DALGETY BAY
RADIUM CONTAMINATION

Preliminary assessment produced by Scottish Environment Protection Agency (SEPA) Environmental and Organisational Strategy Directorate

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SCOTTISH ENVIRONMENT PROTECTION AGENCY

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1. Summary

It is known that radioactive items have been detected on Dalgety Bay since 1990. Many surveys have been undertaken on the beach to determine the potential numbers of items present and possible implications for public health. In 2006 SEPA conducted a limited monitoring and recovery exercise at Dalgety Bay to determine whether the contamination posed realistic risk that should be quantified. The 2006 assessment showed a possibility of significant exposures to members of the public and resulted in the erection of signs at a number of locations.

The current assessment has been developed primarily to provide information to allow SEPA to consider whether some areas of Dalgety Bay should be classified as Radioactive Contaminated Land (RCL) as defined by the Statutory Guidance. It has not been developed to provide a full risk assessment of the hazards and risks at Dalgety Bay from the radium contamination. As, at the time of writing, there is no formal procedure for undertaking these types of assessments within SEPA, a number of assumptions, based on the best scientific information and practice (where available), have been made and these are detailed in the report.

Overall, the 2008 survey showed that the number and activity of point sources remained similar to that reported in our screening assessment undertaken in 2006. This 2008 survey also reports widespread low level contamination of radium on the inter-tidal area at Dalgety Bay. However, it is unlikely that this type of contamination would trigger the relevant levels in the Radioactive Contaminated Land Regulations and the associated Statutory Guidance. With regard to the point sources of radioactivity, these were similar in terms of number and activity as those detected in 2006; the contamination appeared to be broadly located between the old pipeline and New Harbour area. These sources were highly heterogeneous often with localised points of radioactivity amongst a large matrix of inert material. On recovery, a number of the sources physically broke down to smaller pieces which could have consequences for future exposure pathways.

The 2008 survey included monitoring of an area of the Fife Coastal Path. Although the presence of contamination was detected in many areas along the path, the levels were generally low. However, at one location on the path, increased contamination was detected which was attributable to an area of widespread contamination and two point sources. The point sources, together with a sample of the more widespread contamination, were removed.

Earlier surveys at Dalgety Bay have always shown a re-population of the inter-tidal area following any removal programme. In 2008, a limited re-survey of the slipway area, three days after an initial monitoring programme was completed, resulted in the detection and recovery of a further two point sources, indicating a potentially rapid re-population of this area.

With regard to the potential hazard that the point sources could pose, two potential pathways were considered, *viz*. skin contact and ingestion, both of which were assumed to be *via* inadvertent exposures. Given the friability of the sources on recovery, inhalation was a third possible pathway.

The potential range of skin doses is dependent upon the activity of the source, shielding between source and skin, and skin area and depth. Although no direct measurements of dose rates from point sources were undertaken to determine skin doses, a broad

assessment of this indicated that for source activities of around half a million Bq, doses to the surface of the skin could be of the order of a few thousand Gray (Gy) per hour. As the outer layer of the skin is essentially dead, cells at the base of the epidermis are considered to be the focus of any protection. If this approach is used, for an adult the base is at a depth of 70µm, the resultant dose would be around a few Gy per hour for most active sources detected in 2008. For young children, doses are greatest as the reference skin thickness value, recommended by ICRP, is around 45-50 µm. For these children, potential doses, using the data collected in 2008, could be of the order of one to two hundred Grays per hour. However, the effects of self-absorption need to assessed. We recommend direct measurements are made to provide data for skin dose rates.

In relation to the risks from ingestion, a basic leaching experiment indicated similar levels of solubility to those found in the solubility tests conducted in 2006. Overall, for those point sources subjected to leaching in 2008, the potential committed effective doses to a 1 year-old infant would have been around 66 mSv. This value assumes that the reported ^{210}Pb data are valid; if ^{210}Pb were in full equilibrium, the doses would be around double. As the more active, physically larger, point sources break into smaller items, such as those detected in 2006, the potential resultant doses could be significantly greater. Initial data from the Health Protection Agency (HPA) suggests that the dose to a 3 month-old infant could be about 240 mSv. In 2006, a similar leaching experiment indicated that the potential committed effective dose from one point source weighing less than a gram could be in the order of 240 mSv.

It is recommended that a full risk assessment is undertaken. In particular, further work should be undertaken to quantify the:

- Extent of self-absorption.
- Direct measurements of skin doses.
- Rate of point source re-population.
- Associated hazard from ingestion.
- Chance of encounter associated with exposure pathways for direct skin contact and ingestion of contaminated material.

2. Scope and Purpose

This monitoring and recovery exercise was undertaken by SEPA's Radioactive Substances Policy Unit (RSPU) to provide information to SEPA's regulatory arm (EPI) in accordance with SEPA's duties under The Radioactive Contaminated Land (Scotland) Regulations 2007 (RCL Regulations) and the associated Statutory Guidance. The radioactive 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 order to fulfil this duty, SEPA needed to review available data and consider whether the significant harm or significant possibility of significant harm at Dalgety Bay triggered the criteria set in the RCL Regulations and Statutory Guidance. If any of these conditions were triggered then SEPA would also need to delineate the extent of the contamination. Thus, any monitoring exercise would need to be sufficiently extensive to allow delineation, should this be necessary.

The statutory definitions of significant harm and the significant possibility of significant harm are detailed in Appendix A, although for ease of reference, the principal criteria 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 where they are uncertain to occur (such as localised hot spots, i.e. heterogeneous contamination).

2.1. Criteria for Radioactive Contaminated Land

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 $\mu Gy\ hr^{-1}$ to terrestrial biota or plants;
(b) 400 $\mu Gy\ hr^{-1}$ 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 "potential annual equivalent dose" and "potential annual effective dose" 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

This report provides SEPA-EPI with the information from a survey conducted in 2008 at Dalgety Bay and includes reference to earlier work conducted at the same location in 2006. 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 or must not be designated as RCL. For example, if the doses are lower than those defined in the Statutory Guidance, consideration should be given to the break-up of physically large point sources, that do not pose a significant hazard at present, into smaller items which could then be ingested or inhaled and, as a result, pose a greater hazard. Equally, given that all of the items positively identified were recovered, this assessment is primarily a retrospective assessment rather than a prospective assessment. Further commentary on this is detailed in Section 10. It is also notable that the impact of any positive action to mitigate the overall risk could also be considered before a final decision is taken on whether the land is RCL or otherwise.

Under the principles of general radiation protection, irrespective of whether areas of Dalgety Bay are designated as RCL or otherwise, where a source-pathway-receptor exists, interventions should be considered on the basis of doing more good than harm (socio-economic factors taken into account).

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 rail 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.

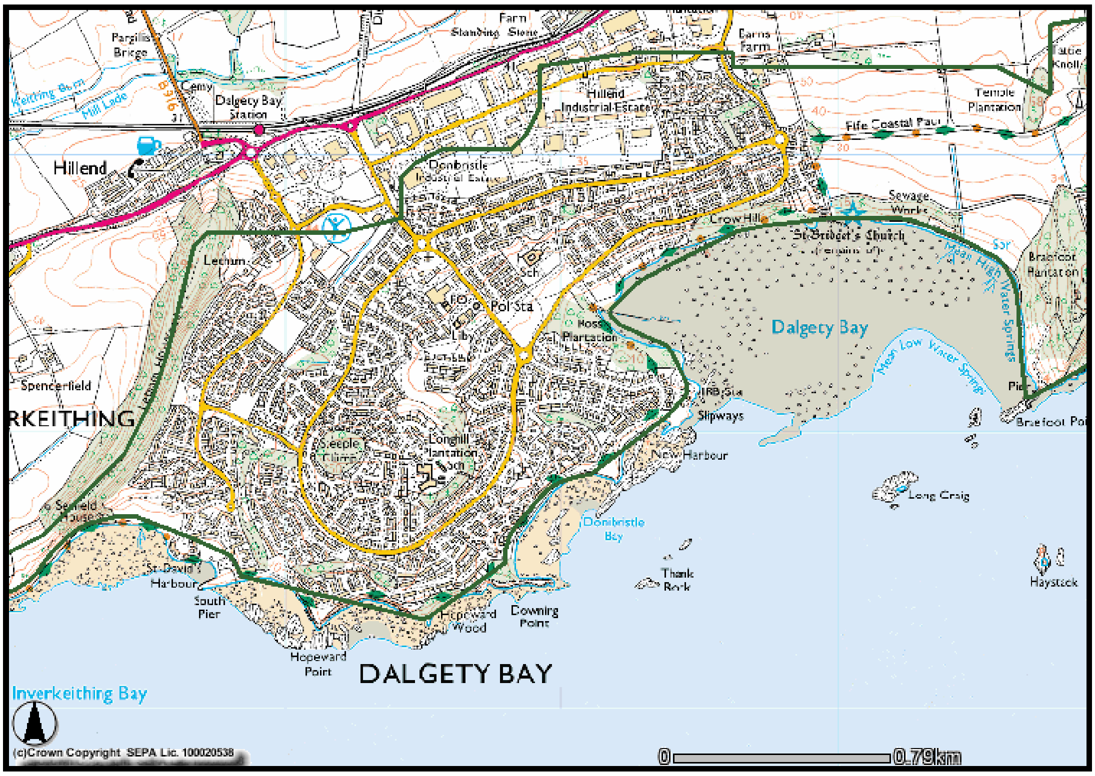

Figure 1: Dalgety Bay

The bay is approximately 400 m wide by 500 m. 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 – New Harbour area
- Made ground – rock armour emplacement
- Slipways
- Boat storage area
- Mudflats – pipeline, coastal path, St. Bridget's Kirk, old landfills

3.2. Brief History of Military Activities

- Donibristle Airfield was a base for the Royal Naval Air Service from 1917
- During World War Two (WWII) site was called HMS Merlin and was a Royal Naval Aircraft Repair Yard
- Post WWII the site was part of HMS Cochrane
- Site closed in 1959
- Anecdotal reports that radium paint was supplied by Luminisers Ltd, based in Overburn Road, Bonhill, Dumbarton
- RNAS Donibristle was home of 22 Squadron, which ran torpedo training runs. The aircraft used by RNAS here were Vickers Vildebeests and Bristol Beauforts.

Part of the 1960/70's residential development at Dalgety Bay is on the site of a former Ministry of Defence (MoD) airfield at Dalgety Bay. Throughout the period between 1917 and 1959 Donibristle played a role as an aircraft repair, re-fitting and salvage yard.

3.3. Summary of previous surveys, 1997-2006

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 – 2006:

Table 1: Summary of previous surveys by Babcock Rosyth Ltd and RWE Nukem Ltd

Year	Area Covered (hectares)	Items identified	Notes
2006	1.1	37	2.2 MBq activity, 1.23 kg total waste Range 30-2,350 cps (background 50-55 cps)
2005	1.75	97	Same area 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 (old pipeline area)
1997	3	120	Large area, including area near old pipeline

3.4. 2006 Screening Assessment

Following the 2006 monitoring and removal survey, RSPU undertook a Probabilistic and Hazard Screening Assessment that attempted to draw together information on the number, activity and solubility of radioactive items that were detected and recovered in the March 2006 survey. The aim of the 2006 study was to determine whether a detailed assessment of the radioactive contamination at Dalgety Bay was warranted, but not to provide detailed or precise information on the risks. The assessment contained a number of assumptions which were detailed.

The 2006 assessment did not attempt to determine the source of the contamination, however, in undertaking the assessment, SEPA did not identify any other potential source of radium other than the previous Ministry of Defence (MoD) site. SEPA requested information from the MoD on their previous activities during the MoD occupation of land at Dalgety Bay. The MoD has confirmed that it does not hold any records of previous activities at Dalgety Bay (or the former HMS Merlin/Donibristle sites), however, MoD did suggest that information could be obtained from the National Archives. Interestingly, during the 2008 monitoring, SEPA's contractors identified and recovered part of an instrument panel that may have originated from a military aircraft.

3.5. Signage and Current Interventions

The 2006 screening assessment concluded that further detailed assessment was warranted and that in the absence of such an assessment, consideration should be given to the adoption of the precautionary principle. To this end, the Dalgety Bay Forum supported the emplacement of signage at key points around the bay by the Local Authority.

Images of the locations of two signs, identified in September 2008, are shown in Figures 2 and 3. The location and size of the wording made it difficult to read the signs from the public paths and there was an absence of any signs at locations where the greatest risk had been identified previously. It is suggested that, if the purpose of these signs is to provide meaningful information to the public to allow it to make an informed decision, the wording, size and locations of the signs could be reconsidered. The current text of the signs displayed at Dalgety Bay is as follows:

Public Notice
Dalgety Bay

Mainly for general hygiene reasons, please wash your hands if you handle material on the beach and do not remove any material including fish and shellfish

Minor radioactivity from materials containing luminous paint have been found and removed from this beach.

There is low risk to the public.

For further information see
http://www.show.scot.nhs.uk/livinginfife/
Search - *Dalgety Bay Contamination*

Fife COUNCIL

SEPA Scottish Environment Protection Agency

Figure 2 and 3 show the location of those signs during the monitoring work in September 2008.

Figure 2: Photograph taken of sign from Fife Coastal Path close to Ross Plantation

Figure 3: Position of sign close to access path near to redundant (old) pipeline

4. Monitoring and Assessment

In 2008, following the issue of the Statutory Guidance for radioactive contamination land legislation, SEPA prioritised Dalgety Bay for assessment. This assessment was undertaken in view of the information indicating the presence of a significant risk from radioactive contamination at this site.

In order to provide SEPA with the necessary information to allow it to reach an informed decision on whether any land at Dalgety Bay should be classified as Radioactive Contaminated Land, information was needed on the concentration of diffuse widespread radioactivity (homogenous contamination) and the number and activity of point sources (heterogeneous contamination). Information was also needed on the littoral extent (the extent of the contamination along the coastline). Separate information would be needed on the levels of radioactivity of homogeneous and heterogeneous contamination and the potential hazards that these posed to humans and non-humans. Due to the significant local interest in the issue it was considered that the work should be undertaken and reported within three months.

Once samples of either point sources or homogeneous samples had been taken these would be sent for laboratory analysis. In order to determine the specific hazard that point sources posed to human health, it was also necessary to determine the detriment that would be caused if these point sources were to be in contact with the skin, ingested or inhaled.

4.1. Monitoring Plan

In Section 3, information is presented on earlier finds of radium-226 sources on the intertidal area at Dalgety Bay, which complemented the summary of NRPB surveys in SEPA's 2006 report. It was believed that the contamination would be mainly concentrated in areas previously surveyed. However, as items had been found in all areas monitored, it was considered appropriate that the monitoring area should be extended further both west and east. The monitoring area was chosen to attempt delineation of the extent of the contamination and, due to the prevailing tidal influences, it was decided to extend the monitoring area further east than west. An area west of the old pipeline was planned to be monitored to a width of 20 m from the high water mark which importantly was the area most accessible to the public and was the area that beach users needed to cross to gain access to the lower areas. In practice, below 15m from the high water mark at Dalgety Bay, the area is very muddy and difficult to access.

In an earlier survey by the MoD in 2008, of the coastal path at Dalgety Bay was surveyed and no contamination was reported. In order to verify this finding the coastal path was re-monitored.

SEPA commissioned Nuvia Limited to undertake a radiological survey to detect and remove any significant radioactive point sources of contamination in the survey area detailed in Figure 5: Map showing full extent of the 2008 survey area. This survey began on 15th September 2008 and concluded on 19th September 2008. This work was originally planned for July 2008, but was postponed to allow discussions with the MoD to take place. The survey area was larger than previous Groundhog monitoring exercises and included a part of the Fife Coastal Path and a large area of foreshore.

4.1.1. Homogeneous contamination

To determine the concentration of homogeneous radioactivity (in terms of radium-226 and its daughters) in the intertidal area, an in-situ gamma spectrometer was used at a number of locations which could provide information on the concentrations of radionuclides over a large area (around 10 m radius) and produce an average concentration. If large numbers of point sources were present on the beach, this monitoring technique would also include the contribution from these sources. This monitoring procedure was coupled with a sediment sampling exercise to provide a check on the degree of correlation between the findings of the two respective sets of measured data. These measurements were undertaken by the Department of Biological and Environmental Sciences at the University of Stirling on behalf of SEPA.

4.1.2. Heterogeneous contamination

Regarding heterogeneous contamination, information in the RCL Statutory Guidance suggested that exposure conditions, where numerous or single point sources could pose a significant hazard, should be assessed. As in-situ gamma spectrometry provided an average response to large numbers of items from a wide range of activities, a separate monitoring technique was required specifically for the detection of discrete point sources of high activity. For this purpose a ‘backpack’ NaI system was selected which could cover large areas of land rapidly and detect any high-activity point sources on or close to the surface of the beach.

4.2. Survey Equipment

In general, it is accepted that the monitoring instrument used will not have detected all of the radioactive items present at the time of survey. Factors such as orientation of the source in relation to the detector, depth of burial and proximity to the detector will have meant that it is highly likely that some point sources will have been missed by this survey. However, all high activity sources at or near to the surface are likely to have been detected. As the purpose of this work was not to undertake a risk assessment, but to provide the basic data to allow SEPA to make an informed decision on whether areas of Dalgety Bay should be classified as RCL, this technique was appropriate for obtaining a sample of the point sources present on the beach. The assessment does not address material which may be present at distance from the area surveyed, either inland, or on other areas of this or other beaches.

4.2.1. Groundhog survey radiation detection equipment

Two Groundhog Mark I site survey systems were configured, each comprising a 76 x 76 mm sodium iodide (NaI) detector and spectrometry rate-meter. These were connected to a mapping-accuracy GPS receiver and computer data logger. The system was capable of alerting the operator to a change in background count-rate via an audible warning alert system.

The results of the survey are shown as total gamma-ray counts per second (cps) from the NaI detector. Nuvia reported that the common ‘natural background’ level for the detector is the region of 200 – 300 cps, based on surveys in Southern England. As the survey was undertaken over different types of substrate (e.g. sand, pebbles, clay, etc.), the background levels are highly variable which can make detection of a point source difficult. To address this natural variability, a point source detector alarm unit was utilised. The alarm unit recorded a 10 second rolling average of the background cps and alarms if the cps rose above four standard deviations of the 10 second rolling average for a period of 1 second.

The response of the instrument to radium contamination has been calculated using MCNP software, which is a general purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport.

Assuming a background radiation level of 150 cps and a threshold for positive identification of a radioactive item producing a count rate of 75 cps above background level, computer modelling has indicated minimum quantities of radium-226 detectable by the detector deployed 0.2 metres above the ground surface for a range of source depths. The minimum detectable activity versus depth is shown in Table 2:

Table 2: Instrument Detector Response

Depth of Source (cm)	Minimum Detectable Activity (kBq ^{226}Ra)
Surface	20
10	70
20	170

4.2.2. Other instruments used during the survey

Additional equipment that was used during the excavation/monitoring survey included:

A ‘mapping grade’ GPS system was used for this survey. GPS data was processed to provide sub-metre horizontal information to Ordnance Survey National Grid (OSNG).

A Thermo Fisher Scientific (Mini) Instruments 44B probe and a Mini 900 Ratemeter were used. This probe has a small (32 mm diameter) sodium iodide crystal which makes the instrument highly suited for pinpointing gamma-emitting radioactive sources during excavation work.

