DALGETY BAY
RADIUM CONTAMINATION

September 2011

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SCOTTISH ENVIRONMENT PROTECTION AGENCY

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1. Summary

Radioactive items have been detected on Dalgety Bay since at least 1990. Since 1990 many surveys have been undertaken on the beach to determine the potential numbers of items present and the possible implications for public health. In 2006, SEPA conducted a limited monitoring and recovery survey at Dalgety Bay to determine whether the contamination posed a realistic risk that should be quantified. The 2006 assessment showed a possibility of significant exposures to members of the public (Dale et al. 2008) which warranted consideration of interventions to protect the public and resulted in the erection of signs at a number of locations. In 2008, SEPA again conducted a further monitoring and recovery survey, combined with comprehensive laboratory analysis of a selection of recovered items. The 2009 assessment resulted in a change to the signage and a monitoring and recovery programme by the Defence Estates[1] which completed its agreed programme of work in 2010. The 2009 report also confirmed that of the approximately 3 km of coastline at Dalgety Bay an area of about 800m or 1/4 was the primary area of concern (for radioactive contamination) with the current focus of that being around the slipways.

Following the 2009 assessment the Defence Estates Agency undertook a series of monitoring and recovery exercises for point sources of radium which initially recovered 128 items. This work gave some level of protection to users of the beach area during the programme of work. The report on that work confirmed SEPAõs view that the beach repopulated within a few months and it was expected that round 100 sources could re-populate the beach each year (Defence Estates, 2010). As this programme is now completed, and plans for further monitoring are being developed[2] SEPA may again need to consider whether the level of hazards present at Dalgety Bay require further actions than simply the presence of signage. The data presented in this report, together with data from previous SEPA reports provides the information upon which SEPA can make an informed decision.

This assessment has been developed primarily to provide information on the potential doses which could result if a point source were to be ingested and to allow SEPA to consider whether some areas of Dalgety Bay have radioactive sources which could deliver doses to users of the area in excess of those specified in the guidance issued to SEPA on Radioactive Contaminated Land (RCL). It is currently not possible to provide a robust risk assessment for Dalgety Bay as several key pieces of information have not been quantified. If this were to be undertaken it would require more information than is available at present e.g. information on public habits, detection effectiveness and the characterisation (e.g. particle dimensions) of a much greater number of the sources recovered. Obtaining this information would be costly in both of time and resources. However, SEPAõs 2006 report gives some initial estimates of the chance of encountering a particle in 2006 for the reportedly most frequently used area of the beach. Therefore,

[1] Defence Estates Agency (DE) manages the military estate, including accommodation for Service personnel and their families, on behalf of the Ministry of Defence (MOD). On 1 April 2011, Defence Estates Agency merged with other MoD departments to become the Defence Infrastructure Organisation (DIO)

[2] SEPA is aware that Defence Estates has committed to a further three years of monitoring and recovery at Dalgety Bay, however detailed plans are not yet available and SEPA remain in discussions with DE

this report has not been developed to provide a full risk assessment at Dalgety Bay from the radioactive contamination.

Overall, the work undertaken by Defence Estates during 2009-2010 reports that the number and likely activity[3] of point sources remained comparable to that reported in SEPA's 2006 and 2009 assessments. The sources recovered by the Defence Estates were highly heterogeneous often with localised points of radioactivity amongst a large matrix of inert material. On analysis in a laboratory, a number of the single sources were actually a number of smaller pieces which could have consequences for exposure pathways and can lead to discrepancies if these two data sets are directly compared.

Defence Estates surveys at Dalgety Bay have shown a re-population of the inter-tidal area within a few months following any removal programme. In the SEPA survey conducted in 2008, it was reported that the slipway area had begun to re-populate within three days, indicating a potentially rapid re-population of that area.

With regard to the hazard that the point sources could pose, two potential pathways have been considered, *viz*. skin contact and ingestion, both of which have historically been assumed to be *via* inadvertent exposures. However, in 2011 SEPA was informed of the potential for selection of items on the beach which could be radioactive e.g. dials, and that there is a practice for the deliberate removal of material from beaches as a memoir. These pathways would significantly increase the potential for exposures to occur.

Skin Doses

The potential range of skin doses is dependent upon the activity of the source, shielding between source and skin, and skin area and thickness. Since SEPA's 2009 report, SEPA has undertaken a detailed assessment the external dose rates on a range of Dalgety Bay particles recovered in 2008. Consistent with the conclusions and recommendations of that report comparisons of dose rates have been drawn to those more recently recovered by the Defence Estates. This report is available on our website www.sepa.org.uk. In summary, the report details that external dose rates do not pose a significant hazard to health with short exposure times. However, these relatively low external dose rates means that the radioactivity is largely trapped within the source itself, which would result in potentially greater committed effective doses if these were to be ingested than if the skin dose rate were greater. With the information currently available to SEPA, SEPA does not consider that the dose rate would be in excess of those values for skin doses prescribed in the guidance issued to SEPA by the Scottish Government for Radioactive Contaminated Land. This pathway will not be considered further unless new information becomes available.

Ingestion Doses

In relation to the risks from ingestion, unlike earlier work conducted to determine the potential solubility of a source should it be ingested, and following the recommendation in our 2009 report. a leaching experiment was undertaken using a more representative gut solution than that undertaken in earlier studies. In total 10 sources were tested to determine the range of solubility should such a source be ingested. The results for the 2010 study have shown that the solubility (up to 25%) was greater than that reported

[3] Defence Estates reported activity in terms of counts per second rather than Bq. It has been shown (SEPA, 2006) that this may be unreliable in the field as a measure of true activity.

previously (up to 15%) by SEPA for the more basic acid solution tests conducted in 2006 and 2009. This may be due to the use of a more realistic gut solution or simply due to the high heterogeneity of sources. For those point sources subjected to this leaching work, the committed effective doses to a 3-month old infant could have been around 128 mSv. In 2006 and 2009, a more basic leaching experiment indicated that the committed effective dose from a point source could be in the order of 240 mSv, there is a possibility that if the greater solubility found in 2010 was attributable to the gut solution then the doses calculated in 2006 and 2009 were an underestimate of the true value. The potential doses which could be received by young children if they were to ingest a source at Dalgety Bay remain significant.

Longevity

The radionuclides of concern at Dalgety Bay is radium-226 and its daughters. Radium-226, has a half-life of 1600 years thus radioactive decay is unlikely to have any significant effect on the total activity for centuries. As the Defence Estates work reports around 100 sources are expected to re-populate the beach each year which is consistent with the number of sources found on earlier surveys and indicates that without intervention, significant radiation hazards will continue to be present at Dalgety Bay for many years to come[4]. A programme of monitoring and removal will mitigate the potential for the public to encounter a source, however it does not have a direct effect on reducing the hazard from sources re-populating the beach if one were to be encountered.

To date, the primary focus of the beach monitoring and recovery work has been to remove radioactive sources present on the beach. As part of the Defence Estates intrusive survey, work was undertaken within the beach to remove sources buried at depth which was considered to be one possible source of the particles. However, the number of sources recovered by Defence Estates means that it was unlikely that the beach itself (at that time) was the primary source of the contamination, thus, if there is to be closure of the issue there is a need to determine and isolate the source(s) of the contamination such that over time the numbers and activities of sources re-populating the beach fall to a level which does not present a significant risk to the public. Such a programme may provide the optimum strategy for management of the contamination in the medium to long term and it is recommended that further work is undertaken to try and locate and then isolate the source of the contamination which may allow monitoring to cease in the future rather than persisting with any long term programme of monitoring and recovery at Dalgety Bay.

[4] As the source is finite, a programme of monitoring and removal must reduce the source over time. It is important to note that the break down of physically large radioactive sources in the local environment may increase the radiological hazards due to the radioactivity not being homogenously distributed throughout a source and the physically smaller source being more easily ingested.

2. Scope and Purpose

This report was developed by SEPA in accordance with SEPA's duties under The Radioactive Contaminated Land (Scotland) Regulations 2007 (RCL Regulations) and the associated Statutory Guidance. The radioactively contaminated land regime allows, in situations of lasting exposure to radiation or where there is a significant possibility of such exposure, for remediation to occur, (under circumstances where intervention is liable to be justified). In 2009, SEPA provided a report which detailed that there was a possibility of significant harm at Dalgety Bay (to a 3 month old child). Following this work Defence Estates undertook a programme of monitoring and recovery at Dalgety Bay which, coupled with the erection of new signs, provided in SEPA's view appropriate level of protection from the hazards present at Dalgety Bay at that time. However, since May 2010, this work programme has been completed. The Defence Estates report on the programme of work states that further particles will continue to be deposited on the beach at Dalgety Bay, thus SEPA needs to consider again, whether further actions are necessary at Dalgety Bay to provide an appropriate level of protection for the public.

The principal criteria for significant harm and the significant possibility of significant harm are set out below. Two types of exposure situations can be envisaged – where exposure conditions are almost certain to occur (a) general widespread contamination, i.e. homogeneous contamination, and (b) where they are uncertain to occur (such as localised hot spots, i.e. heterogeneous contamination). The SEPA 2009 report showed that it was unlikely that condition (a) would be met and thus this report only considers condition (b) hot spots or heterogeneous contamination.

2.1. Criteria for Radioactive Contaminated Land

In 2007, Radioactive Contaminated Land Regulations were introduced which gave SEPA a statutory duty for land contaminated with radioactive substances. The associated statuary guidance provides SEPA with specific criteria where SEPA should regard significant harm as being caused to human beings when lasting exposure gives rise to an individual dose exceeding one or more of the following:

Homogeneous contamination

(a) An effective dose of 3 millisieverts per annum;
(b) An equivalent dose to the lens of the eye of 15 millisieverts per annum;
(c) An equivalent dose to the skin of 50 millisieverts per annum.

