek guidance from the Secretariat or, where it may concern a particular subject which is to be considered at a meeting, from the Chairman at that meeting. Members of the Committee and the Secretariat are under no obligation to search out links between one company and another, for example where a company with which a member is connected has a relevant interest of which the member is not aware and could not reasonably be expected to be aware.

If members have interests not specified in these notes but which they believe could be regarded as influencing their advice they should declare them to the Secretariat in writing and to the Chairman at the time the issue arises at a meeting.

3.1 *Personal interests*

A personal interest involves current payment to the member personally. The main examples are:

(a) *Consultancies and/or direct employment:* any consultancy, directorship, position in or work for the radiation industries which attracts regular or occasional payments in cash or kind.

(b) *Fee-paid work:* any work commissioned by those industries for which the member is paid in cash or kind.

(c) *Shareholdings:* any shareholding in or other beneficial interest in shares of those industries. This does not include shareholdings through unit trusts or similar arrangements where the member has no influence on financial management.

(d) *Membership or affiliation:* any membership role or affiliation that the member or close family member has to clubs or organisations with an interest or involvement in the work of the Department. This will not include professional bodies, organisations and societies.

3.2 *Non-personal interests*

A non-personal interest involves current payment which benefits a department to which a member is responsible, but is not received by the member personally. The main examples are:

(a) *Fellowships:* the holding of a fellowship endowed by the radiation industry.

(b) *Support by industry:* any payment, other support or sponsorship by the radiation industry which does not convey any pecuniary or material benefit to a member personally, but which does benefit their position or department, eg:

(i) a grant from a company for the running of a unit or department for which a member is responsible;

(ii) a grant or fellowship or other payment to sponsor a post or a member of staff in a unit or department for which a member is responsible. This does not include financial assistance for students, but does include work carried out by postgraduate students and non-scientific staff, including administrative and general support staff;

(iii) the commissioning of research or work by, or advice from, staff who work in a unit or department for which a member is responsible.

(c) *Support by charities and charitable consortia:* any payment, other support or sponsorship from these sources towards which the radiation industry has made a specific and readily identifiable contribution. This does not include unqualified support from the radiation industry towards the generality of the charitable resource.

(d) *Trusteeships:* where a member is trustee of a fund with investments in the radiation industry, the member may wish to consult the Secretariat about the form of declaration which would be appropriate.

3.3 *Specific interests*

A specific interest relates explicitly to the material, product, substance or application under consideration by the Committee.

A member must declare a personal, specific interest if they currently receive a payment, in any form, for any significant fundamental development work undertaken previously or at this time, on a material, product or substance or its application under consideration. This will include the production of radioactive substances and devices designed to use ionising or non-ionising radiation for diagnostic, treatment or other purposes.

A member must declare a non-personal, specific interest if they are aware that the department to which they are responsible currently receives payment for significant fundamental development work undertaken previously or at this time, on a material, product or substance or its application under consideration, but they have not personally received payment for that work in any form. This will include the production of radioactive substances and devices designed to use ionising or non-ionising radiation for diagnostic, treatment or other purposes.

3.4 *Non-specific interests*

A non-specific interest relates to a company or associated material, product, substance or application, but not to the specific material, product, substance or application under consideration by the Committee.

A member must declare a personal, non-specific interest if they have a current personal interest in a material, product, substance or application from a particular company, which does not relate specifically to the material, product, substance or application from the company under consideration.

A member must declare a non-personal, non-specific interest if they are aware that the department to which they are responsible is currently receiving payment from the company concerned which does not relate specifically to a material, product, substance or application under discussion.

If a member is aware that a material, product, substance or their application under consideration is or may become a competitor of a material, product or substance manufactured, sold or supplied by a company in which the member has a current personal interest, they should declare their interest in the company marketing the rival material, product or substance.

Members are under no obligation to seek out knowledge of such work done for or on behalf of the radiation industry within departments to which they are responsible if they would not reasonably expect to be informed. This applies to all non-personal, specific and non-specific interests.

4 Declaration of interests

4.1 *Declaration of interests to the Secretariat*

Members should inform the Secretariat in writing when they are appointed of their current personal and non-personal interests and annually in response to a Secretariat request. Only the name of the company (or other body) and the nature of the interest is required; the amount of any salary, fees, shareholding, grant, etc, need not be disclosed. An interest is *current* if the member has a continuing financial involvement with the industry, eg if they hold shares in a radiation company, have a consultancy contract, or if the member or the department to which they are responsible is in the process of carrying out work for the radiation industry. Members are asked to inform the Secretariat at the time of any change in their personal interests, and may be invited to complete a form of declaration when required. It would be sufficient if changes in non-personal interests are reported at the next annual declaration following the change. (Non-personal interests involving less than £5000 from a particular company in the previous year need not be declared.)

The register of interests should be kept up-to-date and be open to the public.

4.2 *Declaration of interests at meetings and participation by members*

Members are required to declare relevant interests at Committee meetings and to state whether they are personal or non-personal interests. The declaration should include an indication of the nature of the interest.

(a) If a member has a current (personal or non-personal) interest in the business under discussion, they will not automatically be debarred from contributing to the discussion subject to the Chairman's discretion. The Chairman will consider the nature of the business under discussion and of the interest declared (including whether it is personal or non-personal) in deciding whether it would be appropriate for the relevant member to participate in the item.

(b) If a member has an interest which is not current in the business under discussion, this need not be declared unless not to do so might be seen as concealing a relevant interest. The intention should always be that the Chairman and other members of the Committee are fully aware of relevant circumstances.

A member who is in any doubt as to whether they have an interest which should be declared, or whether to take part in the proceedings, should ask the Chairman for guidance. The Chairman has the power to determine whether or not a member with an interest shall take part in the proceedings.

If a member is aware that a matter under consideration is or may become a competitor of a product, process or service in which the member has a current personal interest, they should declare the interest in the company marketing the rival product. The member should seek the Chairman's guidance on whether to take part in the proceedings.

If the Chairman should declare a current interest of any kind, they should stand down from the chair for that item and the meeting should be conducted by the Deputy Chairman or other nominee if the Deputy Chairman is not there.

4.3 *Members' declarations of interests – 2013*

Member	Company	Personal interest	Company	Non-personal interest
Dr J Bithell		None		None
Dr P Darragh		None		None
Prof A Elliott		None		None
Prof W Evans		None		None
Prof S Hodgson		None		None
Prof P Hoskin		None		None
Dr B Howard		None		None
Prof M Kadhim		None		None
Prof S McKeown		None		None
Prof P Marsden		None		None
Dr G Maskell		None		None
Dr T Nunan		None		None
Dr M Pearce		None		None
Prof R Taylor		None		None
Mr I Robinson	AMEC	Consultancy		None
Prof R Wakeford	1 Sellafield Ltd	Consultancy		None
	2 Compensation Scheme for Radiation-linked Diseases	Consultancy		
	3 Canadian Nuclear Safety Commission	Contract		
	4 Augean	Contract		
Prof P Warwick	1 Enviras Ltd	Director and shareholder	NDA	Grants
	2 Sellafield Ltd/ Golder	Contract		
	3 NNL/LLWR Ltd	Consultancy		
Prof C West		None		None