A Thermo Fisher Scientific (NET) DP6AD (alpha/beta probe) with Electra 1A Ratemeter was used also. This instrument has a dual phosphor DP6 probe giving both alpha and beta monitoring capability. The probe area is 100 cm^2 and comprises a metal grill in close proximity to the light tight screen, which provides high detection efficiency for alpha and medium/high energy beta radiation. Nuvia used this instrument to provide an in-field assessment of radiation dose rates.

The Eberline RO-2W can be used to monitoring for beta-gamma or gamma-ray radiation. For this survey, the instrument response was dominated by beta emissions. Nuvia used this instrument to determine the dose rate at contact and at 250 mm from the recovered radioactive item. Nuvia stated that this instrument can be used to determine skin dose rates for point sources less than 5 mm in diameter by multiplying the value by 70.

4.3. Survey Area

The monitoring work comprised a surface radiation survey within a defined area (Figure 4) to identify and record the location of radioactive point sources. Following detection of any radioactive ‘hot-spot’, Nuvia staff attempted to identify the location of the source for retrieval, analysis and subsequent disposal.

The area surveyed comprised the New Harbour area, headland, slipways to the redundant pipeline area and the top 10 metres from the High Water Mark to the sewage works on the eastern side of Dalgety Bay. The survey area was separated into three parts:

1. From the disused harbour round to the redundant pipeline (marked green on Figure 4); monitoring from high water to as close to low water as possible, without compromising safety. The estimated dimensions are 1.08 x 0.03 km, giving an area of approximately 3.2 hectares.

2. From the redundant pipeline to the eastern most point of the area bounding the sewage works (blue area marked on Figure 4); monitoring the upper 0.01 km of the foreshore. The estimated dimensions are 1.56 x 0.01 km, giving an area of approximately 1.56 hectares.

3. The Fife Coastal Path from its junction with The Wynd, through to the graveyard at St. Bridget’s Kirk (brown area marked on Figure 4). This path is approximately 2 metres wide and 1.2 km long, giving an area of approximately 0.24 hectares.

The total survey area was approximately 5 hectares.

4.4. Methodology

The survey was undertaken utilising two hand-held Groundhog systems at a distance of 0.2 m above the ground surface. The operator would walk at a speed of approximately 1 ms^{-1} covering a 1-metre strip of ground. Every one second a measurement was recorded automatically, thus providing a measurement of one reading per one square metre of ground.

If the background change alarm sounded, the operator reversed over the area and repeated the walk over. If the alarm sounded on the second pass, the area was subject to intrusive investigation.

On locating the area of interest, the surface was surveyed with the Groundhog detector and the 44B probe and excavation was undertaken with a spade and/or a trowel in order to isolate any point source. Each excavated item was given a unique identification number and photographed and the following information recorded:

- Location
- Depth
- Mass
- Physical dimensions
- Brief description
- Count-rate

The field data were subsequently differentially corrected to enhance positional accuracy and interpolated contour plots of radiation levels produced.

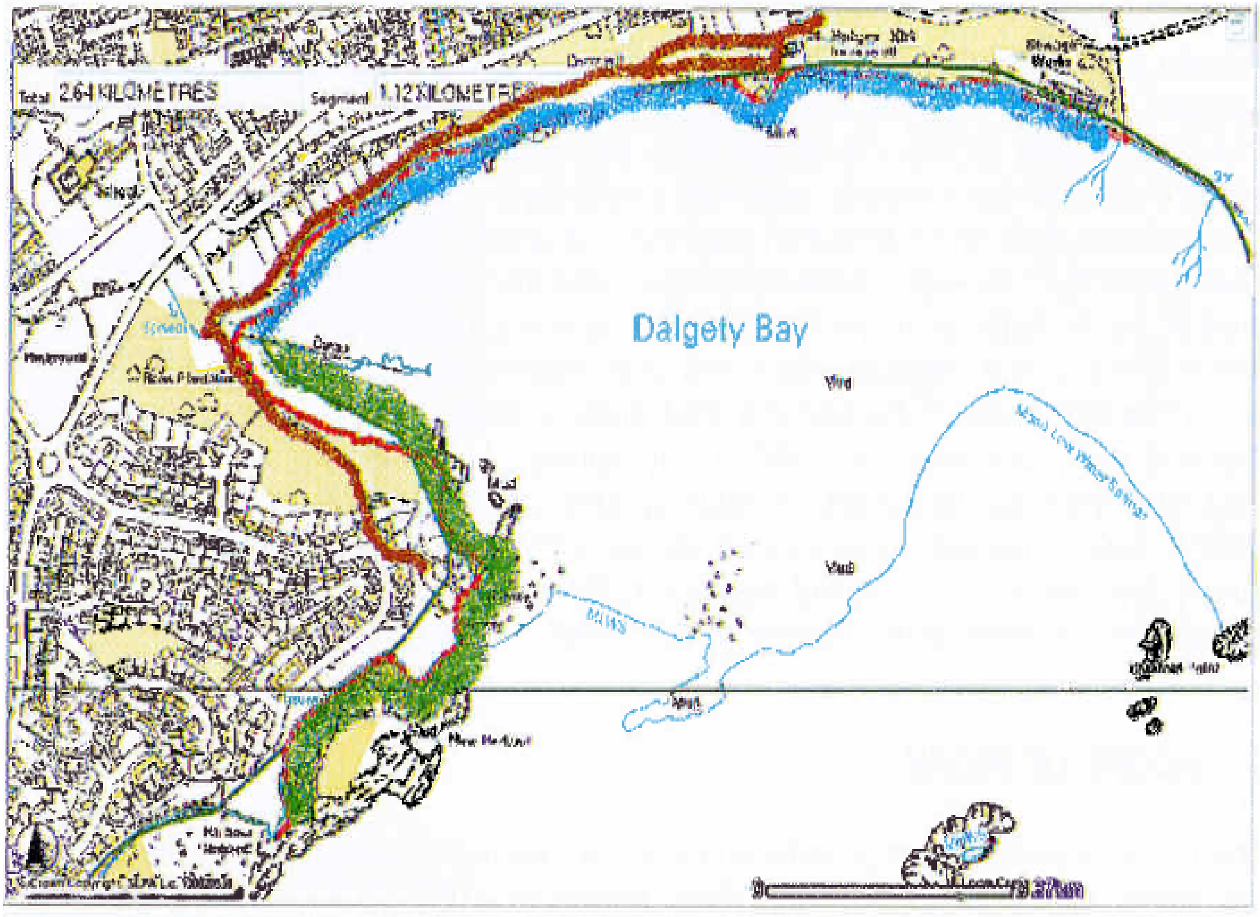

Figure 4: 2008 Planned survey area

5. Field Observations

This section details observations made during the September monitoring exercise, including individual habits that may give rise to exposure pathways.

5.1. Observations of habits

Over the five days of survey work, it was noted that the area was used by bait diggers, sunbathers, dog walkers, horse riders and one individual who was asleep on the intertidal area. SEPA was also aware of the regular visits of a class of nursery-school children to the area. Thus, we conclude, albeit from a short observation period, that the area is used by all age ranges undertaking a range of activities. In our 2006 assessment we considered only doses to adults using the beach. Following the observations in the field and a meeting with MoD Defence Estates, we have now included dose assessments for members of the public of age ranges who could be using the beach.

5.2. Point source friability

During the recovery of two suspected point sources, a number of point sources were recovered during the same excavation. This would seem to suggest that the sources are undergoing physical breakdown and will gradually reduce in size. However, as many of the larger point sources recovered appeared to have most of the radioactivity concentrated in a localised area rather than being distributed throughout the material, it is unlikely that any breakdown would result in the activity being evenly distributed between the resultant pieces. Thus, for prospective protection purposes, it may be necessary to consider the potential effects should large point sources break down into physically smaller sources, but with consequent higher specific activities for some items.

It is also of note that, during laboratory analysis, it was apparent that a number of reported single point sources were in fact multiple fragments, observations which provide further evidence that many of the sources are highly fragile.

5.3. Re-population rates

Previous monitoring and recovery exercises at Dalgety Bay have indicated that within a year, contamination had returned to similar (re-populated) levels. It was decided to undertake a very basic field experiment to try and assess the re-population rate. In practice this meant that the area where previous surveys had indicated the greatest concentration of point sources, was monitored and all detected items removed on Day 1 and 2. On Day 5 this small area was re-monitored and two further point sources were identified and recovered. These sources could have already been present on the beach and either buried at depth or ‘missed’ during the first monitoring exercise. However, these sources were located close to the surface and with activities which should have been readily detectable. Both of these were relatively small (a few mm) and it is suggested that these may have been brought in on the spring tide which occurred that week, as the otherwise stable weather conditions may not have resulted in significant mobilisation of sediment. These observations suggest that there is a rapid re-population of the area.

6. Monitoring and Analytical Results

This section details the results of Groundhog and in-situ gamma-spec monitoring, laboratory analysis and field observations.

6.1. Groundhog survey data

A total of 39 items were retrieved from 33 locations across the survey area during the five-day survey; a summary of which is reported in Table 3. The depth at which these items were retrieved ranged from surface to 300 mm below ground level. The size of the recovered items varied from less than 1 mm to 110 mm, the mass range was from less than 1 g to greater than 250 g (in-field measurements). Nuvia field data are provided in Table 4, however, due to the higher precision of laboratory data, the HPA-RPD data (Table 5, 6 and 7) were used for the dose assessments.

Table 3: Summary of areas surveyed where material was detected and removed

Area Figure Reference/Description	Nuvia Reference of Recovered Items (DB/08/0..)	Total Items
Headland in front of rock armoured cliffs	14 - 16, 21, 33	5
Slipway survey	01 – 13, 17, 23 – 31, 34	24
Slipway re-survey	38-39	2
Sailing Club – Ross Plantation, Western Sealstrand	18-20, 22, 32, 35	6
Fife Coastal Path at Sealstrand	36, 37	2

Figure 5 shows the full extent of the survey area and location of detected items and Figure 6 shows the locations of the point sources that were detected and recovered in 2008.

No items were recovered from the New Harbour, however, upon evaluating the Groundhog data, an area of elevated count rate was identified. The area was approximately 6 metres in diameter and further investigation by Nuvia did not result in the detection of any point sources. A sample of sediment was taken for further analysis and an in-situ gamma-ray spectrometry measurement was taken by staff from Stirling University on 5 November 2008. Analysis of these additional data is discussed in Section 6.4.

Figure 7 details the locations of recovered items for the area in front of the rock-armoured cliff face round to the old pipeline.

The area protected by the rock armour is believed to contain materials that were disposed of from the former RNAS Donibristle airfield. This area is largely rocky. Metallic items, bricks, sections of wall and suspected asbestos sheeting can be identified in this area of the Bay. Five radioactive items were recovered from this area.

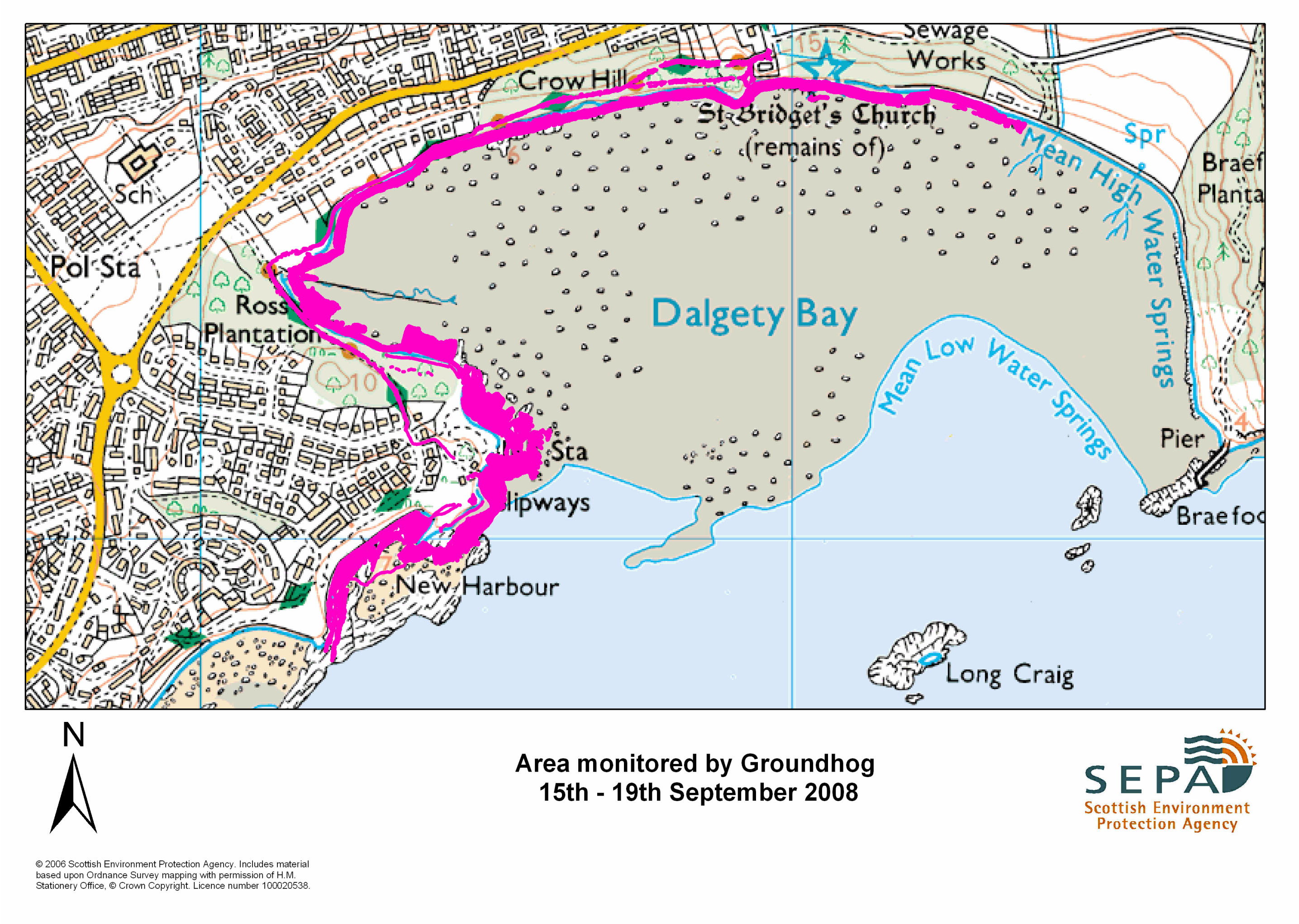

Figure 5: Map showing full extent of the 2008 survey area

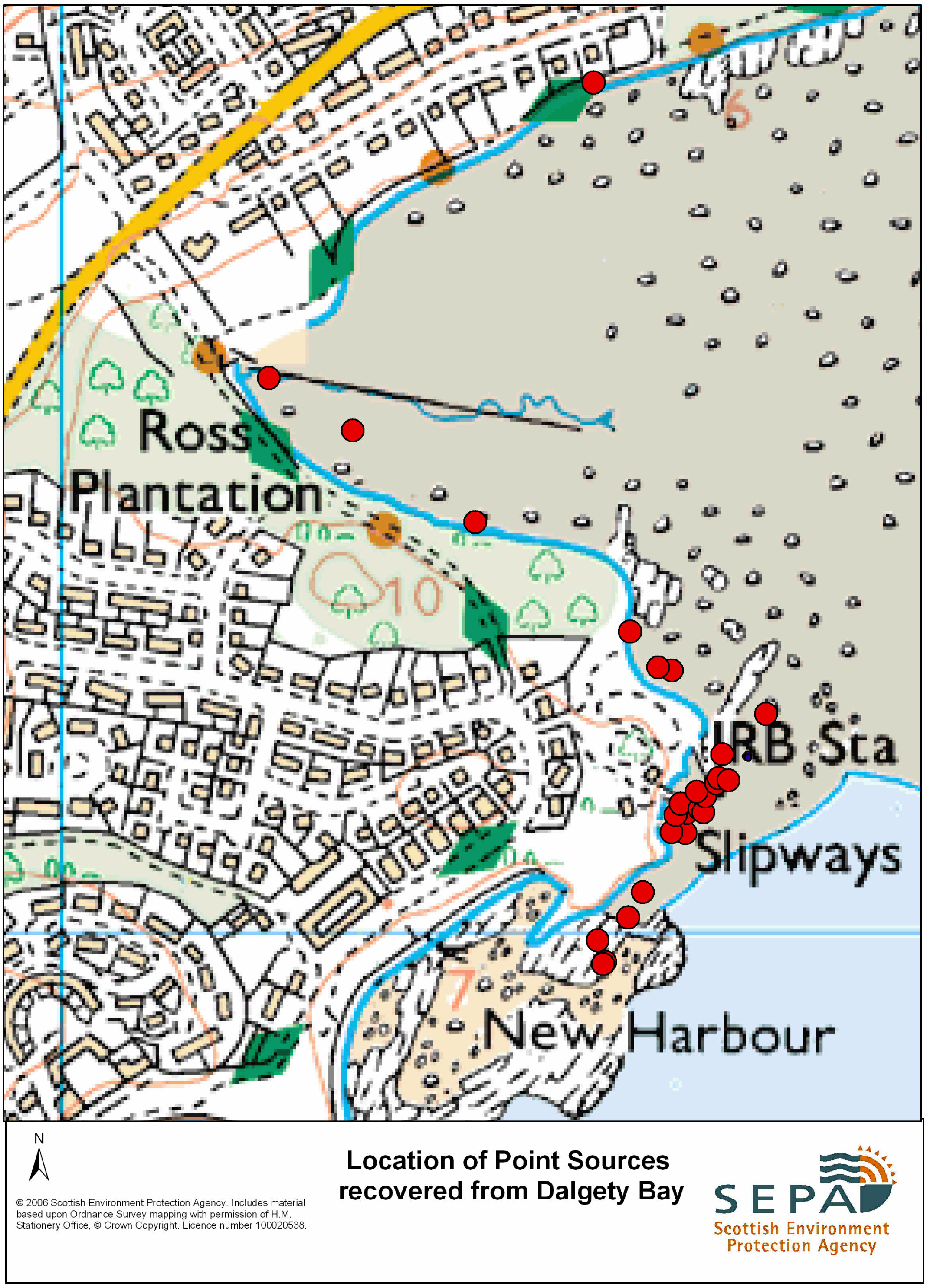

Figure 6: Location of point sources recovered from Dalgety Bay (2008)