SEPA should regard significant harm as being caused to non-human species when lasting exposure gives rise to dose rates that exceed one or more of the following:

(a) 40 µGy hr^{-1} to terrestrial biota or plants;
(b) 400 µGy hr^{-1} to aquatic biota or plants.

In assessing doses to non-human species SEPA will take account of the most up-to-date methodology.

Heterogeneous contamination

In cases of lasting exposure when radiation exposure is not certain to occur the probability of radiation dose being received needs to be taken into account. In the following paragraphs õpotential annual equivalent doseö and õpotential annual effective doseö are doses that are not certain to occur.

Where:
(a) the potential total effective dose is less than 3 mSv; and
(b) the potential equivalent dose to the lens of the eye is less than 15 mSv; and
(c) the potential equivalent dose is less than 50 mSv

SEPA should not regard the possibility of significant harm as significant, irrespective of the probability of radiation dose being received.

Where:

(d) the potential total effective dose is greater than 100 mSv; or
(e) contact with contamination would result in a dose to the skin greater than 10 Gy in 1 hour;

SEPA shall regard the possibility of significant harm as significant, irrespective of the probability of radiation dose being received.

If the conditions in (a) to (e) are not met, the probability of radiation dose being received needs to be taken into account. SEPA shall regard the possibility of significant harm as significant where:

(a) the potential total effective dose multiplied by the probability of exposure is greater than 3 mSv; or
(b) the potential equivalent dose to the lens of the eye multiplied by the probability of exposure is greater than 15 mSv; or
(c) the potential equivalent dose to the skin multiplied by the probability of exposure is greater than 50 mSv.

In order to provide the data necessary to allow SEPA to make an informed judgement on whether areas of Dalgety Bay should be considered as Radioactive Contaminated Land as defined in the Statutory Guidance, information was needed on:

1. The doses likely to occur.
2. Where radiation exposure is not certain to occur, the probability of such an occurrence.
3. The doses of lasting exposure when radiation exposure is not certain to occur.

2.2. Designation as Radioactive Contaminated Land

Irrespective of whether the information in this or other reports suggests that any of the various criteria are exceeded or otherwise, this does not mean that the land must be designated as RCL, as SEPA needs to consider whether sufficient management arrangements are in place prior to determining whether land should be designated as radioactive contaminated land.

2.3. Site Prioritisation

In 2008, following the issue of the Statutory Guidance for radioactive contamination land legislation, SEPA prioritised Dalgety Bay for assessment over other potential sites due to the: high hazards historically detected on the beach; relatively high numbers of radioactive sources recovered; absence of any detectable decline in the numbers of particles detected on the beach over time; lack of management arrangements and; lack of detailed knowledge about the contamination.

This assessment was undertaken in view of the historic information indicating the presence of a significant hazard from radioactive contamination at this site and the continued presence of high numbers of people using the area.

Following the SEPA 2009 assessment, prior to SEPA finalising its view on whether parts of Dalgety Bay should be designated as radioactive contaminated land, Defence Estates committed to undertake a programme of monitoring and recovery of radioactive sources on the beach area at Dalgety Bay. This also included intrusive work to determine whether the source of the contamination was buried at depth within the beach. SEPA welcomed this approach and believed that such a programme of monitoring and recovery work coupled with the presence of signs represented appropriate management arrangements at Dalgety Bay and therefore negated the need for SEPA to consider designation at that time. However, that programme has now been completed, and although Defence Estates has committed to some work over the next three years SEPA needs to re-consider whether the radiological hazards at Dalgety Bay remain at a level where significant exposures could occur and consideration of intervention is justified (Dale et al. 2008).

3. Background

3.1. Site Location and General Description

Dalgety Bay is located on the north side of the Firth of Forth in Fife, about 5 km east of the Forth bridge (Grid Reference NT 165 833). The nearest community is a 1960's housing development, which is also called Dalgety Bay.

Dalgety Bay is a part of the Firth of Forth Special Site of Scientific Interest (SSSI) and also part of the Firth of Forth RAMSAR sites.

The bay is approximately 400m wide by 500m. At low tide the bay is exposed and reveals extensive mud flat habitat, interspersed with rocky outcrops. Along the southern margin of the bay is a pebble and shingle beach on which there is a general collection of debris, including building materials (bricks and fragments of suspected asbestos sheeting), clinker, broken glass, pieces of broken plates, porcelain and general litter (Meehan, 2003). A foot path follows the bay round to the remains of St. Bridget's Church. Behind the western side of the mudflats is a wooded area (Ross Plantation) with grass, trees, shrubs and a network of paths. South east of this area, near the headland, is Dalgety Bay Sailing Club, which has a clubhouse and slipways for launching boats. There is a boat park for several dozen boats and a car park; the latter used by both Sailing Club members and the general public. Close by there is also an Inshore Rescue Boat station. Beyond the headland (heading south west) there is the New Harbour and the Pier of St David's Bay, with another slipway for launching boats. The entire area is open to the public and is a favoured location for dog walking and for children to play (Heaton, 1996), although it is noted that the intertidal area is privately owned.

Main features of the bay

- Includes site of Donibristle ï New Harbour area
- Made ground ï rock armour emplacement
- Slipways
- Boat storage area
- Mudflats ï pipeline, coastal path, St. Bridget's Kirk, old landfills

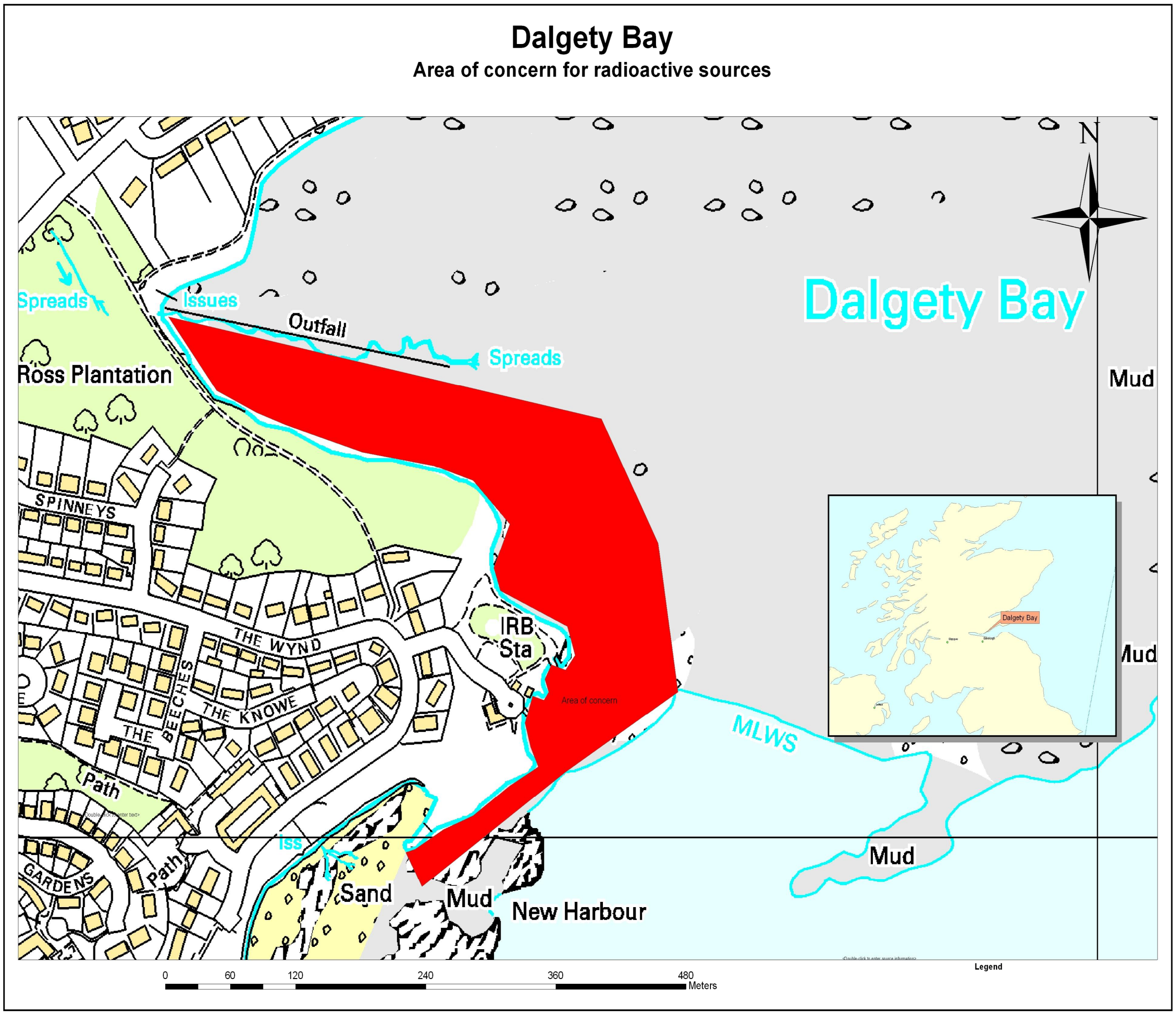

Figure 1: Dalgety Bay & main area of concern (an area of around 2.5 hectares)

3.2. Summary of previous surveys, 1997-2008

A brief summary of previous monitoring activities, conducted for SEPA is detailed in our 2006 report. Table 1 details the items recovered by SEPA surveys using different types of monitoring equipment during the period 1997 ï 2008:

Table 1 Summary of previous surveys by SEPA

Year	Area Covered (hectares)	Items identified	Notes
2008	5	39	Point source activity up to 0.87 MBq radium activity
2006	1.1	37	2.2 MBq, 1,227 g total waste
2005	1.75	97	Range 30 ï 2,350 cps (background 50-55 cps). Same area approx as 2002
2002	1.75	93	
2000	1.6	80	Range 50 -11,000 cps, 15,000 at slipway (75 cps background)
1998	3	11	Not including slipways (pipeline area)
1997	8	120	Large area, including area near pipeline

3.3. 2006 and 2009 Assessment

The 2006 and 2009 assessments did not attempt to determine the source of the contamination, however, in undertaking the assessment and reviewing available information, SEPA has not identified any other potential source of radium other than the previous Ministry of Defence (MoD) site. In 2010, SEPA requested information from the MoD on their previous activities during the MoD occupation of land at Dalgety Bay to determine if any further information had come to light since 2008. SEPA has been invited by MoD (Defence Estates) to view its available information on the site.