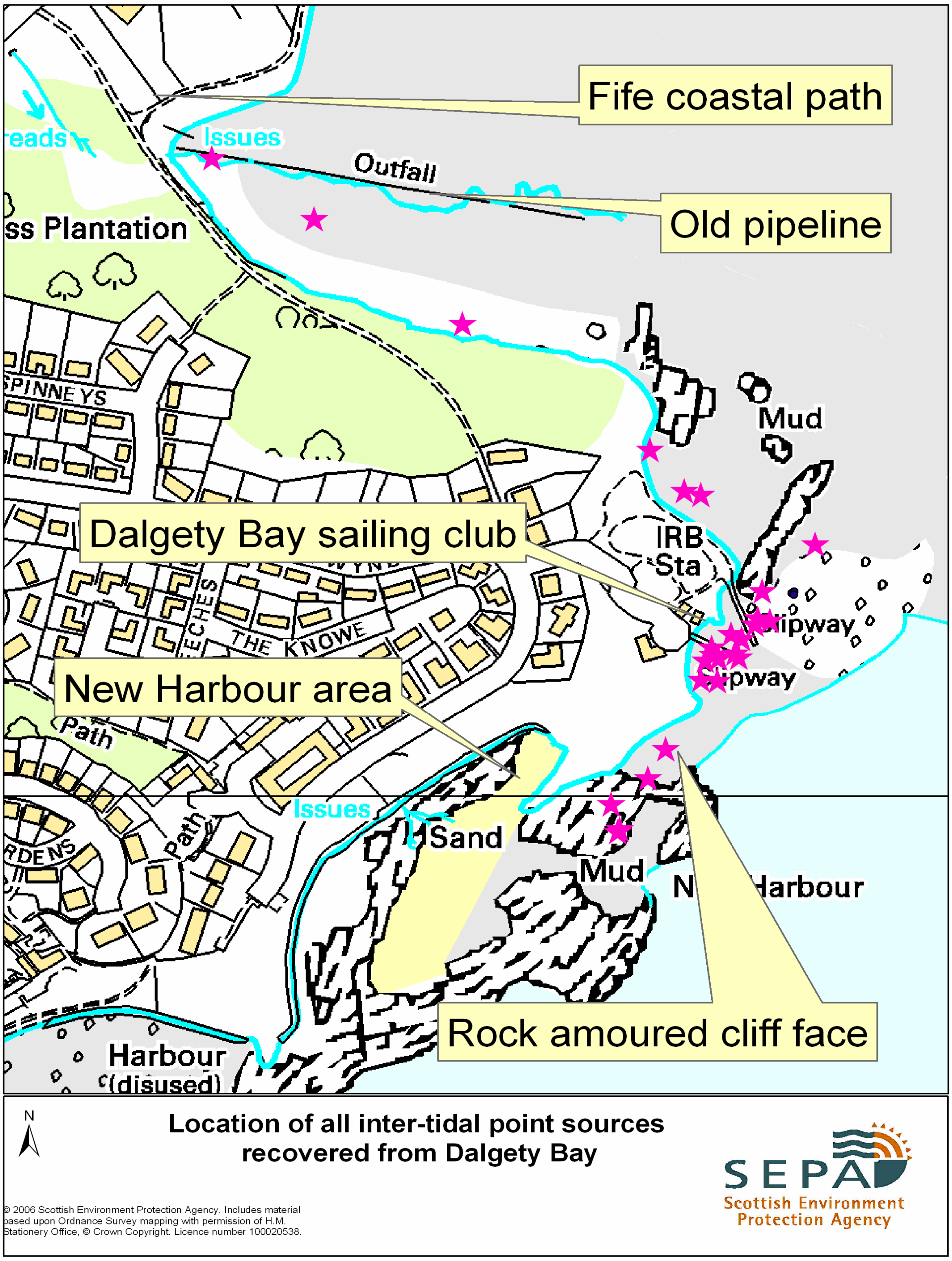

Figure 7: Location of all inter-tidal point sources recovered from Dalgety Bay (2008)

Figure 7 also details the location of recovered items in the area from the Sailing Club foreshore, along the foreshore at Ross Plantation to the area in front of Sealstrand beyond the old redundant pipeline (now removed labelled ‘outfall’). This section also comprised a terrestrial survey of the Fife Coastal Path. Sections of this area of the coastline were difficult to monitor due to the varying stability of the sediment. Six items were detected and recovered from this area.

Figure 8 details the locations of recovered items for the slipway area in front of the Dalgety Bay Sailing Club. This area has been monitored several times previously and radioactive point sources frequently detected. Twenty-four items were recovered from this section and an additional 2 point sources during the re-survey of the area at the end of the week’s monitoring. The locations of the items recovered in the re-survey and the activities (cps) of these finds were recorded. The significance of the items recovered in the re-survey is discussed in Section 5.3.

The upper areas of the beach from Sealstrand to the sewage works at St. Bridget’s Church were also monitored. No items were detected along this upper section of coastline, however, two items were recovered from an area of interest (elevated detection response) along the Fife Coastal Path. The location of these two point sources is shown in Figure 9.

It is notable that at two locations multiple point sources were recovered from the same physical location (i.e. within the same hole dug to recover the point source). It is suggested that this indicates that the sources are undergoing physical breakdown and as a result will become progressively smaller in size. If this fragmentation is occurring generally, sources that were physically too large for ingestion or inhalation may become sufficiently small to be ingested or inhaled. Further, given that the radioactivity was generally localised at one location on such large items, if breakdown occurs, the activity is unlikely to be equally distributed between each piece.

6.2. Gamma-ray spectrometric analysis of point sources

Point sources recovered from Dalgety Bay were sent to the Health Protection Agency – Radiation Protection Division’s Glasgow Laboratory for analysis. The point sources were analysed by gamma-ray spectrometry to determine the activity of key radionuclides. Results for the 39 point sources are detailed in Table 5: Dalgety Bay 2008 HPA point source gamma-ray spectrometric data (HPA). All positively detected nuclides are reported. It is noted that the ^{210}Pb results have been made available by the HPA at SEPA’s request with the caveat that measurement of ^{210}Pb is not UKAS accredited.

Physical measurements and photographs were obtained for each point source. Information and the physical measurements are provided in Table 6: Point source properties 2008 (HPA).

It is possible that due to laboratory conditions the concentrations reported by HPA for radium daughters may be different from that in the field. Further details on this are reported in Appendix F. We consider that the HPA data are valid for the radium daughters.

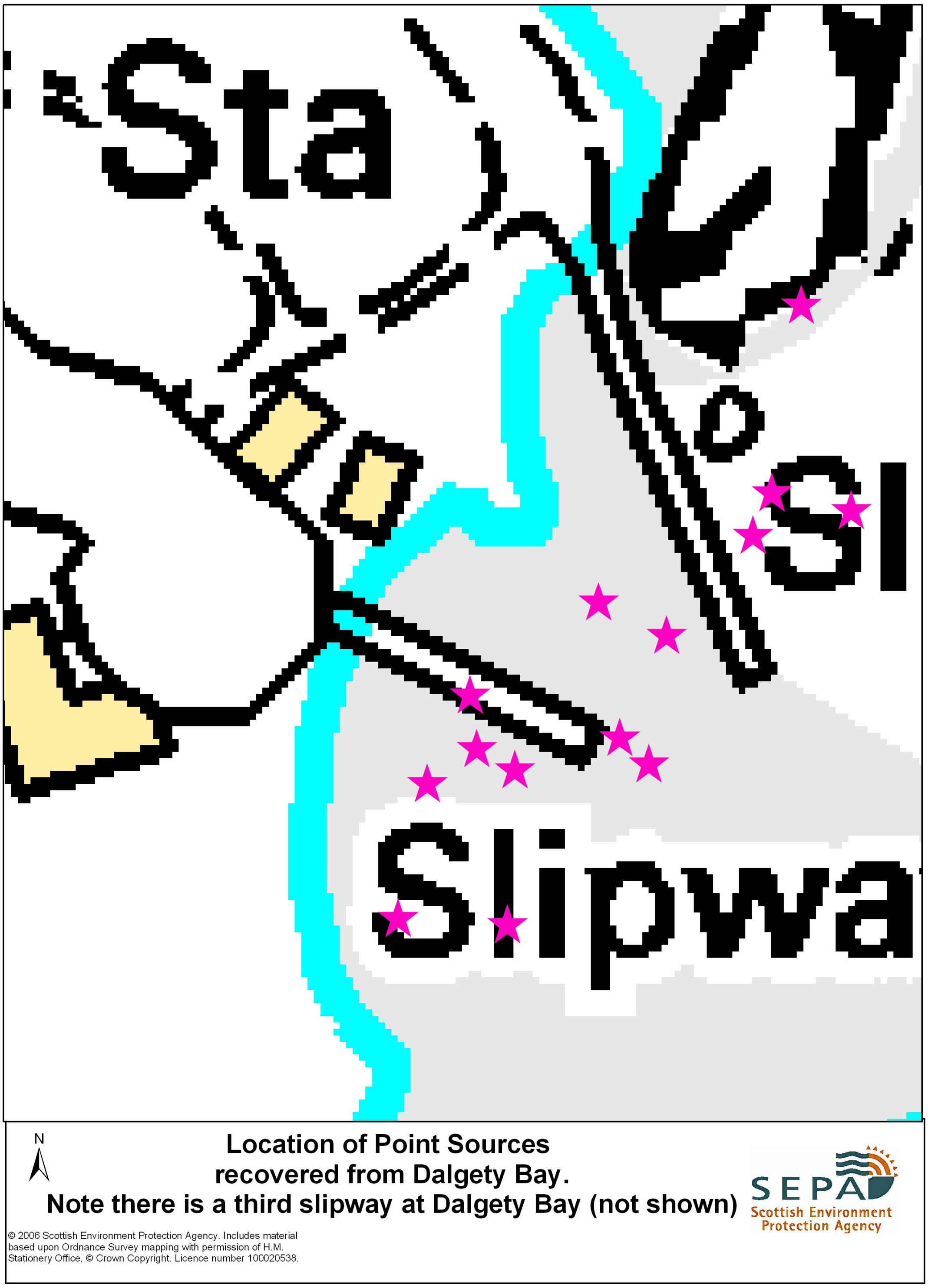

Figure 8. Location of point sources recovered from Dalgety Bay Sailing Club slipway area

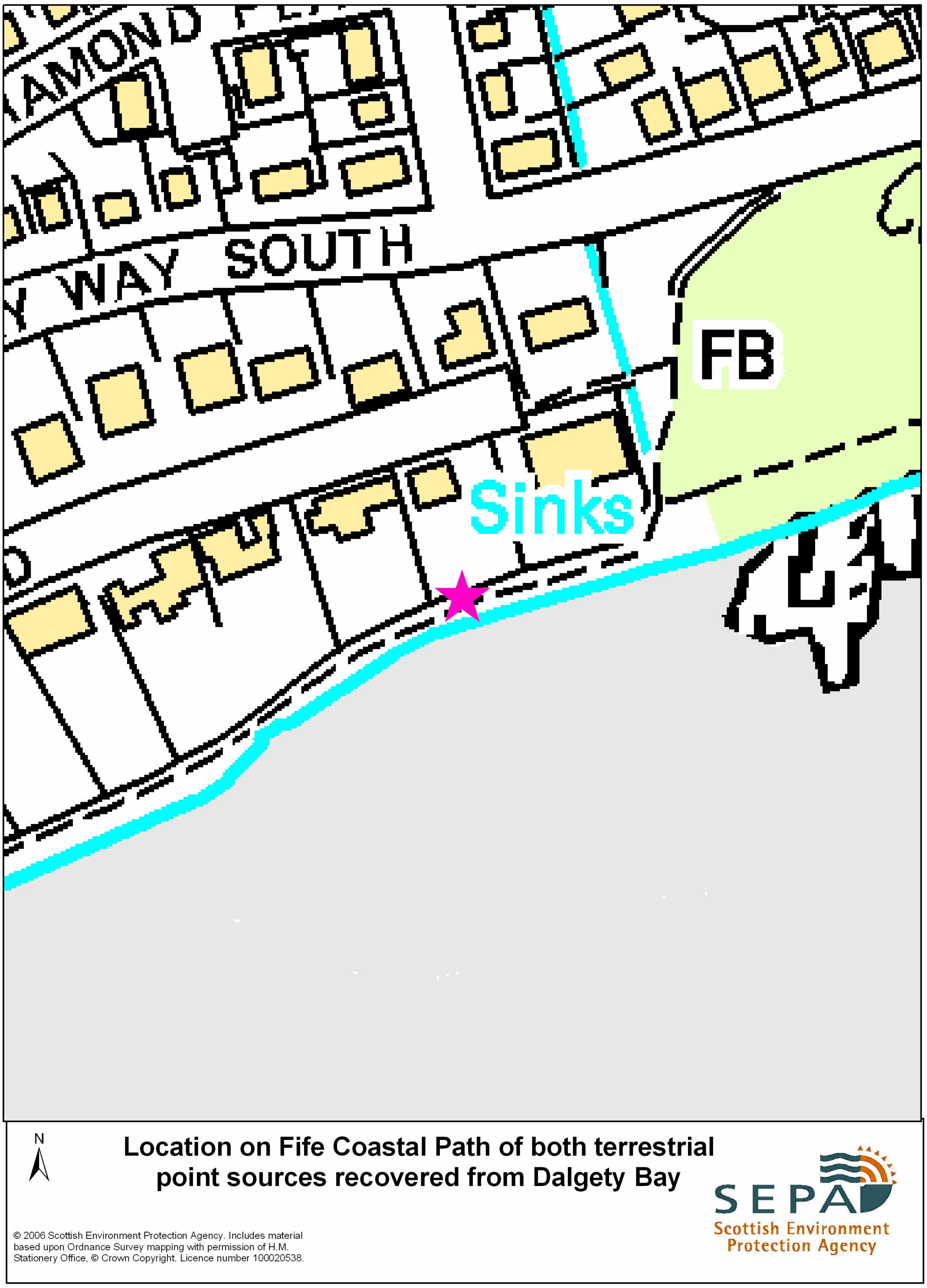

Figure 9. Location of terrestrial point sources

Table 4: Dalgety Bay 2008 Nuvia Record (Nuvia)

Date	ID no.	Easting	Northing	Burial depth (m)	Weight (g)	Physical dimensions (mm)			Volume (mm^3)	DP6/Electra β (cps)	RO2 - Max contact dose rate βγ (μSv/h)	RO2 - Max dose rate βγ (μSv/h) @ 0.25 m
						Length	Width	Depth				
15.09.08	DB/08/001	316486.62	683097.10	0.15	0.358	5	5	< 1	< 25	20000	500	14
15.09.08	DB/08/002	316489.93	683079.06	0.10	5.700	20	15	10	3000	860	28	< 2
15.09.08	DB/08/003	316490.63	683094.21	0.15	2.514	15	10	10	1500	1930	50	< 2
15.09.08	DB/08/004	316485.54	683100.33	0.02	0.065	3	4	< 1	< 12	815	38	< 2
15.09.08	DB/08/005	316478.86	683079.47	0.10	0.721	10	7	5	350	18000	500	16
15.09.08	DB/08/006	316481.33	683091.81	0.25	150.158	70	70	25	122500	16000	430	12
16.09.08	DB/08/007	316498.97	683099.79	0.15	15.256	70	30	10	21000	4930	600	12
16.09.08	DB/08/008	316501.92	683097.10	0.10	19.582	70	25	10	17500	12300	330	16
16.09.08	DB/08/009	316503.76	683109.89	0.10	10.579	70	20	10	14000	4213	100	4
16.09.08	DB/08/010	316496.81	683113.53	0.10	> 250.000	110	30	70	> 231000	250	20	< 2
16.09.08	DB/08/011	316512.46	683115.15	0.10	16.773	30	30	10	9000	1320	50	2
16.09.08	DB/08/012	316514.30	683119.41	0.30	1.021	10	10	5	500	9470	290	7
16.08.09	DB/08/013	316522.12	683117.92	0.30	37.325	50	40	30	60000	43400	1400	40
16.09.08	DB/08/014	316425.28	682978.40	0.10	167.257	60	60	50	180000	7934	120	10
16.08.09	DB/08/015	316443.58	683013.09	0.10	118.184	50	40	60	120000	3093	50	2
16.08.09	DB/08/016	316455.21	683032.88	0.10	17.619	20	30	20	12000	2434	90	5
16.09.08	DB/08/017	316552.58	683171.86	0.20	76.289	85	45	20	76500	85	5	< 2
16.09.08	DB/08/018	316478.24	683206.35	0.02	2.076	70	10	5	3500	605	22	< 2
16.09.08	DB/08/019	316467.61	683208.90	0.02	6.589	70	15	5	5250	5195	200	5
16.09.08	DB/08/020	316162.38	683434.78	0.10	51.38	55	45	30	74250	1183	30	< 2
17.09.08	DB/08/021	316424.12	682976.80	Surface	38.508	50	25	30	37500	3445	100	5
17.09.08	DB/08/022	316324.93	683323.14	0.10	1.196	30	10	5	1500	1350	47	< 2
17.09.08	DB/08/023	316536.51	683138.73	0.05	148.368	50	70	30	105000	104	2	< 2
17.09.08	DB/08/024	316538.09	683139.68	0.05	50.832	50	20	40	40000	1143	36	< 2
17.09.08	DB/08/025	316536.51	683138.73	0.05	89.105	80	50	20	80000	130	4	< 2
17.09.08	DB/08/026	316537.98	683137.82	0.05	19.441	30	15	35	15750	140	4	< 2
17.09.08	DB/08/027	316537.98	683137.82	0.05	26.477	35	20	45	31500	147	4	< 2
17.09.08	DB/08/028	316537.98	683137.82	0.10	13.06	30	20	20	12000	35	2	< 2
17.09.08	DB/08/029	316537.98	683137.82	0.10	3.368	15	10	20	3000	4	2	< 2
17.09.08	DB/08/030	316537.98	683137.82	0.10	10.886	20	15	25	7500	15	< 2	< 2
17.09.08	DB/08/031	316537.98	683137.82	0.10	2.774	20	20	5	2000	12	< 2	< 2
18.09.08	DB/08/032	316443.00	683238.14	0.10	11.154	25	15	20	7500	2650	60	2
18.09.08	DB/08/033	316419.72	682995.50	0.05	2.871	20	10	10	2000	760	19	< 2
18.09.08	DB/08/034	316518.05	683141.13	Surface	0.029	3	2	2	12	7880	330	7

Date	ID no.	Easting	Northing	Burial depth (m)	Weight (g)	Physical dimensions (mm) Length	Width	Depth	Volume (mm^3)	DP6/Electra β (cps)	RO2 - Max contact dose rate βγ (µSv/h)	RO2 - Max dose rate βγ (µSv/h) @ 0.25 m
18.09.08	DB/08/035	316227.98	683393.16	Surface	0.283	10	5	5	250	2400	80	3
19.09.08	DB/08/036	316416.83	683667.40	0.30	0.073	10	5	5	250	1430	44	< 2
19.09.08	DB/08/037	316416.83	683667.40	0.30	0.176	20	10	2	400	270	8	< 2
19.09.08	DB/08/038	316486.27	683097.72	0.02	0.345	10	10	1	100	4890	160	4
19.09.08	DB/08/039	316480.72	683088.23	0.02	0.020	5	3	1	15	3450	140	< 2

Table 5: Dalgety Bay 2008 HPA point source gamma-ray spectrometric data (HPA)

HPA Ref	NUVIA Ref	Ra-226 Bq/sample ± 2σ			Pb-214 Bq/sample ± 2σ			Bi-214 Bq/sample ± 2σ			Pb-210 * Bq/sample ± 2σ		
08-6300	DB/08/001	122000	±	37000	109000	±	33000	102000	±	31000	73000	±	49000
08-6301	DB/08/002	27000	±	8100	22800	±	6900	24400	±	7400	6900	±	4800
08-6302	DB/08/003	33100	±	10000	28400	±	8600	28900	±	8700	13000	±	8800
08-6303	DB/08/004	5500	±	1700	4490	±	1400	4370	±	1400	2000	±	1900
08-6304	DB/08/005	315000	±	95000	278000	±	84000	268000	±	81000	134000	±	90000
08-6305	DB/08/006	624000	±	190000	592000	±	180000	619000	±	190000	**Not Available**		
08-6316	DB/08/007	313000	±	94000	257000	±	78000	252000	±	76000	108000	±	73000
08-6317	DB/08/008	187000	±	57000	159000	±	48000	152000	±	46000	90000	±	60000
08-6318	DB/08/009	90000	±	27000	81600	±	25000	78200	±	24000	53000	±	3600
08-6319	DB/08/010	3400	±	1100	3550	±	1100	4050	±	1300	106	±	76
08-6320	DB/08/011	13200	±	4000	8030	±	2500	3010	±	910	2870	±	800
08-6321	DB/08/012	147000	±	45000	132000	±	40000	128000	±	39000	52000	±	35000
08-6322	DB/08/013	870000	±	270000	749000	±	230000	752000	±	230000	410000	±	270000
08-6323	DB/08/014	420000	±	130000	385000	±	120000	418000	±	130000	79000	±	53000
08-6324	DB/08/015	150000	±	45000	119000	±	36000	149000	±	45000	23000	±	17000
08-6325	DB/08/016	105000	±	32000	95000	±	29000	99000	±	30000	**Not Available**		
08-6326	DB/08/017	5300	±	1600	4300	±	1300	4900	±	1500	710	±	320
08-6327	DB/08/018	5000	±	1500	3040	±	920	1000	±	300	3500	±	1100
08-6328	DB/08/019	24000	±	7200	17900	±	5400	4200	±	1300	16000	±	2600
08-6329	DB/08/020	42000	±	13000	34400	±	11000	32000	±	9600	18800	±	6500
08-6330	DB/08/021	116000	±	35000	94000	±	29000	110000	±	33000	23000	±	17000
08-6331	DB/08/022	10000	±	3000	5600	±	1700	2070	±	630	8100	±	1100
08-6332	DB/08/023	4200	±	1300	3490	±	1100	3550	±	1100	1470	±	510
08-6333	DB/08/024	36000	±	11000	30700	±	9300	32500	±	9800	16100	±	3700
08-6334	DB/08/025	8200	±	2500	6950	±	2100	7100	±	2200	2670	±	920
08-6335	DB/08/026	2240	±	680	1420	±	430	510	±	160	1050	±	27
08-6336	DB/08/027	2330	±	700	1480	±	450	440	±	140	968	±	32
08-6337	DB/08/028	920	±	280	580	±	180	210	±	63	343	±	37
08-6338	DB/08/029	75	±	23	48	±	15	17	±	6	36.00	±	0.92
08-6339	DB/08/030	201	±	61	120	±	36	45	±	14	77.6	±	7.6
08-6340	DB/08/031	97	±	30	61	±	19	22	±	7	60.2	±	5.6
08-6341	DB/08/032	109000	±	33000	90500	±	27000	97800	±	30000	36000	±	24000

HPA Ref	NUVIA Ref	Ra-226 Bq/sample ± 2σ			Pb-214 Bq/sample ± 2σ			Bi-214 Bq/sample ± 2σ			Pb-210 * Bq/sample ± 2σ		
08-6343	DB/08/034	28500	±	8600	13400	±	4100	7460	±	2300	21600	±	3500
08-6344	DB/08/035	7300	±	2200	4540	±	1400	2010	±	610	5610	±	150
08-6345	DB/08/036	3220	±	1000	2000	±	600	940	±	290	3010	±	280
08-6346	DB/08/037	480	±	150	310	±	93	150	±	45	451	±	44
08-6347	DB/08/038	44000	±	14000	35700	±	11000	34800	±	11000	16000	±	11000
08-6348	DB/08/039	15000	±	4500	8680	±	2700	3000	±	900	13100	±	1760

* Result not Accredited by UKAS

Table 6: Point source properties 2008 (HPA)

HPA Ref	NUVIA Ref	Point source mass (g)	Initial Size (Nuvia) Length * Width * Depth (cm)	Point source mass (g) (Leached)	Size of point source taken for leaching Length * Width * Depth (cm)	Description
08-6300	DB/08/001	0.358		0.0152	0.3 * 0.2 * 0.1	Mixture of numerous fragments, activity in finest point sources
08-6301	DB/08/002	5.653	2.0 * 1.5 * 1.0	--	--	Solid point source with coating of sand
08-6302	DB/08/003	2.514	1.5 * 1.0 * 1.0	2.4054	1.5 * 1.0 * 1.0	Solid point source - minimum sand attached
08-6303	DB/08/004	0.065	0.3 * 0.4 * 0.1	0.0551	0.3 * 0.4 * 0.1	Solid fragment - very small
08-6304	DB/08/005	0.721	1.0 * 0.7 * 0.5	0.5815	1.2 * 0.8 * 0.5	Solid point source showing activity, small inactive fragments present
08-6305	DB/08/006	151.6521	7.0 * 7.0 * 7.0	--	--	Solid point source with a coating of sand and small stones
08-6316	DB/08/007	15.1955	7.0 * 3.0 * 1.0	0.1833	0.2 * 0.1 * 0.1	Initial sample contain sand and water mix - point sources separated out
08-6317	DB/08/008	20.0078	7.0 * 2.5 * 1.0	--	--	Sample contained 90% sand/stones and water
08-6318	DB/08/009	10.8457	7.0 * 2.0 * 1.0	0.0446	0.6 * 0.3 * 0.2	Initial sample contain sand and water mix - point sources separated out
08-6319	DB/08/010	115.6	11.0 * 3.0 * 7.0	--	--	Solid point source with small amount of stones and sand
08-6320	DB/08/011	17.0231	3.0 * 3.0 * 1.0	--	--	Solid point source
08-6321	DB/08/012	1.021	1.0 * 1.0 * 0.5	1.0085	1.3 * 1.0 * 0.5	Solid point source
08-6322	DB/08/013	36.9852	5.0 * 4.0 * 3.0	--	--	Solid point source
08-6323	DB/08/014	167.891	6.0 * 6.0 * 5.0	--	--	Solid Particle broken into 3 parts (all active)
08-6324	DB/08/015	118.184	5.0 * 4.0 * 6.0	--	--	Sample wet and a small amount of fragments present but main mass has highest activity
08-6325	DB/08/016	17.59	2.0 * 3.0 * 2.0	--	--	Solid point source with some sand/stones
08-6326	DB/08/017	76.3555	8.5 * 4.5 * 2.0	--	--	Solid point source with some sand/stones
08-6327	DB/08/018	2.0089	7.0 * 1.0 * 0.5	--	--	Small sample but wet - Activity in main concentration of sand
08-6328	DB/08/019	6.6051	7.0 * 1.5 * 0.5	--	--	Small sample but wet - Activity in main concentration of sand
08-6329	DB/08/020	51.3527	5.5 * 4.5 * 3.0	--	--	Large part of mass made up of clay /sand - solid point source within clay/sand mix. Solid point source approximately 1.0 * 1.0 *1.0 in size
08-6330	DB/08/021	38.5144	5.0 * 2.5 * 3.0	--	--	Solid point source
08-6331	DB/08/022	1.2368	3.0 * 1.0 * 0.5	--	--	Mass of small point source
08-6332	DB/08/023	148.3369	5.0 * 7.0 * 3.0	--	--	Solid point source

08-6333	DB/08/024	50.8453	5.0 * 2.0 * 4.0	--	--	Solid point source with coating of sand
08-6334	DB/08/025	90.0014	8.0 * 5.0 * 2.0	--	--	Solid point source with coating of sand
08-6335	DB/08/026	19.4101	3.0 * 1.5 * 3.5	--	--	Solid point source with coating of sand
08-6336	DB/08/027	26.5550	3.5 * 2.0 * 4.5	--	--	Solid point source with coating of sand
08-6337	DB/08/028	13.1212	3.0 * 2.0 * 2.0	--	--	Solid point source with coating of sand
08-6338	DB/08/029	3.4899	1.5 * 1.0 * 2.0	--	--	Solid point source with coating of sand
08-6339	DB/08/030	10.5114	2.0 * 1.5 * 2.5	--	--	Solid point source with coating of sand
08-6340	DB/08/031	2.774	2.0 * 2.0 * 0.5	2.9230	2.5 * 2.0 * 0.5	Solid point source
08-6341	DB/08/032	11.154	2.5 * 1.5 * 2.0	10.8344	2.5 * 1.5 * 2.0	Solid point source with coating of sand
08-6342	DB/08/033	2.871	2.0 * 1.0 * 1.0	2.8657	2.0 * 1.0 * 1.0	Solid point source with sand
08-6343	DB/08/034	0.029	0.3 * 0.2 * 0.2	0.0273	0.3 * 0.2 * 0.2	Solid point source
08-6344	DB/08/035	0.283	1.0 * 0.5 * 0.5	0.2582	1.0 * 0.5 * 0.5	Solid point source
08-6345	DB/08/036	0.073	1.0 * 0.5 * 0.5	0.1271	1.0 * 0.5 * 0.5	Solid point source with sand
08-6346	DB/08/037	0.176	2.0 * 1.0 * 0.2	0.1418		Numerous very small point source
08-6347	DB/08/038	0.345	1.0 * 1.0 * 0.1	0.1724	1.0 * 0.2 * 0.1	Very small clumps of point source and sand
08-6348	DB/08/039	0.020	0.5 * 0.3 * 0.1	0.0152	0.2 * 0.1 * 0.1	Very small point source on one active point source

	Nuvia data

6.3. Solubility testing of point sources

In order for SEPA to have sufficient data to draw comparisons with the criteria specified in the RCL Statutory Guidance, it was necessary to provide some general estimate of the committed effective dose resulting from the ingestion of a point source. Time constraints meant that a full risk assessment was not possible. As only an indicative range of dose estimates was needed, a basic solubility experiment in dilute hydrochloric acid (HCL) was undertaken. Accordingly, 16 point sources were selected for the solubility testing on the basis of physical size across the range of reported activities. The leachate results of these point sources reported in Table 7, showed a range from less than 1 to 7 %. Although the maximum value of this range is lower than the maximum value reported in earlier work (SEPA, 2006), the methodology is slightly different. In comparing the 2006 and 2008 work overall the range of solubilities is similar.

Although the experimentally-determined data of the solubilities for a number of sources are presented in Table 7, these data should be considered as indicative, as the reagent was not a true representation of the matrix of enzymes and chemicals present in the stomach and the associated gastrointestinal (GI) tract. Therefore, the resultant leachate could produce an over, or under estimate of the true solubility of these sources, should one be ingested. For the purposes of this assessment we have reported assessed doses (with their limited accuracy) using the solubility as reported.

For a full risk assessment it is recommended that an improved representation of gut conditions is used, similar to that which was adopted for SEPA's investigation of the solubility of the Dounreay fuel fragments.

6.4. In-situ survey work and sediment analysis

The Department of Environmental and Biological Sciences at Stirling University was commissioned to provide on-site in-situ gamma-ray spectrometry analysis over several areas of sediment. Additionally, several samples of sediment were taken in order to provide a comparison with the in-situ results.

Over the five days of surveying, 44 locations were monitored using the in-situ gamma spectrometry technique. Ten samples of sediment were taken and analysed. Two of the thirty-nine point sources which were recovered were located in the Fife Coastal Path. An area of significant contamination was also detected on the Coastal Path. Data are presented in Table 8.

Table 9 reports data of the sediment samples analysed by gamma spectrometry.

6.4.1. Areas of interest

Two areas of interest (elevated count rates) were identified during the survey, one where two point sources were recovered and a further area where no point sources were recovered. At both of these locations a sample of the material was taken for laboratory analysis at Stirling University. The results of this analysis are shown in Table 10.

Table 7: Leachate results and selection (HPA)

HPA Ref	NUVIA Ref	Leachate Ra-226 (Bq)	±	2σ	% of Original Activity	Pb-214 Bq	Bi-214 Bq	Pb-210 Bq
08-6300	DB/08/001	206	±	20	0.17%	184.05	172.23	123.26
08-6302	DB/08/003	23	±	3	0.069%	19.73	20.08	9.03
08-6303	DB/08/004	345	±	33	6.27%	281.65	274.12	125.45
08-6304	DB/08/005	100	±	12	0.032%	88.25	85.08	42.54
08-6316	DB/08/007	12510	±	880	4.00%	10271.79	10071.95	4316.55
08-6318	DB/08/009	32	±	4	0.036%	29.01	27.80	18.84
08-6321	DB/08/012	805	±	80	0.55%	722.86	700.95	284.76
08-6340	DB/08/031	1.00			1.03%	0.63	0.23	0.62
08-6341	DB/08/032	1.1	±	0.9	0.00%	0.91	0.99	0.36
08-6342	DB/08/033	1.00			0.01%	0.60	0.59	0.59
08-6343	DB/08/034	72	±	8	0.25%	33.85	18.85	54.57
08-6344	DB/08/035	7	±	2	0.10%	4.35	1.93	5.38
08-6345	DB/08/036	28	±	5	0.87%	17.39	8.17	26.17
08-6346	DB/08/037	1.00			0.21%	0.65	0.31	0.94
08-6347	DB/08/038	426	±	41	0.97%	345.64	336.93	154.91
08-6348	DB/08/039	950	±	95	6.33%	549.73	190.00	829.67

- Results for ^{214}Pb, ^{214}Bi, ^{210}Pb are assuming proportional activity from solid component
- Results highlighted in yellow are at the limit of detection (< 1 Bq)

Table 8: In-situ gamma-ray spectrometric results (Stirling University)

Bq kg^{-1} values reported as wet weight

Site ID	Date	Grid Reference	Ra-226 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Pb-214 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Bi-214 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Pb-210 (Bq kg^{-1})	2 σ (Bq kg^{-1})
DB 0101	15/09/2008	NT 16478 83088	55.01	55.0	32.56	8.1	31.07	5.1	65.1	40
DB 0102	15/09/2008	NT 16504 83046	28.53	28.5	25.40	6.6	22.81	3.8	72.3	35
DB 0103	15/09/2008	NT 16520 83057	1.36		13.88	4.1	14.95	2.8	54.3	34
DB 0104	15/09/2008	NT 16512 83067	12.73	12.7	25.99	6.0	23.48	3.7	88.5	38
DB 0105	15/09/2008	NT 16507 83074	52.27	52.3	32.81	52.6	28.65	76.3	74.6	35
DB 0106	15/09/2008	NT 16501 83083	59.66	59.7	36.84	7.7	33.66	5.3	82.8	38
DB 0107	15/09/2008	NT 16493 83089	47.31	47.3	55.45	9.0	58.36	7.5	99.0	39
DB 0108	15/09/2008	NT 16496 83062	21.33	21.3	31.02	8.1	30.12	4.7	52.9	33
DB 0109	15/09/2008	NT 16491 83068	47.48	47.5	30.96	8.0	29.95	4.8	81.3	34
DB 0110	15/09/2008	NT 16486 83078	49.80	49.8	39.02	8.9	33.43	5.4	42.2	33
DB 0111	15/09/2008	NT 16484 83086	94.85	94.9	33.97	7.9	32.20	5.1	75.3	33
DB 0112	15/09/2008	NT 16495 83099	37.81	37.8	34.61	6.5	36.70	5.5	51.7	34
DB 0113	15/09/2008	NT 16486 83104	10.82	10.8	33.66	10.0	26.10	4.5	67.9	35
DB 0113b	15/09/2008	NT 16486 83104	95.68	95.7	37.30	10.9	34.75	7.8	67.1	52
DB 0114	15/09/2008	NT 16460 83055	40.64	40.6	25.31	7.0	24.39	4.1	45.1	39
DB 0115	15/09/2008	NT 16440 83048	9.29	9.3	16.50	5.3	17.23	3.4	83.2	37
DB 0116	15/09/2008	NT 16419 83039	45.45	45.4	28.46	7.0	27.22	4.5	86.5	40
DB 0117	15/09/2008	NT 16366 83050	27.62	27.6	14.47	4.5	12.90	2.5	50.1	34
DB 0118	15/09/2008	NT 16489 83157	20.28	20.3	27.02	6.2	23.83	3.9	60.3	30
DB 0119	15/09/2008	NT 16442 83253	15.06	15.1	20.09	5.1	15.77	3.2	51.2	32
DB 0120	15/09/2008	NT 16456 83258	52.53	52.5	29.69	6.6	29.12	4.8	52.5	32
DB 0121	15/09/2008	NT 16378 83294	25.41	25.4	26.95	5.8	27.79	4.5	50.7	35
DB 0122	16/09/2008	NT 16257 83325	34.57	34.6	23.23	5.6	24.34	4.1	92.8	37
DB 0123	16/09/2008	NT 16509 83087	7.95	7.9	49.03	9.1	45.97	6.7	41.3	37
DB 0124	16/09/2008	NT 16504 83088	49.22	49.2	62.63	11.1	58.27	8.2	79.3	40
DB 0125	16/09/2008	NT 16498 83101	27.18	27.2	73.75	11.8	74.77	10.1	114.7	41

Table 8 cont…..

Site ID	Date	Grid Reference	Ra-226 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Pb-214 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Bi-214 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Pb-210 (Bq kg^{-1})	2 σ (Bq kg^{-1})
DB 0126	16/09/2008	NT 16497 83108	81.31	81.3	68.51	10.6	66.79	8.9	77.6	37
DB 0127	16/09/2008	NT 16495 83118	52.29	52.3	75.62	11.8	79.02	10.6	99.4	37
DB 0128	16/09/2008	NT 16523 83094	49.38	49.4	52.96	11.6	57.14	8.0	52.3	39
DB 0129	16/09/2008	NT 16517 83105	89.00	89.0	64.12	10.8	68.17	9.2	96.8	35
DB 0130	16/09/2008	NT 16522 83111	35.28	35.3	70.00	14.4	80.02	12.4	86.2	69
DB 0131	16/09/2008	NT 16514 83124	51.68	51.7	59.59	12.4	70.65	9.4	94.9	39
DB 0132	16/09/2008	NT 16529 83121	68.04	68.0	40.90	6.7	53.06	7.1	60.8	30
DB 0133	16/09/2008	NT 16537 83123	60.15	60.1	58.44	10.6	52.87	7.3	109.3	37
DB 0135	16/09/2008	NT 16541 83184	52.76	52.8	55.02	9.9	54.16	8.3	77.4	44
DB 0136	16/09/2008	NT 16525 83192	24.83	24.8	56.82	8.7	67.11	9.0	71.2	33
DB 0137	16/09/2008	NT 16503 83190	67.72	67.7	57.31	9.3	53.06	7.8	45.2	34
DB 0138	17/09/2008	NT 16465 83207	36.65	36.6	55.27	11.0	57.38	8.6	81.2	46
DB 0139	16/09/2008	NT 16464 83259	1.54		40.72	7.3	48.16	7.1	56.5	31
DB 0140	17/09/2008	NT 16466 83013	27.39	27.4	25.77	8.3	22.85	3.8	52.2	32
DB 0141	17/09/2008	NT 16431 82981	20.99	21.0	19.47	4.8	16.35	3.1	80.4	33
DB 0143	17/09/2008	NT 16442 83010	31.56	31.6	22.46	5.7	16.70	3.4	38.0	34
DB 0201	17/09/2008	NT 16478 83088	75.82	75.8	37.58	8.5	27.38	5.1	61.3	35
DB 0202	17/09/2008	NT 16504 83046	1.66		26.47	12.9	22.49	3.9	73.8	37
DB 0204	17/09/2008	NT 16512 83067	18.08	18.1	20.13	6.2	15.35	4.1	60.7	50
DB 0205	17/09/2008	NT 16507 83074	85.20	85.2	29.24	8.7	19.81	4.0	62.1	38
DB 0208	17/09/2008	NT 16496 83062	60.77	60.8	28.82	6.8	23.75	4.1	56.9	36
DB 0209	17/09/2008	NT 16491 83068	102.00	102.0	35.18	12.5	24.62	4.2	51.3	35
DB 02010	17/09/2008	NT 16486 83078	53.67	53.7	28.00	5.6	25.18	4.1	54.5	32
DB 02013	17/09/2008	NT 16486 83104	63.61	63.6	33.30	7.1	29.31	4.6	38.1	31
DB 02031	17/09/2008	NT 16514 83124	56.48	56.5	33.41	7.8	29.47	4.7	117.6	32
DB 0225	17/09/2008	NT 16498 83101	47.28	47.3	33.93	7.2	31.10	4.9	62.7	33
DB 0227	17/09/2008	NT 16495 83118	40.04	40.0	34.41	6.4	30.89	5.0	71.4	32
DB 03 07	05/11/2008	NT 16492 83090	50.62	48.4	31.75	9.1	33.63	5.8	19.2	19
DB 03 11	05/11/2008	NT 16486 83110	13.09	41.0	43.63	8.0	39.42	6.4	38.3	39

Table 8 cont….