3.4. Signage and Current Interventions

The 2009 assessment concluded that the signs present at that time did not provide meaningful information to the public as an intervention measure. A change in the wording, size and location of the signs was provided by SEPA in early 2009 following consultation with the Dalgety Bay Forum, these signs were made and erected by Defence Estates. Since this time SEPA have been informed that some visitors to the area walking the Fife coastal path have not seen the signs, however during a SEPA visit in February the signs were present to the inspector walking along the coastal path, although these may not be obvious for an individual whom is unaware of signs presence and is not consciously looking for the signs.

Images of the locations of signs, identified in February 2011, are shown in Figures 2 and 3. The current signs contain a large amount of text and may benefit from a simplification which may aid awareness to people walking along the coastal path.

The current text of the signs displayed at Dalgety Bay is as follows:

PUBLIC NOTICE

Radioactive contamination has been found on this beach as indicated on the map.

This may pose a risk to public health through skin contact or inadvertent swallowing of contaminated items.

To minimise the risk, members of the public are advised:

Not to pick up or remove any materials from this beach. (including bait and seafood).

To wash their hands when leaving the beach.

Further information can be accessed via www.sepa.org.uk/radioactive_substances
www.livinginfife.scot.nhs.uk

Figures 2 and 3 show the current location of the signs in February 2011.

Figure 2: Photograph taken of Path close to Ross Plantation

Figure 3: Position of sign from Fife Coastal path near to Sailing Club

3.5. Defence Estates Work

From May 2009 to May 2010, Defence Estates contractors have undertaken a programme of monitoring and recovery at Dalgety Bay which has resulted in an (currently unquantifiable) reduction of the finite source of the contamination. The Defence Estateõs work included:

- Intrusive investigations of the beach sediments between the Jetty and slipways
- Sampling and trial trenching intrusive investigations of the beach sediments to either side of the slipway/jetty area
- Walkover survey of the coastal path
- Non intrusive repopulation monitoring surveys of the general slipways area

The full report on this work is available on the Defence Estates website (www.mod.uk/DefenceInternet/Microsite/DE), although the principal conclusions are reproduced below:

ñ*Six monitoring surveys, and three intrusive investigations, carried out by Entec (Defence Estates contractors) over the course of twelve months have found that radioactive point sources have been present at the Site, potentially partially derived from a bed of ashy material on the site. Following the thorough investigation of this ash horizon, and the removal of the detectable point sources encountered, recontamination of the beach continued, indicating that either the ash horizon was not the only potential host material, or that point sources continued to be present in the local environment and continued to re-contaminate the beach. Of the 128 point sources, 48 were recovered from intrusive investigations of the ash bed, 28 from clearance surveys of the beach and coastal path, and 51 from subsequent baseline and regular monitoring visits.*

The recovered point sources have been generally similar in physical form, size and activity as those recovered in previous surveys and investigations (SEPA, 2008).

The process of survey and investigation has resulted in the recovery of 128 radioactive point sources, and thus a net benefit, in terms of hazard term reduction, to the Site. However, the data do not indicate a reducing rate of hazard recurrence (or repopulation) at the site. Consequently, it could be argued that, without continued intervention, there will be a progressive increase in the number of point sources present on the beach over time, depending on the nature of specific depositional and erosional phases.ò

The full log of finds is available on the Defence Estates web site. However, for ease of reference, a truncated log of the sources recovered by Defence Estates is reproduced in Table 2.

Doses to the contractors were kept as low as reasonably achievable (socio economic factors taken into account) (ALARA), which meant that for the recovery phase the sources were not fully isolated from the surrounding matrix (as this would have increased exposures) as the primary purpose was to remove the hazard rather than provide information on the sources themselves.

Table 2 Details of sources recovered by Defence Estates contractor

DE I.D. No	De Field probe reading	Other information	DE I.D. No	DE Field probe reading	Other information
1	2250	maroon plastic artefact	43	998	ash sand and clinker
2	1120	Soil	44	4300	ash sand and clinker
3	2000	large clinker/metal artefact	45	103000	ash and clinker
4	4300	small clinker object and sand	46	13600	ash sand and clinker
5	2200	sand gravel and clinker	47	1300	ash sand and clinker
6	5500	sand ash and clinker	48	21000	ash sand and clinker
7	22000	sand gravel and clinker	49	1500	ash sand and clinker
8	7500	sand gravel and clinker	50	4050	ash sand and clinker
9	7300	sand gravel and clinker	51	4900	ashy gravel
10	1800	sand gravel and clinker	52	1700	ashy gravel
11	7300	piece of brick with clinker attached	53	4400	clinker lump
12	1400	5mm piece of clinker	54	1000	ashy gravel
13	1200	sand and gravel	55	4700	clinker piece
14	5100	sand and gravel	56	4300	ashy sand and gravel
15	2200	sand and gravel	57	4000	ashy clinker and gravel
16	2000	gravel and clinker	58	1400	ashy clinker and gravel
17	21700	ashy clinker	59	5950	clinker lump
18	2300	sand and gravel	60	3500	sandy rock
19	2300	ashy clinker	61	5500	gravel
20	3300	ashy clinker	62	1200	sand and mud
21	2250	large lump clinker	63	2000	sand and mud
22	4600	sand gravel and clinker	64	2000	sand and gravel
23	2600	wet clinker object	65	1700	sand and gravel
24	720	sand and gravel nothing obvious	66	12000	clinker piece
25	1900	sand and gravel	67	4800	sand and gravel
26	4900	two objects in sand	68	6500	gravel and clinker
27	6300	sand	69	65000	clinker piece
28	2900	sand and clinker	70	6600	ash clinker and gravel
29	4300	wet sand	71	2200	clinker
30	3200	wet sand	72	39000	clinker
31	2200	wet sand and shells	73	35000	clinker and gravel
32	916	clinker lump	74	5000	sand and gravel
33	1360	sand and ash	75	1500	ash and gravel
34	6300	sand ash and clinker	76	8200	clinker piece
35	3600	sand and ash	77	5150	clinker lump
36	3300	sand ash and clinker	78	11000	clinker piece
37	3600	ashy sand	79	56000	metal disc
38	1100	ashy sand and clinker	80	1900	ash and gravel
39	2200	ashy sand and clinker	81	8000	ash and gravel
40	2050	ashy sand and clinker	82	5900	clinker piece
41	6000	ashy sand and clinker	83	72000	ash
42	3800	ash and clinker	84	10000	ash
85	10000	clinker	107	2000	sand and gravel
86	12000	ash	108	1081	sand and gravel

DE I.D. No	De Field probe reading	Other information	DE I.D. No	De Field probe reading	Other information
87	10000	ash	109	16300	clinker piece
88	2005	piece of burnt metal	110	4260	sand and gravel
89	1600	pieces of clinker	111	4500	clinker and soil
90	5000	gravel and sand	112	1600	clinker piece
91	1100	clinker lump	113	2030	mud and gravel
92	5500	clinker pieces	114	8400	sand and fine gravel
93	10000	gravel and sand	115	2000	clinker lump
94	5000	clinker lump	116	2900	sand and gravel
95	2500	clinker piece	117	8900	clinker lump
96	3700	clinker lump	118	2600	mud and sand
97	2800	gravel	119	3900	sand
98	12400	gravel and sand	120	7600	gravel and sand
99	8300	clinker lump	121	2750	sand and gravel
100	11000	gravel and sand	122	1200	sand and gravel
101	800	gravel	123	2900	clinker piece
102	1700	gravel and sand	124	2800	sand and gravel
103	1200	clinker piece	125	2200	sand and gravel
104	3600	gravel and sand	126	6000	clinker piece
105	10000	gravel and sand	127	7000	sand and gravel
106	6060	sand and gravel	128	2000	sand and gravel

4. Source selection for assessment

To provide SEPA with the necessary information to make an informed view of the potential hazards to the public at Dalgety Bay, SEPA in co-operation with Defence Estates chose to undertake a characterisation of a sample of the point sources recovered by Defence Estates at Dalgety Bay over 2009 and 2010.

During the monitoring and recovery work undertaken by Defence Estates the primary focus was to remove the sources and not to provide further details on the physical characteristics of the sources themselves. Thus, following the principal of ALARA in order to reduce the dose to the workers recovering the sources from Dalgety Bay, sources were often recovered with surrounding sediment and were not fully isolated from the surrounding matrix.

SEPA planned to characterise a total of 30 sources from those recovered by Defence Estates of which 25 were to be selected to provide information on the potential hazard and up to five to provide information on the possible historical context. The only information available to SEPA for the selection of samples was an in-field probe reading and a general description of the samples. As previous SEPA work had indicated that visual inspection of a source within a surrounding matrix was not a reliable guide of the nature of the source itself, this could not be relied upon as a robust basis for sample selection. For the purpose of assessment it was assumed that a greater field measurement value would correspond to generally greater activity, although historically it had been shown that there was a poor relationship between in-field measurements and true source activity (SEPA, 2006).