Site ID	Date	Grid Reference	Ra-226 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Pb-214 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Bi-214 (Bq kg^{-1})	2 σ (Bq kg^{-1})	Pb-210 (Bq kg^{-1})	2 σ (Bq kg^{-1})
DB 03 13	05/11/2008	NT 16485 83101	1.88		31.73	6.2	31.11	5.4	55.1	56
DB 03 26	05/11/2008	NT 16496 83108	1.82		34.50	7.2	33.05	5.1	32.8	33
DB 03 27	05/11/2008	NT 16495 83117	54.84	37.5	25.09	4.8	25.22	4.2	26.4	27
DB 03 44	05/11/2008	NT 16409 83025	21.19	31.5	11.75	6.8	5.95	2.1	3.8	4
DB 03 45	05/11/2008	NT 16351 83011	50.87	75.5	28.20	16.2	14.27	5.1	9.1	9
DB 03 47	05/11/2008	NT 16282 83588	38.82	33.9	18.97	5.4	16.28	3.1	54.6	55
DB 03 48	05/11/2008	NT 16175 83484	15.84	33.0	14.03	3.6	14.27	2.7	30.3	31
DB 03 49	05/11/2008	NT 16195 83367	3.79	36.5	34.03	8.2	34.84	5.3	3.2	3
DB 04 01	06/11/2008	NT 16478 83089	3.00	35.5	26.20	5.9	22.42	3.6	27.2	28
DB 04 10	06/11/2008	NT 16485 83079	16.91	41.9	31.97	7.5	25.51	4.3	27.8	28
DB 04 31	06/11/2008	NT 16514 83124	51.03	42.3	35.70	8.5	34.52	5.3	20.6	21
DB 04 43	06/11/2008	NT 16441 83009	15.14	26.6	19.59	5.4	14.38	3.0	10.4	11
DB 04 50	06/11/2008	NT 16341 83202	25.01	43.3	26.03	7.4	24.42	4.0	15.5	16
DB 04 51	06/11/2008	NT 16424 82997	2.43	25.0	9.60	3.9	7.87	2.2	0.9	1
DB 04 52	06/11/2008	NT 16453 83019	1.80		23.03	5.7	18.55	4.4	28.7	29
DB 04 53	06/11/2008	NT 16486 83073	54.88	36.1	26.52	6.0	23.64	4.0	41.5	42

Ra-^{226} reported as un-corrected values for U-235
Numbers in grey are detection limits. Lines reported in grey indicate qualitative value only.

Table 9: Sediment sample gamma-ray spectrometric analysis (Stirling University)

Numbers in grey are the reported detection limits

Sample Name	Date Sampled	Grid Refence	Depth (cm)	% moisture	uncertainty	Ra-226 Bq kg^{-1}	2 σ Bq kg^{-1}	Pb-214 Bq kg^{-1}	2 σ Bq kg^{-1}	Bi-214 Bq kg^{-1}	2 σ Bq kg^{-1}	Pb-210 Bq kg^{-1}	2 σ Bq kg^{-1}
BD 01-01	16/9/08	NT 16478 83086	0-10	7.1	0.01	33.10	6.10	26.04	1.82	24.96	1.52	25.31	2.61
BD 01-02	16/9/08	NT 16506 83045	0-10	28.8	0.03	15.30	12.50	21.63	1.59	21.26	1.53	32.12	8.90
DB 01-03	16/9/08	NT 16518 83059	0-10	16.9	0.03	15.10	4.20	15.16	1.17	14.85	1.00	29.56	7.01
DB 01-06	16/9/08	NT 16501 83083	0-10	19.8	0.02	27.40	27.40	30.71	2.45	27.89	2.03	29.98	9.15
DB 01-07	16/9/08	NT 16493 83090	0-10	16.4	0.02	78.70	18.10	68.73	5.10	61.56	4.31	43.34	15.85
DB 01-10	16/9/08	NT 16486 83078	0-10	18.0	0.03	25.00	25.00	26.45	2.17	25.57	1.97	30.26	11.70
DB 01-14	16/9/08	NT 16460 83055	0-13.5	34.7	0.04	29.30	9.30	39.08	2.87	36.77	2.60	43.47	8.92
DB 01-16	16/9/08	NT 16419 83039	0-10	31.7	0.04	24.50	23.90	50.97	3.82	52.90	3.98	47.23	10.16
DB 01-27	16/9/08	NT 16495 83118	0-10	33.5	0.05	38.42	13.04	37.86	2.67	37.08	2.27	27.19	4.76
DB 01-35	16/9/08	NT 16541 83184	0-10	24.0	0.03	25.78	17.91	19.79	1.54	18.48	1.23	20.32	4.55

* Results are Bq kg^{-1} dry mass

Table 10: Sediment sample analysis for AoI

Area	Date Sampled	Grid Reference	Depth (cm)	% moisture	uncertainty	Ra-226 (Bq kg^{-1})	error (+/-)	Pb-214 (Bq kg^{-1})	error (+/-)	Bi-214 (Bq kg^{-1})	error (+/-)	Pb-210 (Bq kg^{-1})	error (+/-)
1	18/9/08	NT 1635 8302	n/a	20.5	0.02	409.8	40.1	353.6	24.5	363.5	22.8	302.0	29.2
2	19/9/08	NT 1641 8367	n/a	22.8	0.12	308.1	41.9	280.0	19.6	272.2	16.8	231.4	22.2

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 screening assessment.

7.1.1. Physical Form

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

The radium 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).

7.1.2. The effect of burning

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

At Dalgety Bay it is believed 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 likely 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. Therefore, as an initial screening assessment, it has been assumed that the form of radium would allow absorption to occur. Furthermore, small-scale experimentation on the solubility of some items has been undertaken and has shown that solubility in a GI tract could be up to 15%. The Heaton report in 1996 indicated that around 10% of the material may be available for absorption if ingested.

7.2. Point source size and fragmentation

Recovery of point sources in the field environment 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.

When some of the point sources were analysed in laboratory conditions some contained a number of small point sources which could infer that they originated from a common mass but, on recovery or at an earlier stage, had broken into a number of smaller pieces, some of which were inert and some of which were active. Therefore, for the purpose of prospective radiological protection, 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.

7.3. Exposure Pathways

There are several potential exposure pathways to consider for the probability assessment both for human and non-human species. For the human pathway the methodology adopted is similar to that used in the 2006 Dalgety Bay Assessment. For the non-human exposure pathways, as the contamination appears to be highly localised, and the affected area is not known to be unique (in terms of species diversity), although it is accepted that there may be effects of the contamination on individual biota, the effects at a population level are assumed to be insignificant. Therefore, no further consideration of the effects on non-human biota has been made at present. However, SEPA may consider undertaking a detailed assessment to confirm this in due course. The following section gives details of the methodology used for each potential human exposure pathway.

7.3.1. 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 µm, 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 to the ‘fine sediment material’ recovered from the New Harbour area, a sample of ‘ash’ was taken from the Coastal Path Area. Constituents of both these samples are assumed to be greater than 0.2 mm in size on any axis and therefore not inhalable at present.

7.3.2. Ingestion

It is possible that an individual could inadvertently ingest a radioactive item. Ingestion pathways that have been excluded from this assessment are the deliberate consumption of sediment and the consumption of ‘free’ foods (e.g. fish and shellfish, either through direct consumption or use of bait). It is recommended that SEPA and the Food Standards Agency (FSA) consider the potential food pathway issue further.

7.3.3. 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 is assumed that there is no deliberate selection of radioactive items. 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.

7.3.4. Assessment of the probability of encounter

Assessment of the likelihood of an exposure draws largely upon the methodology developed to assess the potential for a member of the public to encounter a radioactive item whilst on a beach in Caithness (DPAG, 2006). Adopting this approach allowed the development of a robust screening assessment as it utilises a fully reviewed methodology. Although this methodology has been followed, the input parameters such as the type of contamination, nature of sediment and habits are either generic or site specific to Dalgety Bay. Notably, this assessment makes no correction for non-detected point sources.

7.4. Homogeneous contamination

From the data collected from the in-situ measurements it is clear that the entire monitored area has elevated concentrations of ^{226}Ra and its daughters. However, for ingestion, even if the maximum concentrations are used and assuming that all of the activity is readily available for gut uptake (100% soluble), the resultant doses from ingestion of 1 kg of material would be a fraction of 3 mSv. The corresponding values for a child would be around 20 times greater. It is noted that the hourly rate of inadvertent ingestion of sand/sediment is 50 mg for a 1-year old child, 10 mg for a 10-year old and 5 mg for an adult (NRPB W41). Thus, for a 1-year old to consume 1kg of sediment he/she would need to be present on the beach for around 20,000 hours (1 full year is around 8766 hours). On the basis of these data, it is considered highly improbable that the homogenous contamination at Dalgety Bay could lead to committed effective doses greater than a fraction of 3 mSv per year to any member of the public using the beach.

7.4.1. Areas of interest

Two areas of interest were identified in the survey work which indicated concentrations of radium and its daughters around ten times greater than that of the typical contamination of sediment at Dalgety Bay. These areas were located on the coastal path and near the New Harbour, this second location being intertidal. Although this sediment contained higher concentrations of radium contamination, the spatial extent was not extensive. Therefore, it is considered inappropriate to assess these areas as if they were homogeneous as it is unlikely that members of the public would spend significant period of time at these locations. However, even if they did, an infant would still need to spend around 2000 hours to inadvertently consume 100g of sediment which could deliver a dose of around 1 mSv.

7.5. Heterogeneous contamination

Point sources present hazards which are difficult to assess using normal assessment techniques and as a result they require to be assessed separately according to the potential exposure pathways. These are via inhalation, ingestion or skin contact. A division of the sources according to physical size and the potential pathways is presented in Table 11.

Table 11: Potential pathways for point sources

HPA Ref	NUVIA Ref	Mass (g)	Physical dimensions (mm) L	W	D	Volume (mm^3)	Density ($g\ mm^{-3}$)	Radius (mm)	Equiv Dia (mm) d_{equ}	Aero Dia (mm) d_{ae}	Inhalable < 0.2 mm	Undernails < 2 mm	Ingestible < 4 mm
08-6300	DB/08/001	0.358	5	5	1	25	6.98E+01	1.99E+00	3.98E+00	3.64E+00	No	Yes	Yes
08-6301	DB/08/002	5.700	20	15	10	3000	5.26E+02	2.39E+02	4.77E+02	4.37E+02	No	No	No
08-6302	DB/08/003	2.514	15	10	10	1500	5.97E+02	1.19E+02	2.39E+02	2.19E+02	No	No	No
08-6303	DB/08/004	0.065	3	4	1	12	1.85E+02	9.55E-01	1.91E+00	1.75E+00	No	Yes	Yes
08-6304	DB/08/005	0.721	10	7	5	350	4.85E+02	2.79E+01	5.57E+01	5.10E+01	No	No	Yes
08-6305	DB/08/006	150.158	70	70	25	122500	8.16E+02	9.75E+03	1.95E+04	1.78E+04	No	No	No
08-6316	DB/08/007	15.256	70	30	10	21000	1.38E+03	1.67E+03	3.34E+03	3.06E+03	No	No	No
08-6317	DB/08/008	19.582	70	25	10	17500	8.94E+02	1.39E+03	2.79E+03	2.55E+03	No	No	No
08-6318	DB/08/009	10.579	70	20	10	14000	1.32E+03	1.11E+03	2.23E+03	2.04E+03	No	No	No
08-6319	DB/08/010	250	110	30	70	231000	9.24E+02	1.84E+04	3.68E+04	3.37E+04	No	No	No
08-6320	DB/08/011	16.773	30	30	10	9000	5.37E+02	7.16E+02	1.43E+03	1.31E+03	No	No	No
08-6321	DB/08/012	1.021	10	10	5	500	4.90E+02	3.98E+01	7.96E+01	7.28E+01	No	No	No
08-6322	DB/08/013	37.325	50	40	30	60000	1.61E+03	4.77E+03	9.55E+03	8.74E+03	No	No	No
08-6323	DB/08/014	167.257	60	60	50	180000	1.08E+03	1.43E+04	2.86E+04	2.62E+04	No	No	No
08-6324	DB/08/015	118.184	50	40	60	120000	1.02E+03	9.55E+03	1.91E+04	1.75E+04	No	No	No
08-6325	DB/08/016	17.619	20	30	20	12000	6.81E+02	9.55E+02	1.91E+03	1.75E+03	No	No	No
08-6326	DB/08/017	76.289	85	45	20	76500	1.00E+03	6.09E+03	1.22E+04	1.11E+04	No	No	No
08-6327	DB/08/018	2.076	70	10	5	3500	1.69E+03	2.79E+02	5.57E+02	5.10E+02	No	No	No
08-6328	DB/08/019	6.589	70	15	5	5250	7.97E+02	4.18E+02	8.36E+02	7.65E+02	No	No	No
08-6329	DB/08/020	51.38	55	45	30	74250	1.45E+03	5.91E+03	1.18E+04	1.08E+04	No	No	No
08-6330	DB/08/021	38.508	50	25	30	37500	9.74E+02	2.98E+03	5.97E+03	5.46E+03	No	No	No
08-6331	DB/08/022	1.196	30	10	5	1500	1.25E+03	1.19E+02	2.39E+02	2.19E+02	No	No	No
08-6332	DB/08/023	148.368	50	70	30	105000	7.08E+02	8.36E+03	1.67E+04	1.53E+04	No	No	No
08-6333	DB/08/024	50.832	50	20	40	40000	7.87E+02	3.18E+03	6.37E+03	5.83E+03	No	No	No
08-6334	DB/08/025	89.105	80	50	20	80000	8.98E+02	6.37E+03	1.27E+04	1.17E+04	No	No	No

08-6335	DB/08/026	19.441	30	15	35	15750	8.10E+02	1.25E+03	2.51E+03	2.29E+03	No	No	No
08-6336	DB/08/027	26.477	35	20	45	31500	1.19E+03	2.51E+03	5.01E+03	4.59E+03	No	No	No
08-6337	DB/08/028	13.06	30	20	20	12000	9.19E+02	9.55E+02	1.91E+03	1.75E+03	No	No	No
08-6338	DB/08/029	3.368	15	10	20	3000	8.91E+02	2.39E+02	4.77E+02	4.37E+02	No	No	No
08-6339	DB/08/030	10.886	20	15	25	7500	6.89E+02	5.97E+02	1.19E+03	1.09E+03	No	No	No
08-6340	DB/08/031	2.774	20	20	5	2000	7.21E+02	1.59E+02	3.18E+02	2.91E+02	No	No	No
08-6341	DB/08/032	11.154	25	15	20	7500	6.72E+02	5.97E+02	1.19E+03	1.09E+03	No	No	No
08-6342	DB/08/033	2.871	20	10	10	2000	6.97E+02	1.59E+02	3.18E+02	2.91E+02	No	No	No
08-6343	DB/08/034	0.029	3	2	2	12	4.14E+02	9.55E-01	1.91E+00	1.75E+00	No	Yes	Yes
08-6344	DB/08/035	0.283	10	5	5	250	8.83E+02	1.99E+01	3.98E+01	3.64E+01	No	Yes	Yes
08-6345	DB/08/036	0.073	10	5	5	250	3.42E+03	1.99E+01	3.98E+01	3.64E+01	No	Yes	Yes
08-6346	DB/08/037	0.176	20	10	2	400	2.27E+03	3.18E+01	6.37E+01	5.83E+01	No	Yes	Yes
08-6347	DB/08/038	0.345	10	10	1	100	2.90E+02	7.96E+00	1.59E+01	1.46E+01	No	Yes	Yes
08-6348	DB/08/039	0.020	5	3	1	15	7.50E+02	1.19E+00	2.39E+00	2.19E+00	No	Yes	Yes

(yellow) = size "< 1 mm"
(green) = weight > 250 g

7.5.1. Inhalation

In our previous report (SEPA) in 2006 we discounted the possibility that radium point sources could be inhaled. However, in the 2008 survey it was not possible to fully isolate each point source and thus there is a possibility that some of these sources could have been sufficiently small to be inhaled. Although point sources will physically break down in environments such as Dalgety Bay, the specific activity of some of the residual items may be greater after breakdown occurs, increasing the hazard such friable sources pose. The co-location of point sources at two positions during the 2008 survey suggests that such a breakdown may be occurring.

Assessment of the possible hazard from inhalation is problematic and difficult and it is recommended 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 HPA-RPD and in the short timescale available, HPA-RPD were able to provide the following preliminary assessment:

Particles of more than 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 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.*

7.5.2. Ingestion

A number of point sources were selected according to their size and activity for a basic leaching experiment to assess the potential range of material that would be dissolved in gut acid and then absorbed into the body. It is noteworthy that one high-activity sample, which was physically large and where the bulk of the activity was focused in one small area, was not analysed. The methodology used to perform this experiment was similar to that recommended by Dounreay Particles Advisory Group (DPAG) to UKAEA for Dounreay particles in order to determine whether large portions of the items were soluble by dissolving in HCL. For this reason the information is not an accurate value of what would be available for gut uptake but indicative and should be considered as a range of what was potentially available.

In 2006, following a similar leaching experiment, it was assumed that the soluble fraction of each point source could be up to 15 %. In the work conducted in 2008, the solubility ranged from less than 1% to 7% which was broadly comparable with the 2006 work, even though a slightly different methodology was used. In the absence of confirmatory data, we have also assumed that the ^{210}Po and ^{210}Pb are in equilibrium with ^{214}Po and ^{214}Pb. The potential doses derived from the results of the leachate work conducted in 2008 and 2006 are presented in Appendix D and in our 2006 report respectively. The doses were derived using standard ICRP dose coefficients and are detailed in Appendix E.

Of the point sources subjected to leaching experimentation in 2008, the highest dose, using the methodology adopted, would have been around 66 mSv to a 1-year old child, with contributions of around 12, 0.01, 0.01, 16, 0.04, 38 mSv from ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi, ^{210}Po, respectively. This assumes that the ^{210}Pb data are valid, if ^{210}Pb were in full equilibrium the doses would be around double that value. 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 Section 9.1. Higher doses would result if a 3-month old infant were to be considered.

SEPA requested comments from HPA-RPD on SEPA assessment of committed effective dose and in the short time available HPA-RPD provided the following preliminary assessment:

*Doses were calculated for the example of item DB/08/007, showing dissolution of 4% (see table 7), regarded as a preliminary measure of availability for gut uptake. The initial activity of Ra-226 is about 300 kBq and the dissolved activities are as shown in the table 7. If all activity were to associate with a smaller particle that could be ingested, doses are estimated as totals of about 15 mSv to an adult, about 90 mSv to a one year-old child and about 240 mSv to a 3 month-old infant. (*The Statutory Guidance is 100 mSv). *These are committed effective doses, calculated using standard gut transfer factors applied to the activities shown in the table and taking account of doses from the remaining activity passing through the intestinal tract.*

The data from HPA-RPD is largely the same as that calculated by SEPA. SEPA believe that the primary reason for greater doses to the 1 year-old (90 mSv as opposed to 66 mSv) is the contribution to dose from the remaining activity passing through the intestinal tract, which SEPA did not assess.

7.5.3. Skin contact

There are several possible exposure pathways for direct skin contact. This work is based on research conducted for SEPA by the Health Protection Agency and also the work of the 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 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 report. It is recommended that SEPA and FSA consider this issue further.

7.6. Skin Dose Assessment

The point sources recovered from Dalgety Bay represented a wide range of mass, physical size and radioactive content. To assess the overall hazard from the point sources, work was commissioned from the University of Birmingham and an extract is produced below.

Radium-226 is a product of the decay of ^{238}U. The main decay route is illustrated in Figure 10. The decay of ^{226}Ra produces the radioactive gas radon (^{222}Rn). Unless this escapes the radon activity will build up to its equilibrium value within a few half lives – i.e. 10-15 days. During this time the subsequent 4 radionuclides (^{218}Po, ^{214}Pb, ^{214}Bi & ^{214}Po) in the decay chain, which are all short-lived, reach secular equilibrium within a few hours. The next member of the decay chain is ^{210}Pb with a half-life of 22 years. Secular equilibrium of ^{210}Pb and subsequent progeny is achieved only over several subsequent decades. A major problem with the evaluation of skin dose rate from contact with ^{226}Ra is the extent to which progeny have been retained within the radium sample. This will depend upon the construction of the radium sample and the extent to which this has allowed the ^{222}Rn, and its progeny to escape from the sample.

The extent of equilibrium can be assessed by comparing the recently measured levels of ^{226}Ra, ^{214}Pb and ^{214}Bi. A regression of ^{214}Pb activity against ^{226}Ra activity indicated that over the whole range of the 39 environmental samples the ^{214}Pb activity is at about 90% of the equilibrium value. Lack of total equilibrium is presumably due to some loss of radon gas from the decay chain. The regression of ^{214}Pb and ^{214}Bi indicates that these two progeny are in close equilibrium with each other. The assumption, for the purpose of calculations, that the ^{226}Ra decay series is in equilibrium will thus produce an over-estimate of dose by about 10% since progeny in the chain following ^{222}Rn will be in deficit. The fact that equilibrium has been almost achieved and maintained over several decades is indicative that all radionuclides are well bound and sealed from the external environment. This implies the presence of binding and sealing material within the samples. The relevance of this is that binding materials and external sealants are likely to significantly reduce the alpha dose estimates – which assume no absorption within the sample. This could be checked if necessary by direct alpha dose measurement using, for example, Radiochromic dye film and thin absorber foils. For the '210' daughters, direct measurement of ^{210}Pb indicated that this daughter was typically around 50 % of the equilibrium point, the implications of this are discussed later in this section.

In the absence of any agreed protocol for the assessment of point sources on the skin (with respect to RCL), it was assumed that, following ICRP recommendations for non-uniform exposures, (ICRP Publications 60 and 75) any dose derived should be averaged over the most highly exposed area of 1 cm^2. Skin absorbed doses for beta and photon emitters have been calculated for the benchmark ^{226}Ra source using the code VARSKIN 3. Alpha absorbed doses have been calculated using the code ALDOSE. The basal layer of the epidermis of the skin on some body sites for a proportion of the population may be less than the nominal value of 70 μm recommended in ICRP 89 for an adult. For a child the corresponding value is around 45 μm. Doses for a range of depths of 20-100 μm, which covers the actual range of skin thicknesses found in a population over the majority of body sites, have also been assessed.

The work undertaken by University of Birmingham for SEPA indicates a range of possible dose rates for a benchmark 1 MBq ^{226}Ra point source with no shielding effect for a skin area of 1 cm^2 and a range of skin depths. Figures 11 and 12 show the dose rate from radium and its daughters to varying skin depths from a 1 MBq source assumed to be in full equilibrium with its daughters. It is notable that the greatest activity detected in 2008 was around 870,000 Bq ^{226}Ra from a source which was physically large. In 2006 the greatest activity was 1,200,000 Bq ^{226}Ra which was again associated with a physically large object, however in contrast, a smaller point source (a few mm) had 730,000 Bq ^{226}Ra. Potential doses, therefore, need to be pro-rata calculated, together with some consideration of shielding.

Thus, there is a potential for significant skin doses to be received from the Dalgety Bay point sources when contributions from all emissions and daughters are considered. However, we recommend further work to provide better data on the potential skin doses. If the reference values of skin thickness, given in ICRP Publication 89, are used, the greatest potential doses are to children up to 5 years of age who could potentially receive doses in excess of 10 Grays per hour. However, we recommend that further work is undertaken to determine if the calculated values are realistic.

In the assessment of skin doses it has been assumed that the daughters of ^{226}Ra are in full equilibrium. Appendix E shows that this is likely to be valid for '214' daughters which have half-lives in the range of minutes, whilst HPA data for ^{210}Pb, which has a rather longer half-live of 22 years, is around half of the equilibrium value. As the skin dose is dominated by ^{214}Po which is approximately in equilibrium, there is no significant effect on the dose to the skin if the lower value of the '210' daughters is taken into account. Thus, we have not changed the values for skin doses.

7.7. Skin Dose and Effective Dose

7.7.1. Skin thickness

It is assumed that, for beach users at Dalgety Bay, the most likely areas of the skin that will be exposed are the hands, arms and legs. In these areas, the mean depth is around 60 µm with a standard deviation of around 19 µm. For the remainder of the trunk of the body the mean is around 42 µm with a standard deviation of 12 µm. This contrasts with the nominal skin thickness of an adult of 70 µm assumed by the ICRU and ICRP. Overall the skin depth can range up to around 100µm. For new-born up to 5-year old children the ICRP reference depth is 45 µm, for a 10 year old 50 µm and a 15 year old 60 µm (ICRP 89).

7.7.2. Skin Dose Rate for ^{226}Ra in the presence of all progeny

Skin Thickness assumed to be 70 µm

Ra-226 alone is primarily an alpha emitter (energy ~ 4.8 MeV) with a low-intensity, low-energy gamma emission. The range of the ^{226}Ra alpha particles is ~ 30 µm in tissue, much less than the nominal skin thickness of 70 µm assumed by the ICRU and ICRP. Regarding skin exposure, the hazard from ^{226}Ra is therefore due primarily to its daughter products.

If ^{226}Ra is in equilibrium with all its progeny then all of the radionuclides shown in Figure 10 will contribute to skin dose. The major contribution to skin dose at the nominal skin depth of 70 µm is from beta radiation. On the assumption of a skin thickness of ~ 70 µm,

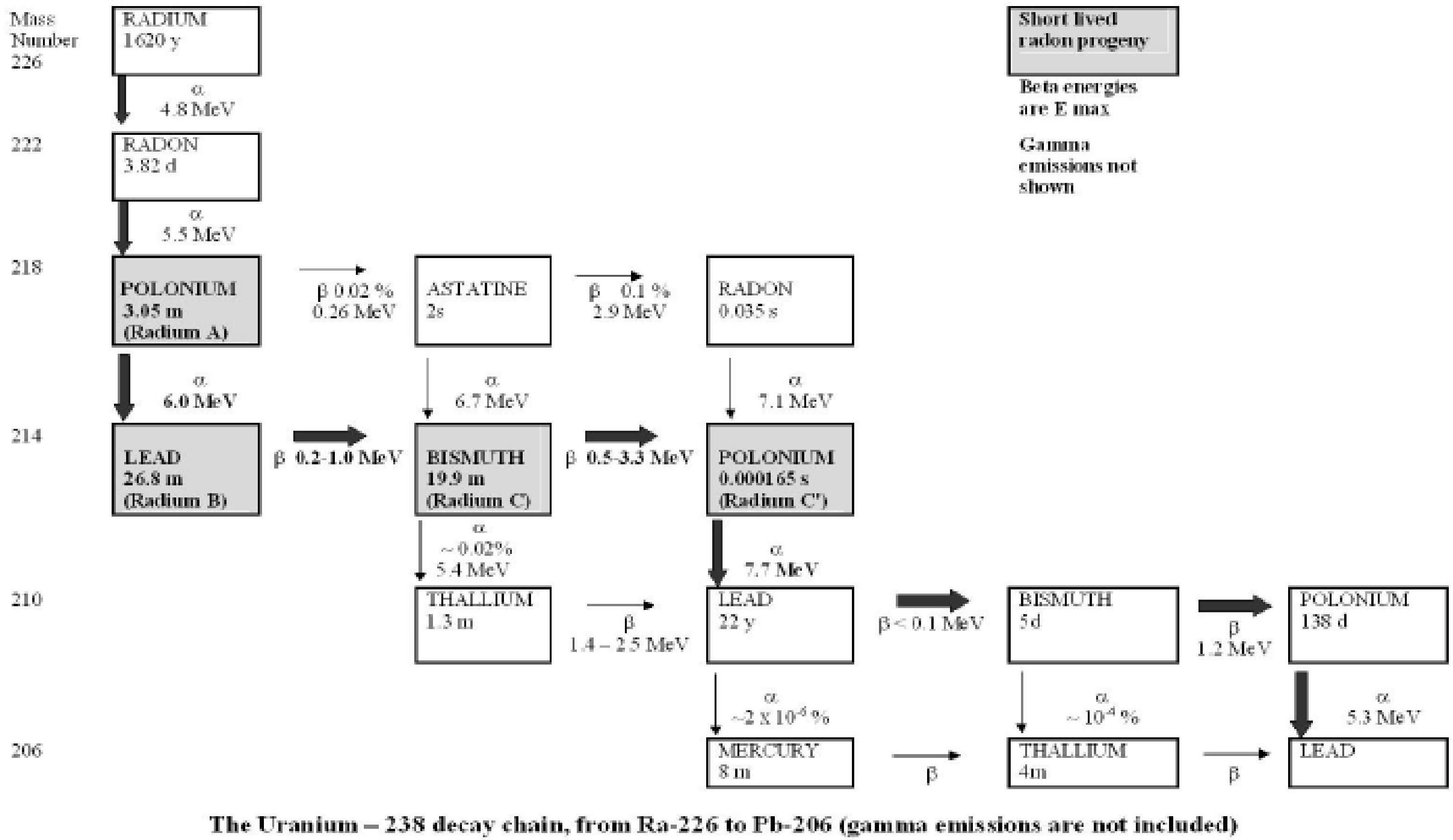

Figure 10: U-238 decay chain from Radium-226

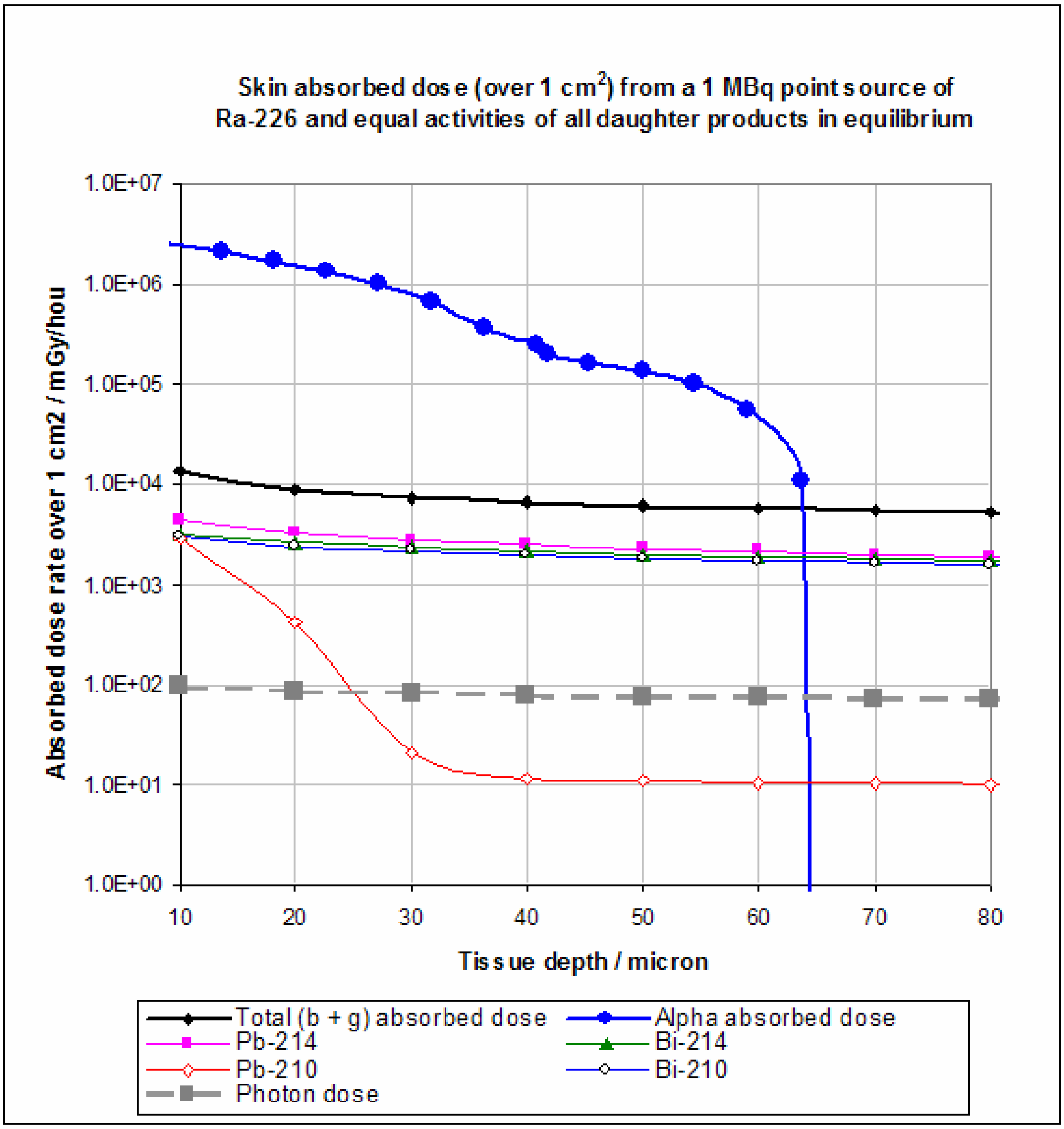

Figure 11: Absorbed dose (averaged over 1 cm^2) versus depth in tissue from a 1 MBq point source of radium-226 in equilibrium with all its progeny [(i.e. all products have activity of 1 MBq). Absorbed dose calculations assume a thin source at a semi-infinite tissue/air interface. Beta dose rates were evaluated using VARSKIN. Alpha dose rates were calculated using ALDOSE. A skin tissue density of 1,100 kg m^{-3} was assumed].

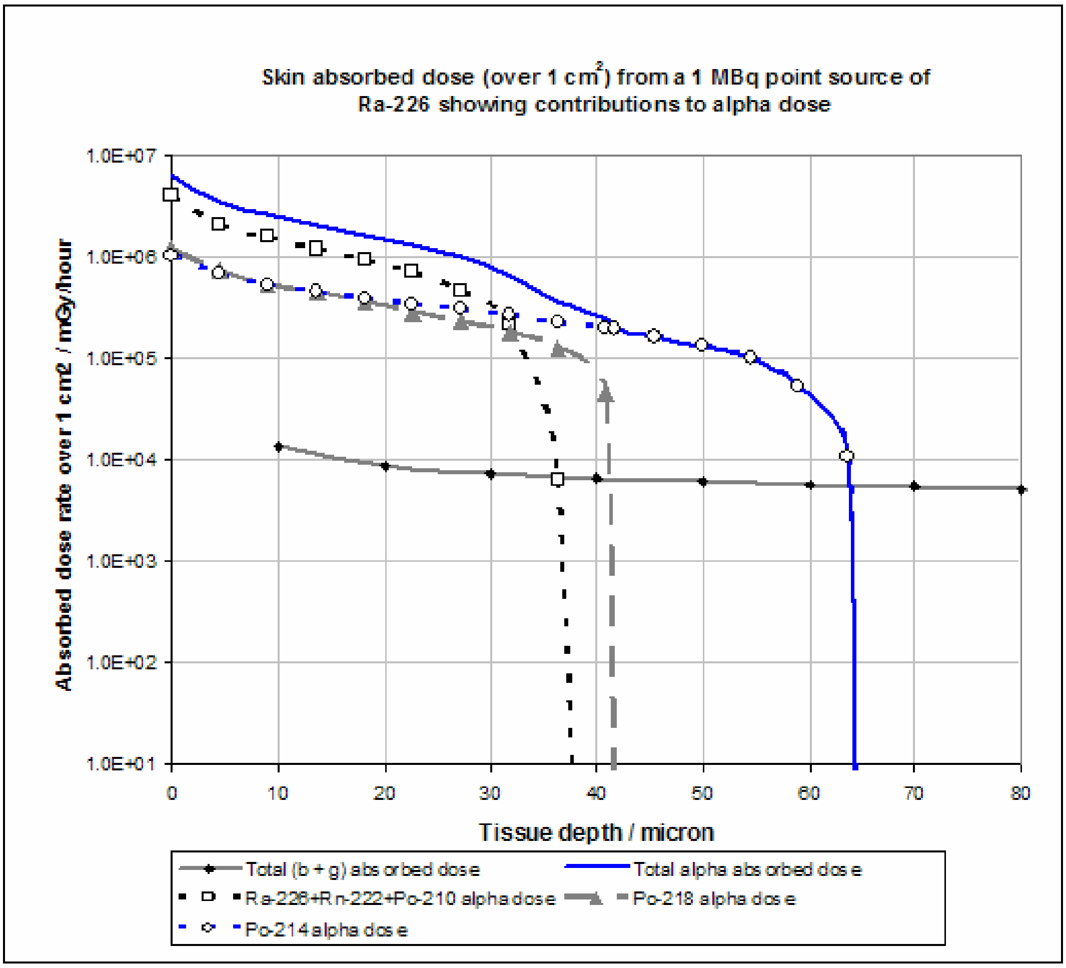

Figure 12: Absorbed dose (averaged over 1 cm^2) versus depth in tissue from a 1 MBq point source of radium-226 in equilibrium with all its progeny [(i.e. all products have activity of 1 MBq). Contributions to alpha dose to the skin are dominated by ^{214}Po (7.7 MeV). Alpha dose rates were calculated using ALDOSE. A skin tissue density of 1,100 kg m^{-3} was assumed].

the alpha dose to the skin is zero. Gamma[1] dose is negligible. Using VARSKIN 3, the total skin dose rate (at a depth of 70 µm over an area of 1 cm^2) from a ^{226}Ra point source activity of 1 MBq (in equilibrium with all progeny) is ~ 5.5 Gy hr^{-1}. For the point sources recovered this is likely to be an over-estimate of dose by about 10% since progeny in the chain following ^{222}Rn will be in deficit. Photon dose to skin is ~ 72 mGy hr^{-1}. The main contributors to skin dose are:

^{214}Pb: 2.01 Gy hr^{-1} ^{214}Bi: 1.81 Gy hr^{-1} ^{210}Bi: 1.63 Gy hr^{-1}

Po-214 and ^{218}Po are the major alpha emitters but, although their energies are 7.7 & 6.0 MeV respectively, their depths of penetration just fail to make a contribution to skin dose at a depth of 70 µm.