A list of initially selected samples included around six from each of the four categories describing the sources (other than artefacts) - sand, gravel, clinker and a mix of the previous categories. Five samples were also initially allocated to provide historical information e.g. artefacts, as characterisation of these sources may provide information on the potential solubility of the original radium source, together with an assessment of the potential hazard should an individual choose to remove an artefact from the beach at Dalgety Bay.

For practical purposes, a reserve list (R) of samples was also developed to allow these to be selected should the initial samples be unavailable for any reason. Therefore, when samples were selected from the store (field selected) in the event that a sample was not available a suitable alternative had already been identified.

The samples selected and reserves are indicated in Table 3[5] together with those which were eventually taken for analysis (field selected) due to the non-availability of samples.

[5] It is unknown why some samples were at DSTL

Table 3 Particles selected for characterisation

DE I.D. No	DE Field probe reading	Other information	Initially Selected	Selected for historical reasons	selected for CED reasons	Field Selected (sent to Stirling University)	Notes
1	2250	maroon plastic artefact	Y	Y		Y	
4	4300	small clinker object and sand	Y	Y		Y	
7	22000	sand gravel and clinker	Y		Y	N	At DSTL
8	7500	sand gravel and clinker	Y		Y	Y	
17	21700	ashy clinker	Y		Y	Y	
26	4900	two objects in sand	Y	Y		N	At DSTL
27	6300	sand	Y		Y	Y	
45	103000	Ash and clinker	Y		Y	Y	
46	13600	ash sand and clinker	Y		Y	Y	
48	21000	ash sand and clinker	Y		Y	N	At DSTL
66	12000	clinker piece	Y		Y	Y	
69	65000	clinker piece	Y		Y	Y	
72	39000	Clinker	Y		Y	Y	
73	35000	clinker and gravel	Y		Y	Y	
78	11000	clinker piece	Y			Y	
79	56000	metal disc	Y	Y		Y	
81	8000	ash and gravel	Y		Y	Y	
83	72000	Ash	Y		Y	N	At DSTL
84	10000	Ash	Y		Y	Y	
86	12000	Ash	Y		Y	Y	
87	10000	Ash	Y		Y	Y	
88	2005	piece of burnt metal	Y	Y		Y	
93	10000	gravel and sand	Y		Y	Y	
98	12400	gravel and sand	Y		Y	Y	
100	11000	gravel and sand	Y		Y	Y	
105	10000	gravel and sand	Y		Y	Y	
109	16300	clinker piece	Y		Y	Y	
114	8400	sand and fine gravel	Y		Y	Y	
120	7600	gravel and sand	Y		Y	Y	
127	7000	sand and gravel	Y		Y	Y	
34	6300	Sand ash and clinker	R			N	At DSTL
68	6500	gravel and clinker	R			Y	
70	6600	ash clinker and gravel	R			Y	
11	7300	Piece of brick with clinker attached	R			N	
9	7300	sand gravel and clinker	R			Y	
76	8200	clinker piece	R				
99	8300	clinker lump	R				
117	8900	clinker lump	R				
126	6000	clinker piece	R				
41	6000	ashy sand and clinker	R				
106	6060	sand and gravel	R			Y	Replacement sandy gravel
85	10000	Clinker	R				

The sources selected from the store were sent to the University of Stirling to be fully isolated from the surrounding sediment which would allow the physical size and radioactivity measurements to be made. During this process Stirling University followed the ALARA concept to ensure doses were as low as reasonably achievable to achieve the objective of the work[6]. Following this initial size and activity characterisation, a further 10 samples were selected from these sources on the same basis as that outlined above to determine the potential hazard from those particles to human health.

[6] During the recovery phase the Defence Estates contractors did not have an objective of providing details e.g. size on the sources recovered. Thus they minimise the dose (ALARA) by not fully isolating the sources. For the Stirling University work, the objective of the work was to provide details on the physical size, thus doses were kept ALARA whilst providing the data to satisfy the objective.

5. Pathways of Exposure

5.1. Observations of habits

In 2009 SEPA reported that the area of Dalgety Bay from which sources have been recovered is used by bait diggers, sunbathers, dog walkers and horse riders. SEPA also responded to an enquiry relating to the regular visits of a class of nursery-school children to the area. Thus, we concluded, albeit from a short observation period, that the area is used by all age ranges undertaking a range of activities.

Since 2009, SEPA has been informed that ñthe foreshore in question has since the 1970's been actively used by members of the Sailing Club which has junior members and runs a youth week every year. In addition, young children with parents who are members of the Sailing Club constantly use the area during the sailing seasonò(Dalgety Bay Community Council Chairman, September, 2010). SEPA has also recently been informed that there is a practice for people to remove material from beaches they visit as a memoir of the visit, and that one individual whom removed material on two separate occasions after visiting the beach during a walk along the Fife coastal path and foreshore had not seen or been aware of the signs stating that people should not removal material from the beach. As two WW2 aircraft artifacts (Figure 4) recovered by Defense Estates were radioactive, these items could be attractive to adults or children using the beach wishing to obtain a memoir. Other radioactive artifacts have been recovered on earlier surveys. Exposures via these pathways are not inadvertent exposures as assessed in our 2006 and 2009 and would be difficult to assess without specific habits data and knowledge of the potential number of artifacts. Determination of probability of encounter for deliberate selection of contaminated items requires further study.

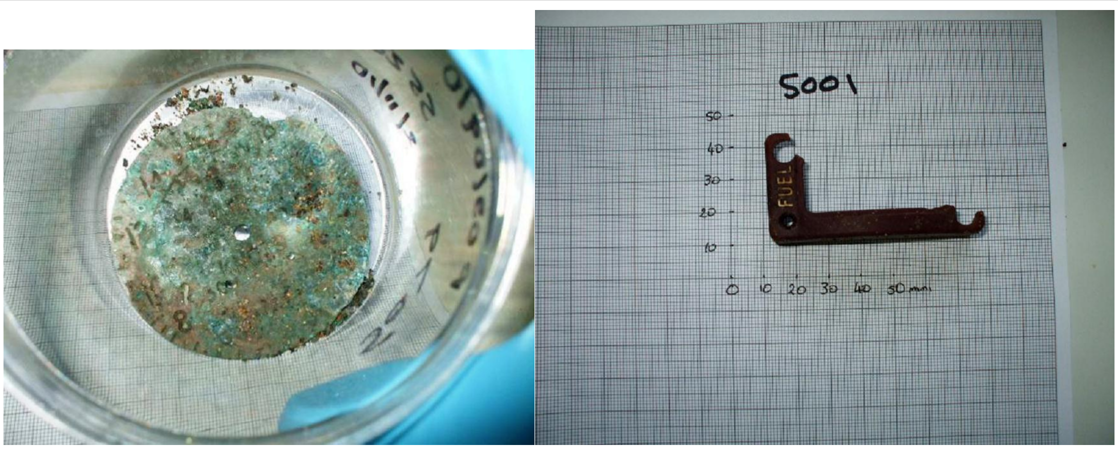

Figure 4 – Tachometer Gauge and Fuel Handle

5.2. Repopulation rates

Previous monitoring and recovery exercises at Dalgety Bay have indicated that within a year, contamination had returned to similar (re-populated) levels across the Dalgety Bay beach area (Table 1). In 2009 SEPA reported that over a small area some repopulation was occurring within a few days. The work undertaken by Defence Estates from 2008-2010 has confirmed that repopulation with a period of months continues to occur and has estimated by ñ*extrapolating the measured average recontamination rate to future years results in an overall quota of 100 new sources being deposited on the site each year*ò (Defence Estates 2010)

6. Analytical Results

6.1. Gamma-ray spectrometric analysis of point sources

Following selection, the 30 sources were sent to the University of Stirling for characterisation, which involved isolation of the radioactive source(s) from its surrounding sediment matrix and then assessment of the physical size and activity.

Point sources were analysed in a specifically calibrated gamma spectrometer to determine the activity of key radionuclides. Results for the 30 point sources are detailed in Table 4. All positively detected nuclides are reported. It is notable that, for the first time, together with other radionuclides the activity of ^{210}Pb is an accredited result.

Table 4 Particle dimensions and activities

Source ID	Min mm	Max mm	Ra 226	Pb 214	Bi 214	Pb 210
			ORIGINAL Particle Activity (Bq)			
06/10 grit			54	62	62	99
S001	9	71	11053	8646	8573	8422
S004	14	32	12050	13811	14892	4094
S008	11	13	18350	21306	21277	13266
S009	55	81	18123	23863	25810	5815
S017	18	23	51169	60384	63684	13531
S027	5.5	8	27888	30403	32036	24889
S045	25	40.5	694560	814610	818680	363070
S045 upside down			709870	825240	847110	405010
S045B	40	44	<20	<3.9	<4.4	32
S046	7	8.5	101940	113260	113010	93529
S046 upside down			95378	111090	112700	80565
S066	27	44	35082	40087	41549	17113
S068	37	55	19157	21355	22968	6643
S069	31	44	226030	252830	256000	136010
S069 upside down			205550	232550	246080	84956
S070	22	38	22054	23714	25799	8721
S072	9	10	154840	170900	169200	115850
S073	67	100	108400	128720	140640	<1583
S078A 1	23	35	28096	32118	34317	15470
S078A 2	9	14	In pot 78A			
S078A 3	7	15	In pot 78A			
S078B			2360	2766	2810	1736
S079 face down	76	76	167250	164790	165630	155460
S079 (face up 1st count only)			156660	155870	160490	68887
S081	4	7	37726	43346	42444	35191
S084	1	2	46886	48532	50661	48872
S086			52048	62194	69425	22878
S086 T&G (1)			4785	5522	5621	4296
S086 T&G (2)						
S087	4	5	16079	16850	17802	14212
S088 (1)	23	27	59009	68522	68945	29691
S088 (2)	54	87	14198	15036	15654	10791
S093 (2)	10	11.5	209370	235110	245410	157920
S093 (i) A	14	20	53092	56403	59848	47718
S093 (i) B	20	33	In pot S093 (1)			
S098	31	40	166840	188580	196070	106130
S098 (1)	7	7	979	1080	1105	812
S100	20	29	30017	36120	39154	6756
S105	4.5	6.5	34352	37389	35573	34209
S106	19.5	31	72827	79582	80679	55575
S109	26	31	52514	58480	61539	33618
S114	10	18	23771	27087	26574	22684
S120	31	34	24083	27957	29582	8256
S127	7	8.5	39522	40535	40505	38865

6.2. Solubility testing of point sources

The solubility of the source determines the amount which can enter the body, and in the case of radium this is important as material entering the body from the GI presents a greater hazard than when it was in the GI tract. In order for SEPA to have sufficient data to draw comparisons with the criteria specified in the RCL Statutory Guidance and to provide the data to assess the hazard, it was necessary to provide a calculation of the committed effective dose resulting from the ingestion of a point source. Unlike SEPA leachate (solubility) studies reported in 2006 and 2009, in 2010, SEPA conducted a specific experiment to mimic the acidic, enzymatic and temperature conditions of the lower intestine.