[1] This should strictly be referred to as photon dose since x-rays as well as gamma rays are involved

SEPA received further advice on the potential doses from skin exposure from HPA-RPD. However, the timescale for this was limited, hence the comments below are brief.

University of Birmingham (Confidential report to SEPA) reports that, using VARSKIN 3, the total skin dose rate (at a depth of 70 µm over an area of 1 cm^2) from a ^{226} Ra point source activity of 1 MBq (in equilibrium with all progeny) is ~ 5.5 Gy hr^{-1}. For the point sources recovered this is likely to be an over-estimate of dose by about 10% since progeny in the chain following ^{222}Rn will be in deficit. The main contributors are: ^{214}Pb (2.1 Gy hr^{-1}), ^{214}Bi (1.8 Gy hr^{-1}) and ^{210}Bi (1.6 Gy hr^{-1}). Alpha particles do not penetrate to 70 µm. The main deterministic effect of importance is ulceration for which cells at greater depths in the dermis are implicated. These dose rates can be compared with those considered for Dounreay particles in terms of potential harm, bearing in mind differences in physical characteristics (ED_{50} of 10 Gy; threshold of 2 Gy). Committed effective doses are not of concern because dose is first averaged over the whole skin (i.e. 2m^2 from 1cm^2) and then a w_T of 0.01 is applied.

7.7.3. Skin Dose Rate to the superficial basal layer of the skin

Skin Thickness < 70 µm

The basal layer of the epidermis of the skin on some body sites for a proportion of the population may be les than the nominal value of 70 µm recommended by the ICRP (see Figure 13). Thus, the basal layer on some body sites may be subject to alpha exposure from the higher energy alpha particles from ^{226}Ra progeny – primarily Po-214 (7.7, MeV, range in skin ~ 64 µm).

In the case of a 1 MBq ^{226}Ra source in equilibrium with its daughter products, an average skin absorbed dose rate at a depth of 0-100 µm (weighted by the skin thickness distribution in a population) is about 66 Gy hr^{-1}. The surface dose is around 6 kGy hr^{-1} (Figure 12). Again this is likely to be an over-estimate since progeny in the chain following ^{222}Rn will be in deficit, and no account has been made of self-shielding.

For children, who may be potentially exposed, the nominal depth of skin is around 45-50 µm which would correspond to a dose of around 200-100 Gy hr^{-1} from a 1 MBq source. However, again no effects of shielding or ^{222}Rn loss have been taken into account. However, for children the possibility exists that the 10 Gray hr^{-1} threshold will be exceeded for some Dalgety Bay point sources.

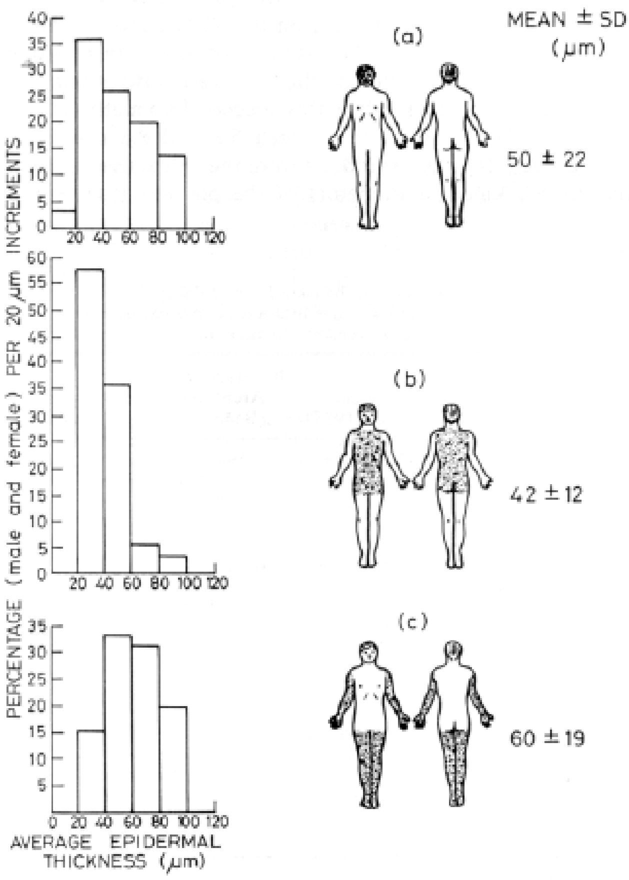

Figure 13: Variation in the distribution of the average epidermal thickness in man for three body regions (a) face (b) trunk (c) arms and legs

It is necessary to be extremely careful in interpreting high numerical values of dose rate. Actual doses may be very much less due to self-absorption within the sample. Importantly, biological effects are generally judged on the basis of doses estimated at a depth of 70 microns (see 7.9.2). The fact that equilibrium in actual measured samples is high indicates that the source is bound and sealed effectively against radon loss. This implies significant self absorption, particularly for alpha particles. This conjecture could be tested directly by contact dose measurements using radiochromic dye film. The very high surface doses are delivered to the dead keratinized outer layer and are not relevant to induced biological effects. These doses should not be compared directly with recommended dose limits which are based primarily on experience with photon irradiations which irradiate the full skin thickness. A literature search indicates that such large alpha doses have been observed to produce reddening (erythema) and pigmentation in human skin, but evidence is lacking to convincingly link such superficial alpha exposures with more severe detrimental deterministic effects such as ulceration, or with subsequent skin cancer.

7.7.4. Consideration of Effective Dose

A skin absorbed dose rate (70μm, 1 cm^2) of ~ 3 Gy hr^{-1} level is near the threshold for just perceptible transient and superficial visible skin damage if the duration of exposure is about 1 hour. Exposure in this case is dominated by beta radiation. The contribution to effective dose from such an exposure is small since the proportion of the whole body skin that is exposed is small and the tissue weighting factor for skin is only 0.01.

A bench mark ^{226}Ra source with an activity of ~ 1 MBq will deliver this dose in 0.5 - 1 hours.

For skins thinner than the nominal 70 μm value, there are arguments that as an overall evaluation of the evidence that alpha radiation does not produce skin cancer[8,9] and should therefore not be included in an evaluation of effective dose. However, for a 0.6 MBq ^{226}Ra source, which in 1 hour delivers a beta absorbed dose to skin (70μm, 1 cm^2) of 3 Gy, the alpha absorbed dose to skin over 1 cm^2 at depths of 20-100 μm is ~ 40 Gy (weighted by the skin thickness distribution in a population). In this case the contribution to effective dose E is given by

$$E = \frac{[(40 \times 20) + (3 \times 1)] \times 0.01}{2 \times 10^4} \approx 0.4 mSv$$

where 2 x 10^4 cm^2 is the total external skin area of around 2 m^2.

The radiation weighting factor W_R for alpha radiation for routine radiological protection situations is 20.

7.7.5. Doses to the lens of the eye

This report has not specifically assessed doses to the lens of the eye as it is considered that the most probable and limiting factor would be a dose to the skin. Work undertaken for SEPA for the Dounreay particles (Harrison et al, 2005) reported that the equatorial epithelial cells around the periphery of the lens lie at a depth of at least ~ 2.5 mm from the eye surface. For a point source at any position on the corneal surface, the majority of the equatorial region of the eye is much deeper than this and the risk of cataract induction is small.

As the cornea of the eye is approximately 0.5 mm (500 μm) thick consisting of connective tissue sandwiched between an outer epithelial layer and an inner endothelial layer, it is suggested that doses to the skin with a depth of 45-50 μm will be more limiting than doses to the entirety of the cornea for the purposes of this assessment.

If further work is needed in this area it is recommended this should be undertaken in a full risk assessment.

8. Probability of Encounter

This section of the report deals with the probability of an individual encountering a radioactive point source at Dalgety Bay. The basis for the assessment is the same to the screening assessment conducted in 2006.

8.1. Habits Data

In order to undertake a dose or probability assessment, habits survey data are required to assess the duration of time individuals spend in a particular area or if any local food is consumed. The results of a habits survey can be used to determine the 'critical group', or most exposed person or group.

SEPA's 2006 Screening Assessment for Radium Contamination at Dalgety Bay made a series of assumptions in relation to beach occupancy in the probability of encounter assessment. These assumptions were detailed in the report and as such can be amended to take account of new information. For the 2008 assessment the same data have been used in order to provide a direct comparison with the 2006 assessment. No site-specific data have been gathered for this assessment, however, observations of the use of the beach by the public during the 5-day monitoring exercise are detailed in Section 5.1. These observations suggest that the area is popular with the public and that individuals spend a considerable amount of time in the areas where point sources have been detected.

8.2. Probability Assessment

The probability of encounter assessment has been undertaken following the methodology developed for SEPA for Dounreay particles but adapted for circumstances at Dalgety Bay. The methodology is detailed in Appendix B.

The survey area has been separated into the 4 regions described in Table 12 for the assessment:

Table 12: Areas selected for Probability of Encounter Assessment

Zone	Area (m^2)	Point sources Recovered
1 – Headland	4,950	5
2 – Slipway (First Survey)	4,000	24
3 – Slipway – Old Pipeline	6,525	6
4 – Full Intertidal Zone	15,475	35

Generalised habits data relevant to the probability assessment are shown in Tables 13 and 14.

Table 13: Inadvertent ingestion rates of soil and sand (NRPB-W41 Generalised Habits Data)

Age	Hourly ingestion rate (mg h^{-1})
1 year old	50
10 year old	10
Adult	5

Table 14: Representative critical group occupancy data for beach/intertidal areas (NRPB-W41 Generalised Habits Data)

Age	Beach/Intertidal Area Occupancy Data (h yr^{-1})
Infant	30
Child	300
Adult	2000

8.3. Probability of direct encounter

One of the criteria for radioactive contaminated land is that the probability of exposure multiplied by the committed effective if that was to occur is greater than 3 mSv.

Thus, for a point source which could deliver 100 mSv, the probability of encounter (ingestion) would need to be greater than one in 33 to reach this criterion (3 mSv) and for a 1 Sv dose, greater than 1 in 333 and so on. In 2008, the number of point sources found was similar to the number recovered in 2006. However, the numbers could be increased if point sources, which were identified as multiple point sources in the laboratory, were to be considered as several or a number of individual point sources. The 2006 assessment showed that the probability of ingestion would be in the range of one in half a million for an adult using the beach for 2000 hours. To trigger the 3 mSv value this would correspond to a hazard of around 1500 Sv. Section 7 and Appendix D provide some information on the possible range of the committed effective doses via ingestion. As a result we consider it unlikely that these criteria could be exceeded.

9. Uncertainty

Uncertainties arise at several stages in the assessment of radium contamination at Dalgety Bay. Throughout this report large numbers of uncertainties exist, notably these include: the number of point sources detected, determining the activities of the radionuclides contained within the point sources and solubility testing. As no appropriate direct measurements have been taken of skin doses, this is also an area of uncertainty.

9.1. Consequences of uncertainty

The effect of the uncertainties of insolubility and dose rates may mean that the resultant doses could be greater or less than those calculated. Given that the focus of the report was to provide data against which RS-EPI may be able to determine if areas of Dalgety Bay should be designated as RCL, the magnitude of these uncertainties is of importance. For example, if the solubility of all of the point sources were consistent, the uncertainty of assessing point sources not subjected to the leaching experiment would be lower than it is at present. It has been reported that the most potentially exposed individual could have received an effective dose of around 66 mSv. This assessment assumes that the ^{210}Pb data are valid; if ^{210}Pb were in full equilibrium the doses would be around double. An uncertainty of less than an order of magnitude, could mean that one of the criteria was exceeded (> 100 mSv) or was far below this threshold value. As the uncertainty is large we are unable to assess if this criterion is exceeded or otherwise and as a result have recommended further work be undertaken.

For skin dose rates, clarity is needed from the Scottish Government on the area and depth of skin to be considered for assessment. Although subject to uncertainty itself, data have been provided which show that the dose rate to 1 cm^2 of skin at 70µm is low and even if the effect of large uncertainties is included, it is unlikely that the criteria would be exceeded. However, for infants, with a lesser skin depth to the basal layer, the criteria may be exceeded, although, again, the uncertainties of gamma spectrometry data and self-absorption need to be considered. Derived data have been presented that show that the dose rate at the skin surface could be very large; interpretation of these data also needs to take into account the effect of self-absorption. Thus, we have recommended that clarity is sought from the Scottish Government and empirical measurements are undertaken to provide real data on the potential dose rates from Dalgety Bay point sources.

9.2. Point sources not detected

The 2008 survey was designed to detect high-activity point sources rather than every point source of any activity. It is therefore highly likely that point sources of radioactivity remained on the intertidal area at Dalgety Bay following the survey work. The potential effects of this should be considered in any full risk assessment of the Dalgety Bay point sources.

9.3. Clarification of criteria

In this report SEPA has assessed the doses to the skin and via ingestion. In doing this SEPA has, *inter alia,* made a number of assumptions regarding the nature of the radiological units contained in the Guidance issued to SEPA by the Scottish Government and hence on the methods used to generate assessed doses for comparisons with the values given. If different assumptions were used in the report this could make significant differences in the resultant assessment. It is therefore suggested that clarity is sought from the Scottish Government perhaps in conjunction with the HPA, on the methods to be used in the calculation of doses for use in conjunction with the Guidance issued by the Scottish Government.

10. Discussion

In September 2008 radium contamination was detected on the intertidal area and coastal path at Dalgety Bay. This monitoring and recovery exercise showed the presence of both homogeneous and heterogeneous contamination.

Homogeneous contamination was detected across the beach and on the coastal path with two areas showing significant sources of contamination including an area of the costal path where a previous survey carried out for the MoD did not report contamination. If this MoD survey was indeed conducted over this particular area, the robustness of this earlier survey may need to be examined.

Thirty-nine point sources of radium were detected and removed which showed a diverse range of activities and physical properties. In this report we have presented data on the potential doses that could be received via skin contact and ingestion. However, these should only be considered as indicative as limited precision should be given to the derived data. For improved accuracy, it is recommended that the point sources are subjected to direct alpha dose rate measurement followed by solubility measurements using a realistic gut fluid simulation.

In the absence of specific criteria for skin depth and area, we have provided data based upon ICRP guidance. However, if values, other than those recommended by ICRP, are used, clearly different doses may arise.

For potential committed effective doses from ingestion, derived using only the results from the point sources subjected to leachate testing using dilute HCL, the greatest potential dose would be to a 1 year-old infant who could have received a dose of around 66 mSv (the RCL threshold level in the Statutory Guidance is 100mSv) assuming that the unaccredited ^{210}Pb data are valid; if ^{210}Pb were in full equilibrium the doses would be around double. However, this assessment can only be taken as indicative as the solubility testing solution was not a true representation of gut fluid. Analysis by the HPA for a 3 month-old infant suggests committed effective doses of around 240 mSv.

The solubility data obtained in 2006 and 2008 showed a range of solubilities from practically zero to around 15 %. Information on the physical dimensions could infer that a relationship between solubility and physical size exists, resulting in greater solubility as physical size decreases. If this relationship does exist, as larger point sources, where the activity is concentrated in a localised area, breakdown (such as point source DB/08/013), the potential solubility may be greater than assessed resulting in potentially larger doses.

In the 2006 screening assessment we assumed that the solubility could be up to around 15% which was consistent with that reported by Heaton et al in 1996. If a solubility of 15% were applied to the highest activity point source recovered in 2008, the potential doses could have been around 150 mSv (with contributions of around 37, 0.02, 0.01, 42, 0.08 and 74 mSv from ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi and ^{210}Po, respectively) for an adult and around 900 mSv (with contributions of 125, 0.11, 0.08, 220 0.6 and 540 mSv from ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi and ^{210}Po, respectively) for a 1-year old child. However, this assumes that the ^{210}Pb data are valid; if ^{210}Pb were in full equilibrium the doses would be around double.

This report is a retrospective assessment of the potential risks from radioactive contamination at Dalgety Bay. It is clear that the contamination is highly heterogeneous in size, activity and occurrence and there is no robust relationship between activity or size and potential effective doses. However, the potential committed effective doses from ingestion are greatest to infant children using the beach.

Appendix C reports the probability of encounter for various pathways. However, these probabilities could be under or over-estimates as no account has been taken of the number of point sources not detected, nor the uncertainty of exposure times.

10.1. Current intervention measures

In our 2006 report, following a calculation of the potential doses and probabilities of encounter, we recommended that, as the doses and probability of encounter were sufficiently great, a full risk assessment should be undertaken. In the absence of such an assessment, it was recommended that the precautionary principle was adopted.

In 2008, two signs were located at Dalgety Bay that advise users of the beach of the possible risks. However, given the location and wording of these signs, it seems that this signage may not be the optimal method to break the source-pathway-receptor linkage. It is notable that, during the 2008 monitoring survey, SEPA was informed that a class of children from a local nursery school regularly visit the beach. It is therefore recommended that, if intervention is warranted, the use of these signs, in respect of location, number and wording, is reconsidered.

The series of monitoring and recovery programmes undertaken at Dalgety Bay have provided evidence of re-population of the beach probably via the marine environment. It could be stated that these programmes provided some level of protection to the public as point sources were removed. However, the 2008 re-surveyed area showed that the rates which point sources re-populated cleared areas could be rapid. Therefore, unless an almost continuous monitoring programme were initially adopted, it is unlikely that a monitoring and retrieval programme, in itself, would be an optimal intervention measure.

11. Conclusions

This assessment was undertaken to provide data to determine whether some parts, all or none of Dalgety Bay should be classified as RCL. This included an assessment of the extent and potential effects of both homogeneous and heterogeneous contamination.

Widespread homogenous radium contamination was detected across the beach, however, it is unlikely that any individual using the beach would receive committed effective doses greater than 1 mSv per year from such contamination. Two localised areas of further enhanced contamination were also detected, one along the coastal path where point sources were also recovered and a second in the New Harbour area. However, even in these areas, it is considered that adults would be highly unlikely to ingest inadvertently sufficient material to receive a committed effective dose greater than 1 mSv per year.

Regarding point sources, 39 discrete items were located; two within the coastal path and the remainder in the intertidal area between the old pipeline and the New Harbour area. The activities of the items were similar to those recovered in 2006 and a number of the point sources broke into smaller pieces during recovery and again in the course of laboratory investigations. Subject to the beach being cleared of all detectable radioactive point sources, there was evidence that areas of the beach re-populating rapidly.

Based on the results of a small number of point sources subjected to solubility testing, indicative committed effective doses could range up to 66 mSv for a 1-year old infant, with the majority of the dose being from radium daughters. However, there is significant uncertainty with this value and there is the potential for significantly greater or lesser doses for other point sources. Equally, doses could be greater for younger children if they used the beach. Doses could also increase if the relatively small number of samples subjected for leaching was not representative of the population as a whole. Due to the high variability in the nature of the Dalgety Bay point sources, we conclude that there are currently insufficient robust data to allow any definitive conclusions to be drawn as to whether or not Dalgety Bay point sources could realistically deliver committed effective doses greater than 100 mSv. We recommend this information is acquired by carrying out a full risk assessment of the Dalgety Bay point sources, including a habits survey to determine if 3 month-old children are present on this beach.