The protocol for assessing this followed the same procedure as that undertaken for Dounreay particles by the Health Protection Agency www.sepa.org.uk/radioactive_substances/publications/dounreay_reports (Health implications Dounreay fuel fragments) for SEPA. The composition of simulated stomach and small intestinal fluids used is shown in Tables 6 and 7. As it has been reported previously that sources physically break down, to determine any potential change in solubility as this occurs two particles were also ócrushedô into smaller parts before being subjected to the same leachate analysis, using a small amount of physical pressure.

Ten point sources were selected for the solubility testing on the basis of range of reported activities. Some of the particles appeared to be reactive to the acid solution and needed to be buffered throughout the digestion process which meant that time was extended to ensure that the correct acidity had been maintained. The leachate results of these point sources are reported in Tables 8, 9 and 10, which showed a range from practically zero to 25%. Although the maximum value of this range is higher than the maximum value reported in earlier work (SEPA, 2009), the methodology is slightly different.

In total, 32 Dalgety Bay sources have now been subjected to solubility testing six in 2006 16 in 2009 and ten in 2010. Overall the range is from effectively 0 to 25%, with a mean of 5 % and a standard deviation of 8%.

Table 5. Sample physical characteristic and source activity

			ORIGINAL Particle Activity (Bq)								
Source ID	**Min mm**	**Max mm**	**Ra226**	**%**	**Pb 214**	**%**	**B1 214**	**%**	**PB 210**	**%**	**Notes (with 2-d shape)**
06/10 grit			54	61	62	28	62	27	99	41	Grit
S001	9	71	11053	26	8646	24	8573	24	8422	30	FUEL SIGN -L-shaped artefact
S004	14	32	12050	25	13811	24	14892	24	4094	38	Long & narrow
S008	11	13	18350	26	21306	24	21277	24	13266	31	Round
S009	55	81	18123	27	23863	24	25810	24	5815	43	Triangular
S017	18	23	51169	25	60384	24	63684	24	13531	33	Round
S027	5.5	8	27888	25	30403	24	32036	23	24889	25	Oval
S045	25	40.5	694560	24	814610	24	818680	24	363070	26	Irregular
S045 (opposite side)			709870	24	825240	24	847110	24	405010	25	
S045B	40	44	<20		<3.9		<4.4		32	78	Round
S046	7	8.5	101940	24	113260	24	113010	24	93529	25	Crushed (formerly triangular)
S046 (opposite side)			95378	25	111090	24	112700	24	80565	31	
S066	27	44	35082	24	40087	24	41549	23	17113	25	Irregular
S068	37	55	19157	25	21355	24	22968	24	6643	35	Rectangular
S069	31	44	226030	24	252830	24	256000	24	136010	25	Irregular
S069 upside down			205550	24	232550	24	246080	24	84956	30	
S070	22	38	22054	24	23714	24	25799	24	8721	32	Rectangular/Irregular
S072	9	10	154840	25	170900	24	169200	24	115850	26	Triangular
S073	67	100	108400	24	128720	24	140640	24	<1583		Irregular
S078A 1	23	35	28096	24	32118	24	34317	23	15470	25	Irregular
S078A 2	9	14	In pot 78A								Rectangular
S078A 3	7	15	In pot 78A								Irregular
S078B			2360	24	2766	24	2810	24	1736	24	Gravel
S079 face down	76	76	167250	24	164790	24	165630	24	155460	25	DIAL circular 1-2mm thick copper disc
S079 (face up 1st count only)			156660	24	155870	24	160490	24	68887	31	residue after digestion
S081	4	7	37726	24	43346	24	42444	24	35191	25	Rectangular/Irregular
S084	1	2	46886	25	48532	24	50661	24	48872	26	Irregular
S086			52048	25	62194	24	69425	24	22878	29	Whole sample (not distinguishable from matrix)
S086 T&G (1)			4785	25	5522	24	5621	24	4296	26	Subsample Tissues and Gravel of S086
S086 T&G (2)											Subsample Tissues and Gravel of S086 (Tissues etc)
S087	4	5	16079	25	16850	24	17802	24	14212	27	Round/Irregular
S088 (1)	23	27	59009	25	68522	24	68945	24	29691	28	Round/Irregular

S088 (2)	54	87	14198	25	15036	24	15654	24	10791	27	Angular/Irregular
S093 (2)	10	11.5	209370	24	235110	24	245410	24	157920	25	Irregular
S093 (i) A	14	20	53092	25	56403	24	59848	24	47718	26	Rectangular/Irregular
S093 (i) B	20	33	In pot S093 (1)								Triangular/Irregular
S098	31	40	166840	24	188580	24	196070	24	106130	28	Rectangular/Irregular
S098 (1)	7	7	979	24	1080	24	1105	24	812	25	Round
S100	20	29	30017	24	36120	24	39154	24	6756	43	Oval
S105	4.5	6.5	34352	25	37389	24	35573	24	34209	26	Triangular
S106	20	31	72827	25	79582	24	80679	24	55575	27	Crushed - formerly Rectangular/Irregular
S109	26	31	52514	24	58480	24	61539	24	33618	26	Round/Irregular
S114	10	18	23771	25	27087	24	26574	24	22684	27	Irregular
S120	31	34	24083	24	27957	24	29582	23	8256	25	Irregular
S127	7	8.5	39522	25	40535	24	40505	24	38865	27	Oval/Irregular

Table 6 Composition of the 'Stomach' solution[7]

Compound	g dm-3	mmol.dmï 3
Calcium carbonate (Anhydr.)	0.200	Ca2+ 2.0
Magnesium carbonate	0.200	Mg2+ 2.1
Potassium chloride	*0.670*	K+ 9.0; Clï 9.0
Sodium chloride	2.800	Na+ 48.0; Clï 48.0
Sodium Lactate	0.250	Na+ 2.2; (lact)ï 1 2.2
Citric acid	0.040	2.1 x 10ï 1
Urea	0.300	5.0
Pepsin (powder)	1.000	ï

Table 7 Composition of the 'Small intestine' [7]

Compound	g dm-3	mmol.dmï 3
Calcium carbonate (Anhydr.)	0.200	Ca2+ 2.0
Magnesium carbonate	0.200	Mg2+ 2.1 x 10ï 3
Potassium chloride	*0.670*	K+ 9.0; Clï 9.0
Sodium chloride	2.800	Na+ 48.0; Clï 48.0
Sodium Lactate	0.250	Na+ 2.22; (lact)ï 1 2.22
Citric acid	0.040	2.1 x 10ï 1
Urea	0.800	13.3
Ox Gall	2.000	
Glucose	0.400	2.2
Pancreatin	2.000	
ï		

Analyses of the leachates were performed using standard accredited gamma spectrometry techniques. The results are in tables 8, 9 10 and 11

[7] The composition of the leachate solution was taken from that used for the Dounreay particles by the Health Protection Agency and reported in module 6 of SEPA's work (www.sepa.org.uk/radioactive_substances/publications/dounreay_reports.aspx

Table 8 Total Activity in Simulated Stomach Acid (Bq)

Source ID	**Ra 226**	% uncertainty	**Pb 214**	% uncertainty	**Bi 214**	% uncertainty	**Pb 210**	% uncertainty	**Comments**
S027	98	7	27	7	26	7	23	7	Oval
S046	59	6	25	7	23	6	36	7	Crushed (formerly triangular)
S079 face down	5697	6	868	7	798	6	18147	6	DIAL circular 1-2mm thick copper disc
S081	1164	6	323	7	302	6	930	7	Rectangular/Irregular
S084	2380	6	629	7	572	6	2081	7	Irregular
S086 T&G (1)	567	8	88	10	80	9	574	9	Subsample Tissues and Gravel of S086
S087	3913	6	1754	7	1648	6	3154	6	Round/Irregular
S100	3	18	2	11	1	9	14	10	Oval
S105	61	6	29	7	27	6	83	6	Triangular
S106	53	7	38	7	35	6	45	8	Crushed - formerly Rectangular/Irregular

Table 9 Lower Intestine Activity (Bq)

Source ID	**Ra 226**	% uncertainty	**Pb 214**	% uncertainty	**Bi 214**	% uncertainty	**Pb 210**	% uncertainty	**Comments**
S027	2.8	47.5	0.5	32.3	0.6	26.6	2.0	58.9	Oval
S046	8.1	25.3	2.6	8.0	2.5	7.7	1.2	3.9	Crushed (formerly triangular)
S079	165.7	6.8	125.7	6.6	116.1	6.1	11.0	34.7	DIAL circular 1-2mm thick copper disc
S081	2.9	31.5	0.1	100.0	0.4	33.6	0.5	100.0	Rectangular/Irregular
S084	97.2	6.1	46.9	6.6	42.7	6.0	7.3	19.2	Irregular
S086 T&G (1)	134.4	5.5	39.1	5.1	34.3	4.9	50.2	12.0	Subsample Tissues and Gravel of S086
S087	44.3	7.8	21.4	7.1	20.0	6.8	23.2	13.0	Round/Irregular
S100	0.4	100.0	0.1	100.0	0.1	100.0	0.2	100.0	Oval
S105	0.6	100.0	0.4	25.5	0.4	32.8	0.5	100.0	Triangular
S106	1.0	70.8	0.1	100.0	0.6	100.0	0.4	100.0	Crushed - formerly Rectangular/Irregular

Table 10

Total Activity in Stomach Solution (Stomach Acid + Lower Intestine) Activity (Bq)

Source ID	**Ra 226**	% uncertainty	**Pb 214**	% uncertainty	**Bi 214**	% uncertainty	**Pb 210**	% uncertainty	Comments
S027	101.0	7.3	27.4	7.1	26.9	6.6	25.4	7.7	Oval
S046	67.1	6.0	27.7	6.0	25.9	5.4	36.8	6.4	Crushed (formerly triangular)
S079	5862.4	5.8	994.1	6.0	914.4	5.4	18158.4	6.4	DIAL circular 1-2mm thick copper disc
S081	1166.6	6.2	323.0	6.8	302.9	6.3	930.9	7.0	Rectangular/Irregular
S084	2477.2	5.9	675.9	6.3	614.3	5.8	2088.4	6.6	Irregular
S086 T&G (1)	701.5	6.9	126.8	6.8	114.7	6.4	624.2	8.6	Subsample Tissues and Gravel of S086
S087	3957.3	5.7	1775.7	6.4	1667.7	5.8	3177.1	6.2	Round/Irregular
S100	3.4	20.0	1.6	11.1	1.6	9.6	14.5	10.3	Oval
S105	61.6	6.0	29.6	6.5	27.4	5.9	83.8	6.4	Triangular
S106	53.9	6.8	38.1	6.6	35.4	6.2	45.3	7.6	Crushed - formerly Rectangular/Irregular

Table 11 Percentage in of Total Activity Available to Simulated Stomach Solution (percent of original particle activity)

Source ID	**Ra 226**	Range min	Range Max	**Pb 214**	Range min	Range Max	**Bi 214**	Range min	Range Max	**Pb 210**	Range min	Range Max	**Comments**
S027	0.36	0.27	0.51	0.09	0.07	0.13	0.08	0.06	0.12	0.10	0.08	0.15	Oval
S046	0.07	0.05	0.09	0.02	0.02	0.03	0.02	0.02	0.03	0.04	0.03	0.06	Crushed (formerly triangular)
S079 face down	3.51	2.65	4.91	0.60	0.46	0.84	0.55	0.42	0.76	11.68	8.75	16.57	DIAL circular 1-2mm thick copper disc
S081	3.09	2.34	4.34	0.75	0.56	1.04	0.71	0.54	0.99	2.65	1.97	3.78	Rectangular/Irregular
S084	5.28	3.99	7.44	1.39	1.05	1.94	1.21	0.92	1.68	4.27	3.17	6.16	Irregular
S086 T&G (1)	14.66	10.91	20.91	2.30	1.73	3.23	2.04	1.54	2.86	14.53	10.54	21.32	Subsample Tissues and Gravel of S086
S087	24.61	18.55	34.73	10.54	7.96	14.73	9.37	7.13	13.00	22.36	16.51	32.52	Round/Irregular
S100	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.21	0.13	0.41	Oval
S105	0.18	0.13	0.25	0.08	0.06	0.11	0.08	0.06	0.11	0.24	0.18	0.35	Triangular
S106	0.07	0.06	0.11	0.05	0.04	0.07	0.04	0.03	0.06	0.08	0.06	0.12	Crushed (formerly Irregular)

7. Assessment

7.1. Nature of Hazard

This section details the potential hazard from radium point sources and draws on previous work conducted for the 2006 and 2009 assessments.

7.2. Physical Form

This section was detailed in our 2006 screening assessment report and is included here for completeness.

The radioactive contamination at Dalgety Bay is believed to have originated from historic MoD operations. The radium used by the MoD was primarily in luminescent paints. Radium based luminescent paint was typically made by mixing a radium salt, zinc sulphide and a carrier material (typically varnish or lacquer).

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, while lower grade material used on watches, switch markings and other devices requiring less critical reading could contain between 50 and 100 μg of radium per gram of material. It is likely that in most cases radium sulphate was the form of radium used by the MoD in luminescent paints during the Second World War. However, radium chloride and radium bromide have been used in luminescent paints in the UK, both of which are very soluble (Ferguson, 1999).

7.3. The effect of burning

This section was detailed in our 2006 screening assessment report and is updated here.

At Dalgety Bay anecdotal evidence suggests that during the break-up of some aircraft it was common for at least some of the redundant luminescent materials to be burnt. It is suspected that the resultant ash and clinker produced from burning were either buried or spread on the ground surface.

Little information is available on the effect of a fire on the chemical reactions of radium sulphate. The temperature of open fires is unlikely to allow radium sulphate to form radium oxide; however, the burning of radium sulphate with other materials such as wood may allow the formation of radium sulphide.

When radium bromide is heated it is possible that this, together with other forms of radium, can be converted into carbonate.

It is therefore possible that the action of burning of luminised dials can produce a diverse range of chemical forms each of which has a differing potential for absorption and uptake by man.

The Heaton report in 1996 indicated that around 10% of the material may be available for absorption if ingested. Our 2006 and 2009 reports indicated solubility's up to 15%. However our 2011 work which used a more representation of gut conditions indicated that this value could be up to 25%. As this work was conducted on different samples it does not necessarily negate the earlier work, however data derived using a true gut solution are clearly preferable to a more basic representation. However, given that only 10 sources have been subjected to this ‘true gut solution’ it may be that the solubility could be greater in other samples. If a value of 25% solubility as a true value of a soluble particle would have increased the doses calculated in 2006 and 2008.

The sources selected for examination were selected independently from the location of recovery. It may also be worthwhile exploring whether sources recovered from a specific location had greater solubility than those recovered from elsewhere. However, the current limitation in the number (n = 10) mean that any interpretation on the basis of recovered location can only be subjective.

7.4. Point source size and fragmentation

In 2008 the recovery of point sources in the field environment which was reported in 2009 was often associated with other material, which, where practicable, was separated and the radioactive component identified. In two cases, during the recovery of a point source, a number of discrete sources were recovered which inferred some form of break-down in situ.

In the 2008 recovery work, when some of the point sources were analysed in laboratory conditions some sources were actually a number of other lower activity or inert point sources which may indicate that the radium is not uniformly distributed throughout a given source. Therefore, for the purpose of prospective radiological assessment, any division of point sources according to physical size is potentially problematic as some may be highly friable and likely to breakdown easily, thus creating other potential pathways, e.g. ingestion and inhalation may become viable. For this reason two of the sources recovered by the Defense Estates, analysed by SEPA in 2011, were physically broken into pieces before analyses to determine if the solubility of these sources changed compared to other sources examined upon physical breakdown, due to new surfaces being exposed which had not been chemically or physically weathered in the environment.

7.5. Exposure Pathways

There are several potential exposure pathways to consider for the probability assessment both for human and non-human species which were discussed in our 2009 report. These include inhalation, ingestion and skin contact.

7.5.1. Inhalation

It is possible that individuals could inhale an item that was (re)suspended in the air. The maximum diameter that can be inhaled is assumed to be 200 εm, i.e. 0.2 mm. Similar to the 2006 survey, the recorded dimensions of the items recovered from the beach were greater than 0.2 mm. However, consideration of friability suggests that initial source size merits further investigation. In addition the Defence Estates report states that sources were removed from an ashy layer around the slipways, if during burning sources have broken down to become ash they may have become inhalable. As the Defence Estates work was focussed on high activity sources small sources of 1 kBq may not have been detected. However, given the area is wet for a large period of time and the ashy layer was reported to be present at depth it is unlikely that these would be inhalable at present.

7.5.2. Skin Contact (inadvertent)

It is possible that an item could come into contact with the skin and it is also possible that an item could be trapped, for example, under nails. It was assumed that there was no deliberate selection of radioactive items; however we now believe this is to be the case[8]. As the rate of sediment mobilisation is unknown, it is assumed that all of the items detected could be available for skin contact irrespective of the depth of the recovered item.

There are several possible exposure pathways leading to direct skin contact, based on research conducted for SEPA by the Health Protection Agency and also the work of the Dounreay Particles Advisory Group (DPAG).

- Under the fingernails

It is possible that a small item could be trapped underneath the fingernails. It is assumed that the maximum size of an item that could become trapped and remain there for a reasonable period of time (> 10 minutes) is 2 mm x 2 mm.

- On clothes

It is possible that an item could attach to an individual's clothes, whether by sitting/lying on the beach or by material suspended by air.

- In a shoe

It is possible that an item could become trapped inside an individual's shoe during a visit to the beach.

- Food Pathways

Potential exposure through ingestion of related foods has not been considered in this SEPA report[9].

7.5.3. Deliberate encounter

In SEPA's 2009 and 2006 assessments, it was assumed that there was no possibility of preferential selection of contaminated items from the beach. However, the Defence Estates work has shown that artefacts exist within the environment at Dalgety Bay which retain the radium paint. It is therefore possible that people seeing an item such as a luminised dial or fuel gauge lever may remove these items as an object of interest. Without specific monitoring for the presence of radium it is impossible to judge by visual inspection whether radium paint remains on these objects. In 2011, SEPA was also informed of a practice of removal of stones or artefacts as a memoir from beaches people had visited. This has occurred on more than one occasion. The person in question has told SEPA that they were walking the Fife coastal path and had not seen the signs advising people not to remove items from the beach, although when SEPA visited the area the signs were present. This may indicate that the signs are not

[8] The presence of artefacts e.g. a dial and fuel gauge lever may mean that adults and children are attracted to these objects.

[9] Radiation exposure from foodstuffs is the responsibility of the Food Standards Agency (FSA). However, analysis of winkles, cockles and mussels from Dalgety Bay has not shown the presence of any point sources.

effective at present. It is suggested that one possible reason for this is the large amount of information present on the signs.

Practices currently occurring at Dalgety Bay may result in a significant increase in the potential for exposures to occur than those assessed in SEPA's 2006 report. However, this is impossible to assess without specific information on these habits and the number of artefacts which are contaminated and may be visually attractive.

7.5.4. Assessment of the probability of exposure

An assessment of the likelihood of an inadvertent exposure occurring was undertaken in the 2006 and 2009 assessments. This has not been updated in the current assessment the difficulties in providing an updated or any refinement of those assessment are:

There is now a need to consider the deliberate removal of items from the beach
The sources are highly heterogeneous in terms of physical size, activity and solubility
Limited number of the total number of sources recovered have been fully characterised
There is no comprehensive site specific information on usage of the beach

Without this information it is impossible to determine with any accuracy the potential for inadvertent exposure.. A robust assessment of the probability of encounter should also consider the correction needed for non-detected point sources.

8. Hazard

SEPA's previous reports have provided details of the potential hazard of both high activity particles and potential low level widespread contamination. In 2009, SEPA concluded that discrete point sources of radioactive contamination could give rise to doses in excess of the relevant criteria, whilst the low level contamination of the environment at Dalgety Bay would not be high enough to trigger the relevant criteria in the guidance issued to SEPA by the Scottish Government for Radioactive Contaminated Land. SEPA has no reason to believe that the concentrations of homogenous low level contamination in the environment have changed since the 2009 report and for this reason it is not considered further in this assessment. Thus, for this assessment of hazard we have only considered the potential effects of encountering a radium source, either by inhalation, ingestion or skin contact.

8.1.1. Inhalation

In the 2009 report SEPA considered that there was a possibility that some of Dalgety Bay sources could have been sufficiently small to be inhaled. Although point sources will physically break down in coastal environments such as that found at Dalgety Bay, the specific activity of some of the residual items may be greater after breakdown occurs, increasing the potential hazard such friable sources pose. The co-location of point sources at two positions during the SEPA 2008 survey suggests that such a breakdown may be occurring.

Assessment of the possible hazard from inhalation is problematic and it was recommended in 2009 that, if this pathway needs to be considered, it should be undertaken in a full risk assessment. However, to provide some basis on whether such work is warranted, SEPA requested specific advice on this matter from Health Protection Agency – Radiological Protection Division (HPA-RPD) and in the short timescale available, HPA-RPD were able to provide the following preliminary assessment:

Particles of more then a few 10s of µm have a very low probability of reaching the airways and alveolar region of the lungs – if inhaled, they are trapped in the nose and extrathoracic airways. Assuming a particle of 1 kBq Ra-226 (+ daughters at 0.9 kBq: Pb-214, Bi-214, Pb-210, Po-210) was sufficiently small to deposit in the alveolar or bronchial regions of the lung, and assuming Type M[10] solubility, rough first estimates of committed effective dose are:

Deposition in the alveolar region of an adult: 10 – 25 mSv
Deposition in the alveolar region of a 1 year-old child: 50 – 150 mSv
Potentially higher doses if deposited in the bronchiolar region.

Thus, it may be worthwhile investigating the ashy layer, described in the Defence Estates report to determine if sources of a few kBq are present or otherwise. Given the

[10] Type M solubility assumes that the particle has 'average' solubility in ICRP 72

likely costs of this work, if further work is to be undertaken at Dalgety Bay, it is recommended that this is given consideration.

8.1.2. Ingestion

Section 4 reports that ten point sources were selected according to their size and activity to determine the potential solubility. The methodology used to perform this experiment was the same as that used to assess the Dounreay particles and represents a more representative assessment of the gut conditions.

Following a more basic experiment in 2006 and 2009, the soluble fraction of each point source could be up to 15 % and between 1-7% respectively. In the work conducted in 2011, the solubility ranged from less than 1% to almost 25% which was broadly comparable with the 2006 work, even though a slightly different methodology was used. If large numbers of higher activity sources exist which had a solubility of around 25% this may give rise to significant concern.

In the absence of actual data, we have also assumed that the ^{210}Po and ^{210}Pb are in equilibrium. Given that it is believed the sources have been in their present form for around 50 years this would give sufficient time for the in growth of Po-210. As the report on skin doses shows that the alpha radiation is not released from the sources in any quantity, it is highly possible that Po-120 will also not be released from the sources. The doses were derived using standard ICRP dose coefficients (ICRP 72). It is noted that the 2010/11 analytical work, the ^{210}Pb results are accredited

Of the point sources subjected to leaching experimentation in 2011, the highest dose, using the methodology adopted, would have been around 128 mSv to a 3 month old child, with contributions of around 19, 0, 0, 27, 0, 83 mSv from ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi, ^{210}Po, respectively (the values have been rounded). If ^{210}Pb were in full equilibrium the doses would have been around 155 mSv. The size dimensions were derived using photographs thus only two dimensions were reported which for the source giving the highest potential dose was 4 x 5 mm. It is assumed that for the smaller particles normal settling process will mean that the third dimension will be less than those measured, in the same manner as, for example, a coin being dropped tending not to land on its thinnest edge. For the source giving the next highest dose the size was 1 x 2 mm and gave a potential dose 83 mSv to a 3 month old child. This compares to a source recovered in 2006 which although subject to a slightly different solubility test had a mass of less than a gram and a potential dose of 240 mSv. The potential doses from the other point sources, not subjected to leaching experimentation have not been assessed. These data should be considered as indicative rather than precise for reasons detailed in Sections 4 and 7

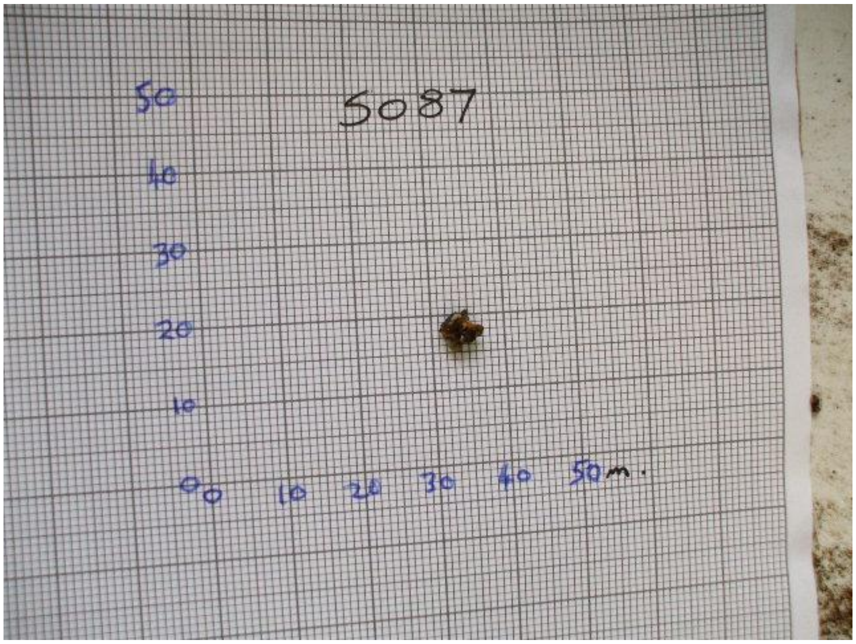

Figure 5. Source which would give a dose of 128 mSv to a three month old if ingested

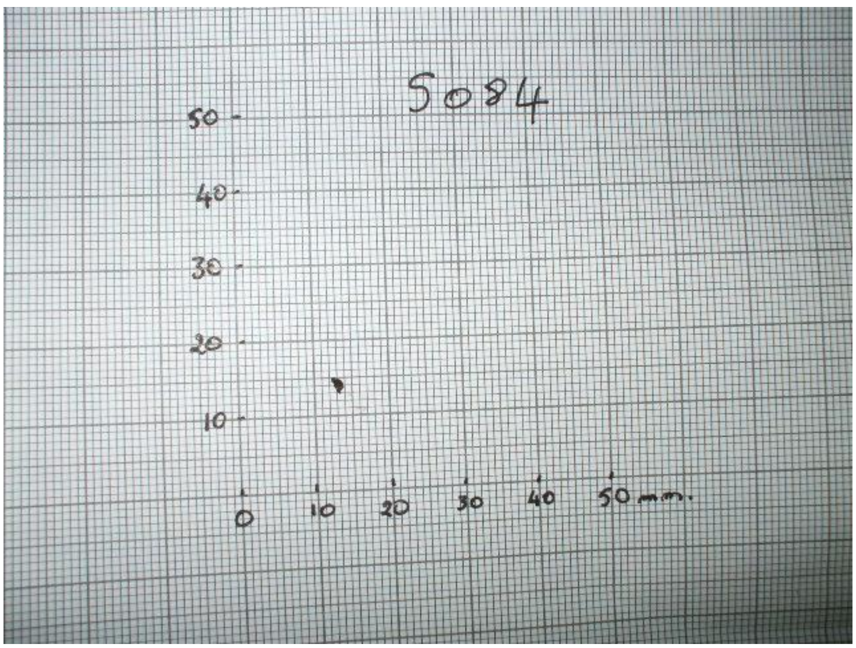

Figure 6. Source which would give a dose of 83 mSv to a three month old if ingested

SEPA requested comments from HPA-RPD on the SEPA assessment of the potential committed effective dose which confirmed the SEPA assessment for the three month old infant. HPA-RPD provided the following commentary :

"We note the assumption made about Po-210 being in equilibrium with Pb-210 in the particles. In terms of the activity of the original particles, this is probably reasonable given the age of the Ra-226. Given the current information available, we agree that it is

more realistic to use the in-vitro dissolution data for Pb-210 for calculating doses from Po-210 than the f1 value for Po-210 given in ICRP72. However, given the importance of the contribution of Po-210 to the total dose (about 50%), we recommended that further analyses are undertaken to confirm that these assumptions are valid.

We also note that Bi-210 is assumed by SEPA to be in equilibrium with Pb-210. For the calculation of doses from Bi-210, the in-vitro dissolution data for Pb-210 have been used rather than those for Bi-214. This is a conservative approach as the solubility of Bi-214 is lower than that of the Pb-210 in the particles analysed. This assumption does not have any impact on the total doses estimated as the contribution from Bi-210 is very small.

The ICRP 72 dose coefficients include the dose to the GI Tract from the non-absorbed material passing through the gut but assume that the activity is distributed through the gut contents rather than present as a particle. As the dose is dominated by the contribution from other organs due to absorption to blood, the assumption that doses scale directly with the particle uptake fraction determined in-vitro is a reasonable one to make. Therefore, for your present purposes, it is not necessary to explicitly consider doses to the gut arising from particles in transit through the gut"..

8.1.3. Skin contact

The point sources recovered from Dalgety Bay represented a wide range of mass, physical size and radioactive content. Potentially the dose rate to the surface of the skin could be very high and in the SEPA 2009 report, SEPA recommended specific work be undertaken to determine the realistic dose rate for exposure to the skin. This work has now been completed on a range of sources recovered from Dalgety Bay by SEPA in 2008 and is reported separately and is available on the SEPA website (www.sepa.org.uk). The relatively low external dose rates means that the radioactivity is trapped within the source, which will result in potentially greater committed effective doses if these were to be ingested.

The report includes a recommendation regarding a screening approach to determine whether the nature of the hazard has changed compared to that assessed in 2009. This was adopted for those sources selected for solubility analysis and that although qualitative data are only available the relative dose rates for the 2011 sources selected the maximum count rate for the Defence Estates recovered sources in 2009/10 was lower than that assessed by SEPA for sources recovered in 2008. Thus, we conclude that the hazard posed by the Dalgety Bay source from the skin pathway from sources recovered by Defence Estates is consistent with that assessed in SEPA's separate report on Dalgety Bay skin doses. The SEPA skin dose report concludes that for those particles analysed it is unlikely that the dose rate to the skin will exceed the value specified in the Statutory Guidance issued to SEPA for Radioactive Contaminated Land in Scotland.

9. Probability of Encounter

Section 7 considered the difficulties in estimating the probability of an individual encountering a radioactive point source at Dalgety Bay. The Defence Estates report concluded that it expected that around 100 sources would populate the beach each year, which is consistent with the general number of sources found in previous years, and thus previous assessments of the probability of encounter may remain valid. However, if preferential selection did occur this probability would probably increase, although in the absence of information on the numbers of people present, the number and type of items which could be removed it is not possible to quantify the number of people deliberately picking things up from the beach which may be either radioactive or inert.

10. Discussion

Work undertaken by Defence Estates, SEPA and HPA over the past twenty years has shown that Dalgety Bay continues to be re-populated with radium sources of high activity.

Of the 128 sources recovered by Defence Estates 30 were selected by SEPA to be characterised and from that 10 were selected to determine potential solubilities in the GI tract should they be ingested. These point sources of radium showed a diverse range of activities and physical properties. In this report we have presented data on the potential doses that could be received from ingestion. A separate report is also available on the potential effects of skin contact.

For potential committed effective doses from ingestion, derived using a more realistic representation of the gut fluid, the greatest potential dose (from a source which was on the verge of being inadvertently ingestible (Heaton et al 1998) would be to a 3 month old infant and would be around 128 mSv. Doses to a 1 year old and 5 year old child, would be 43 and 23 mSv respectively, with the dose to an adult being 7 mSv. The doses for the second most hazardous source would be 84 mSv to a 3 month old infant, and 28 and 15 mSv to 1 year and 5 year old children respectively, with the dose to an adult being around 5 mSv. This compares to a dose of 66 mSv to a 1 year old infant reported in SEPA's 2009 report where the Health Protection Agency estimated the dose to a three month old as 240 mSv.

The solubility data obtained in 2006 and 2008 show a range of solubilities from practically zero to around 15%. In 2011 using a more realistic representation of the gut fluid this value ranged from practically zero to around 25%.

This report presents a retrospective assessment of the potential risks from radioactive contamination at Dalgety Bay. It is clear that the contamination is highly heterogeneous in terms of size, radioactivity content and occurrence and there are no robust relationships between activity or size and potential effective doses. However, the potential committed effective doses from ingestion are greatest to infants. It is known that nursery age children have used the beach.

10.1. Current intervention measures

In our 2009 report we suggested that the use of signs, in respect of location, number and wording, was reconsidered which was undertaken. However, anecdotal evidence has now emerged that people using the coastal path or foreshore do not encounter the signs and are therefore unaware of the advice, thus, there may be a further requirement to review the signage.

The series of monitoring and recovery programmes undertaken at Dalgety Bay have provided evidence of repopulation of the beach. It could be stated that these programmes have provided some level of protection to the public as point sources were removed. However, the 2009 SEPA report showed that the rates at which point sources re-populated cleared areas could be rapid, which has been confirmed by the Defence Estates work. Therefore, unless a frequent monitoring programme was adopted, it is unlikely that a monitoring and retrieval programme, in itself, would be an optimal intervention measure affording an appropriate level of protection.

Over the last 20 years surveys of the beach area at Dalgety Bay consistently reported that around 100 point sources a year were detected on the beach. There is now a need to consider whether a programme of monitoring and recovery provides an optimal solution to the continuing problem at Dalgety Bay, or whether isolation of the point sources would be more optimal than a rolling programme of monitoring and removal.

If the programme of monitoring and removal is to continue without isolation of the source, there is a clear need for further work to determine the physical properties of the sources, as well as radioactivity content and solubility. This information would help inform the frequency with which any monitoring and recovery programme should be undertaken. However, it is accepted that this may result in greater doses to the workers and significant costs. Such an assessment may take a period of years to complete as it will need to consider any potential seasonal effects on occurrence and activity of sources.

If a programme is undertaken to isolate the source at Dalgety Bay this may have significant costs in the short term in terms of resources and finance. However, it could result in a significant decline in the numbers of sources present on the beach and allow the frequency of monitoring to be reduced in the short to medium term (it is noted that during any isolation process there will be a need for monitoring to verify that this has reduced the hazard present). It may eventually also allow the removal of all current intervention measures and the cessation of monitoring. If this programme of isolation was undertaken soon it may also negate the need for further characterisation of particles and thus reduce doses to the workers and costs.

11. Conclusions

Work undertaken by Defence Estates has confirmed the typical number, size and activities of point sources at Dalgety Bay. It has also shown that the beach area continues to re-populate with high activity point sources once cleared and that it is estimated that over a year these will number about 100 in total. Thus there remains a hazard to the public at Dalgety Bay from these point sources, and the total number of radioactive sources at Dalgety Bay remains unknown.

Based on the results of solubility testing, indicative committed effective doses could range up to 128 mSv for a 3 month old infant, with the majority of the dose being from radium daughters. However, the 2010 work has indicated that the solubility of these sources may be greater than previously expected (25% rather than up to 15%). Doses could also be greater if the relatively small number of samples subjected for leaching was not representative of the population as a whole. Overall our 2006, 2009 and this 2011 report have shown that several of the sources recovered from Dalgety Bay could give committed effective doses in excess of the relevant value for some age groups, prescribed in the Statutory Guidance issued to SEPA by the Scottish Government for Radioactive Contaminated Land.

Direct measurements of point sources to determine potential skin doses have been undertaken. The results have been reported separately which indicate that it is unlikely the dose rate from the Dalgety Bay sources could exceed the relevant criteria specified in the guidance issued to SEPA by the Scottish Government for Radioactive Contaminated Land.

The potential committed effective doses from Dalgety Bay point sources remain significant. The primary pathway of concern is via ingestion and as any potential effects (e.g. cancer) may take many years to be expressed and be unlikely to be easily attributable to an exposure from a visit to Dalgety Bay.

The locations and suitability of the current signage, as an optimal intervention measure, should be reviewed. Given the numbers of people using the beach there is also a need for an ongoing monitoring and recovery programme to reduce the hazard present on the beach. In the longer term, as radium has a half life of 1600 years, a programme of work to determine the primary source of the contamination at Dalgety Bay beach and isolate it from the environment may be the only manner in which the level of contamination can be reduced to a negligible level where no further interventions are needed. Given the potential costs involved of developing any robust risk assessment this approach to isolate the contamination from the environment may be the most cost effective approach to mitigating the contamination in the long term.

The absence of any programme to isolate the radioactive contamination at source will mean that sources which pose a significant hazard to health will continue to be present on the beach at Dalgety Bay. It is concluded that a programme to identify the primary source or sources is needed to reduce the number and hazard of these sources to the public using the beach at Dalgety Bay.

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