No direct measurements of point sources to determine skin doses were undertaken, however, indicative work indicates that the dose rate could be up to several thousand Grays per hour at the surface of the skin. As the outer layer of the skin is essentially dead, cells at the base of the epidermis are considered to be the focus of any protection. It is recommended that this approach is used, therefore, the potential skin doses are greatest to young children whose reference skin thickness value, recommended by ICRP, is around 45-50 µm. Using the data collected in 2008, these potential doses to children could be of the order of tens to hundreds of Grays per hour. However, the effects of self-absorption need to be assessed. We recommend direct measurements are made to provide data for skin dose rates.

The probability of encounter remains high with the most likely encounter being direct skin contact.

The potential skin and committed effective doses from Dalgety Bay point sources are potentially large and we re-iterate our 2006 recommendation that a full risk assessment is undertaken and, in the absence of such an assessment, the precautionary principle is adopted. The locations and suitability of the current signage, in delivering and optimal intervention measure, should be reviewed.

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14. Glossary of terms

Absorbed dose	Quantity of energy imparted by ionising radiation to unit mass of matter such as tissue, measured in gray
ALDOSE	Computer program which calculates the absorbed dose rate, equivalent dose rate
Alpha particle	A particle consisting of two protons plus two neutrons, emitted by a radionuclide.
Alveolar	Area of the respiratory tract
Astatine (At)	The chemical element and its chemical symbol
Becquerel (Bq)	Unit of radioactivity 1 Bq = 1 disintegration per second
Beta (radiation)	An electron emitted from the nucleus of a radionuclide
Bismuth (Bi)	The chemical element and its chemical symbol
Bronchilor	Area of the lung
Committed effective dose	The effective dose which is received following ingestion of a radionuclide
Cornea	Area of the eye
Cps	Counts per second
Daughter	Product of the decay of a parental radionuclide
Deterministic effects	Injury in population of cells characterised by a threshold dose
Effective dose	The quantity obtained by multiplying the equivalent dose to various organs and tissues by a weighting factor appropriate to each and summing the product measured in sievert
ED50	The dose at which 50 % of the exposed population show an effect
Gamma (radiation)	A discrete quantity of electromagnetic energy without mass or charge
Gray	Quantity of absorbed dose 1 Gray = 1 joule per kilogram
Friability	The degree to which something is easily broken
Heterogeneous	High concentrations of contamination which is in the form of hot spots among larger areas of lower contamination
Homogenous	Disperse contamination of a generally uniform concentration
Intervention	A human activity that prevents or decreases the exposure of individuals to radiation from sources, by acting on the sources, transmission pathways or individuals.
Kilo (k)	One thousand units
Lead (Pb)	The chemical element and its chemical symbol
Mercury (Hg)	The chemical element and its chemical symbol
Mega (M)	One million units
Micron (µm)	One millionth of a meter, i.e. one thousandth of a millimetre
Milli sievert (mSv)	One thousandth of a sievert
Photon	A quantum of electromagnetic radiation
Polonium (Po)	The chemical element and its chemical symbol
Point source	A discrete and highly localised source
Progeny	See daughter
Radionuclide	A nucleus which is capable of releasing radiation spontaneously
Radiation weighting factor (W_R)	A dimensionless factor used to derive the equivalent dose from the absorbed dose averaged over a tissue or organ and is based on the quality of radiation (ICRP, 1991).
Radium (Ra)	The chemical element and its chemical symbol
Radon (Rn)	The chemical element and its chemical symbol

Sievert (Sv)	See effective dose
Thallium (Tl)	The chemical element and its chemical symbol
Tissue weighting factors (W_T)	The factor by which the equivalent dose in a tissue or organ is weighted to represent the relative contribution of that tissue or organ to the total detriment resulting from uniform irradiation of the body (ICRP, 1991)
VARSKIN	The VARSKIN computer program calculates the radiation dose (gamma and beta) to skin from radioactive contamination

Appendices

Appendix A. Requirements of the Radioactive Contaminated Land & Statutory Guidance

This appendix should be read in conjunction with the Statutory Guidance as it is only intended to serve as a brief extract and not a definitive set of requirements. There may exist references to parts of the Guidance that are not represented in this appendix.

A.1. Significant harm

The Radioactive Contaminated Land (Scotland) Regulations 2007 creates a definition of contaminated land which applies specifically to radioactive contaminated land:

"any land which appears to SEPA to be in such a condition, by reason of substances in, on or under the land, that –

"(a) SIGNIFICANT HARM is being caused or there is a SIGNIFICANT POSSIBILITY of such harm being caused; or

"(b) SIGNIFICANT POLLUTION OF THE WATER ENVIRONMENT is being caused or there is a significant possibility of such pollution being caused".

Where substance is defined in S78A(9) as:
"substance" means, whether in solid or liquid form or in the form of a gas or vapour, any substance which contains radionuclides that are or have been processed as part of a work activity or past practice, but shall not include radon gas and any radionuclide present as a result of the radioactive decay of radon;

The definition of significant harm is:

The definition of CONTAMINATED LAND includes the notion of "SIGNIFICANT HARM and the "SIGNIFICANT POSSIBILITY" of such HARM being caused. When considering land that may be contaminated with radioactivity SEPA is required to act in accordance with statutory guidance issued by The Scottish Ministers in determining what is "significant" in either context (*section 78A(2) & (5)*). This set out at Chapter A of Annex 3 of the statutory guidance.

The statutory guidance uses the concept of a "POLLUTANT LINKAGE" – that is, a linkage between a CONTAMINANT and a RECEPTOR, by means of a PATHWAY. The CONTAMINANT may be described as a POLLUTANT only when a PATHWAY and RECEPTOR are present. The statutory guidance then explains: (a) the types of RECEPTOR to which SIGNIFICANT HARM can be caused (HARM to any other type of RECEPTOR can never be regarded as SIGNIFICANT HARM); (b) the degree or nature of HARM to each of these RECEPTORS which constitutes SIGNIFICANT HARM (*Chapter A paragraph A.25 to A.30*); and (c) for each RECEPTOR, the degree of possibility of the SIGNIFICANT HARM being caused which will amount to a SIGNIFICANT POSSIBILITY (*Chapter A, paragraphs A.32 to A38*).

Before SEPA can make the judgement that any land appears to be CONTAMINATED LAND on the basis that SIGNIFICANT HARM is being caused by radioactivity possessed by any substance, or that there is a SIGNIFICANT POSSIBILITY of such harm being caused by radioactivity possessed by any substance, SEPA must therefore identify a SIGNIFICANT POLLUTANT LINKAGE. This means that each of the following has to be identified:

(a) a RADIOACTIVE CONTAMINANT;
(b) a relevant RECEPTOR; and
(c) a PATHWAY by means of which either:
(i) that RADIOACTIVE CONTAMINANT is causing SIGNIFICANT HARM to that RECEPTOR, or
(ii) there is a SIGNIFICANT POSSIBILITY of such harm being caused by that RADIOACTIVE CONTAMINANT to that RECEPTOR (*paragraphs A.13 and A.20*).

Significant harm is defined in the statutory guidance which states that:

A.2. Significant harm to human beings

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:

(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.

A.3. Significant harm to non-human species
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 $\mu Gy\ hr^{-1}$ to terrestrial biota or plants;
(b) 400 $\mu Gy\ hr^{-1}$ to aquatic biota or plants;

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

A.4. Background radiation

When assessing doses arising from lasting exposure no account shall be taken of the natural level of background ionising radiation, i.e. to radionuclides contained in the human body, to cosmic radiation or to radionuclides present in the undisturbed earth's crust.

A.5. Whether the possibility of significant harm being caused is significant?

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 "potential annual equivalent dose" and "potential annual effective dose" 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:

(a) the potential total effective dose is greater than 100 mSv; or

(b) 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.33 and A.34 of the Statutory Guidance 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.

The possibility of significant harm being caused as a result of any changes of use of any land to one which is not a “current use” of that land (as defined in paragraph A.27 above) should not be regarded as a significant possibility of significant harm.

When considering the possibility of significant harm being caused in relation to any future use or development which falls within the description of a “current use” as a result of paragraph A.27(b) of the Statutory Guidance, SEPA should assume that if the future use is introduced, or the development carried out, this will be done in accordance with any existing planning permission for that use or development. In particular, SEPA should assume:

(a) that any remediation which is the subject of a condition attached to that planning permission, or is the subject of any planning obligation, will be carried out in accordance with that permission or obligation; and

(b) where a planning permission has been given subject to conditions which require steps to be taken to prevent problems which might be caused by contamination, and those steps are to be approved by the planning authority, that the planning authority will ensure that those steps include adequate remediation.

A.6. Whether the possibility of significant harm being caused to non-human species is significant?

SEPA should regard the possibility of significant harm being caused to non-human species as significant when significant harm to non-human species is likely to be caused. For this purpose SEPA should regard something as being “likely” when on the balance of probabilities it is judged more likely than not to be caused.

Appendix B. Methodology used to determine probability of encountering a radioactive item on Dalgety Bay.
Note input parameters (other than number of items and area) are taken from SEPA 2006

B.1. Estimation of Total Items on the Beach

Using the data gathered from the survey the total number of radioactive items on the beach can be estimated.

Determine the number of items per square metre in the survey area:

$$F_a = \frac{N_f}{A_s}$$

Where:

F_a is the number of items per metre squared of the survey area, m^{-2}
N_f is the number of items detected in the survey area
A_s is the total area surveyed, m^2

Estimate the total number of items on the beach

$$F_t = F_a \times A_b$$

Where,

F_t is the total number of items on the beach
F_a is the number of items per metre squared of the survey area, m^{-2}
A_b is the total area of the beach, m^2

B.2. Item Density

In order to determine the item density, it is necessary to convert the number of items per m^2 of beach (detection limit depth is 0.1 m). The following formula was used:

$$F_d = \frac{F_a}{d \times D_s}$$

Where,

F_d is the number of items per gramme of sand, g^{-1}
F_a is the number of items per m^2 of sand, m^{-2}
d is the depth of sand to which the value of F_a applies, 0.1 m
D_s is the density of sand to which the value of F_a applies

Assumption: The beach is assumed to be composed of sand. A range of density values is used to calculate an average sand density. This value is detailed in the calculation section.

B.3. Inadvertent ingestion with sand

The probability of inadvertently ingesting a fragment in sand, both per visit and annually, is determined as follows:

$$P_{ing} = F_d \times I_R \times O_R$$

P_{ing} is the probability of ingestion
F_d is the fragment density, g^{-1}
I_R is the inadvertent ingestion rate, g h^{-1}
O_R is the occupancy rate (per visit or per year)

Assumption: Inadvertent ingestion rate is for sand

B.4. Direct Skin Contact

Probability of a fragment coming into direct contact with the skin is determined separately for skin contact, clothes and shoes.

B.4.1. Contact with dry sand

The probability of encountering a fragment inadvertently in dry sand during a visit to the beach is given by the following equation:

$$P_{skin,dry} = (S_1 + 0.5 \times S_2) \times D_{L,d} \times F_d \times D_{S,d}$$

$P_{skin,dry}$ is the probability of direct skin contact with dry sand
S_1 is the area of skin on hands and feet that was exposed to dry sand, cm^2
S_2 is the area of skin on other parts of the body exposed to dry sand, cm^2
$D_{L,d}$ is the dermal loading of dry sand on hands and feet, g cm^{-2}
F_d is the fragment density, g^{-1}
$D_{s,d}$ is a factor to account for the re-adherence of dry sand on skin during the visit

Assumption: Dermal loading rate is assumed to be valid.

B.4.2. Contact with wet sand

The probability of encountering a fragment inadvertently in wet sand during a visit to the beach is given by the following equation:

$$P_{skin,wet} = (S_3 + 0.5 \times S_4) \times D_{L,w} \times F_d \times D_{S,w}$$

$P_{skin,wet}$ is the probability of direct skin contact with wet sand
S_3 is the area of skin on hands and feet that was exposed to wet sand, cm^2
S_4 is the area of skin on other parts of the body exposed to wet sand, cm^2
$D_{L,w}$ is the dermal loading of wet sand on hands and feet, g cm-2
F_d is the fragment density, g^{-1}
$D_{s,w}$ is a factor to account for the re-adherence of wet sand on skin during the visit

Assumption: Dermal loading rate is assumed to be valid.

B.4.3 Contact with dry and wet sand

The probability of encountering a contaminated item inadvertently in dry and wet sand during a visit to the beach is given by the following equation:

$$P_{skin,dry\&wet} = \left[\left(\frac{S_1 + 0.5 \times S_2}{50}\right) + \left(S_3 + 0.5 \times S_4\right)\right] \times D_{L,wet} \times F_d \times D_{s,d\&w}$$

$P_{skin,dry\&wet}$ is the probability of direct skin contact with both dry & wet sand
S_1 is the area of skin on hands and feet that was exposed to dry sand, cm^2
S_2 is the area of skin on other parts of the body exposed to dry sand, cm^2
S_3 is the area of skin on hands and feet that was exposed to wet sand, cm^2
S_4 is the area of skin other parts of the body exposed to wet sand, cm^2
$D_{L,wet}$ is the dermal loading of wet sand on hands and feet, g cm^{-2}
F_d is the item density, g^{-1}
$D_{s,d\&w}$ is a factor to account for the re-adherence of both dry & wet sand on skin during the visit

Assumption: Dermal loading rate is assumed to be valid.

B.5. An item under fingernails

The probability of being exposed to a contaminated item trapped under nails on a visit to the beach is given by:

$$P_{nails} = F_d \times S_n$$

P_{nails} is the probability of contacting an item in sand trapped under nails per beach visit
F_d is the item density, g^{-1}
L_d amount of sand trapped under nails per visit to the beach, g

Assumption: The value of L_d is assumed to be valid.

B.6. An item on clothes

The probability of being exposed to an item trapped on clothes

$$P_{cl,v} = F_d \times A_c \times L_d \times f_s$$

$P_{cl,v}$ is the probability of an item adhering to clothing per beach visit
F_d is the item density, g^{-1}
A_c is the area of clothing exposed, cm^2
L_d is the loading of sand on clothing, g cm^{-2}
f_s is a factor to account for the change of sand adhering during the visit

Assumption: The value of L_d is assumed to be valid.

B.7. A item in a shoe

The probability of a fragment being trapped in an individual's shoe on a visit to the beach:

$$P_{shoe,v} = F_d \times S_s$$

$P_{shoe,y}$ is the probability of an item being trapped in an individual's shoe per visit
F_d is the item density, g_{-1}
S_s amount of sand trapped in shoes per visit to the beach, g

Assumption: The value of S_s is assumed to be valid.

Appendix C Probability Results

Probability of encountering radioactive fragment at Dalgety Bay

November 2008
2007-3

Following the methodology in RPD-EA-9-2005, this sheet details the results for the following area and detected fragments.

Number of fragments	Nf	5 fragments
Area Surveyed	As	4,960 m^2
Depth of monitoring	D	0.10 m
Adult Occupancy Rate	O_R	2000 $h\,y^{-1}$

Note: Occupancy values for Children and Infants remain at the generic rates stated in NRPB-W41. This will not be valid for assessments of adult habits (bait digging, bird watching etc.) - results for these columns should be treated with caution.

Results of Calculations

Survey Data

	Exposure Pathway		Adult	Child	Infant
1	Inhalation of an item	per visit	2.80E-12	3.61E-13	1.24E-13
		per year	5.19E-09	1.08E-10	3.72E-12
2	Inadvertent Ingestion	per visit	2.82E-11	5.64E-11	2.82E-10
		per year	5.64E-08	1.69E-08	8.46E-09
3	Direct Skin Contact				
	dry sand	per visit	3.27E-09	3.52E-09	1.53E-09
		per year	6.55E-06	1.05E-06	4.59E-08
	wet sand	per visit	1.64E-07	1.76E-07	7.65E-08
		per year	3.27E-04	5.27E-05	2.29E-06
	dry and wet sand	per visit	1.67E-07	1.79E-07	7.80E-08
		per year	3.34E-04	5.38E-05	2.34E-06
4	Fragment under fingernails	per visit	2.42E-09	8.69E-10	1.92E-10
		per year	4.85E-06	2.61E-07	5.76E-09
5	Fragment on clothes	per visit	2.14E-08	1.26E-08	5.98E-09
		per year	4.29E-05	3.79E-06	1.79E-07
6	Fragment in a shoe	per visit	5.64E-08	5.64E-08	5.64E-08
		per year	1.13E-04	1.69E-05	1.69E-06
	Total probability	per visit	2.47E-07	2.49E-07	1.41E-07
		per year	4.94E-04	7.48E-05	4.23E-06

In terms of Chance

	Exposure Pathway		Adult	Child	Infant
1	Inhalation of a fragment	per visit	385,239,130,435	2,768,906,250,000	8,055,000,000,000
		per year	192,617,922	9,229,633,420	268,550,961,680
2	Inadvertent Ingestion	per visit	35,442,000,000	17,721,000,000	3,544,200,000
		per year	17,721,010	59,070,032	118,140,017
4	Direct Skin Contact				
	dry sand	per visit	305,534,483	284,446,228	653,911,439
		per year	152,768	948,155	21,797,049
	wet sand	per visit	6,110,690	5,688,925	13,078,229
		per year	3,056	18,964	435,941
	dry and wet sand	per visit	5,990,872	5,577,377	12,821,793
		per year	2,996	18,592	427,394
5	Fragment under fingernails	per visit	412,500,000	1,151,162,791	5,210,526,316
		per year	206,250	3,837,210	173,684,251
6	Fragment on clothes	per visit	46,634,211	79,111,607	167,179,245
		per year	23,318	263,706	5,572,642
7	Fragment in a shoe	per visit	17,721,000	17,721,000	17,721,000
		per year	8,861	59,070	590,700
	Total probability	per visit	4,044,500	4,011,363	7,098,329
		per year	2,023	13,371	236,611

Following the methodology in RPD-EA-9-2005, this sheet details the results for the following area and detected fragments.

Number of fragments detected	Nf	24 fragments
Area Surveyed	As	4,000 m^2
Depth of monitoring	D	0.10 m
Adult Occupancy Rate	O_R	2000 $h\ y^{-1}$

Note: Occupancy values for Children and Infants remain at the generic rates stated in NRPB-W41. This will not be valid for assessments of adult habits (bait digging, bird watching etc.) - results for these columns should be treated with caution.

Results of Calculations **Survey Data**

Exposure Pathway		Adult	Child	Infant
1 Inhalation of an item	per visit	1.54E-11	2.15E-12	7.37E-13
	per year	3.08E-08	6.44E-10	2.21E-11
2 Inadvertent Ingestion	per visit	1.68E-10	3.35E-10	1.68E-09
	per year	3.35E-07	1.01E-07	5.03E-08
3 Direct Skin Contact				
dry sand	per visit	1.94E-08	2.09E-08	9.08E-09
	per year	3.89E-05	6.26E-06	2.73E-07
wet sand	per visit	9.72E-07	1.04E-06	4.54E-07
	per year	1.94E-03	3.13E-04	1.36E-05
dry and wet sand	per visit	9.92E-07	1.07E-06	4.63E-07
	per year	1.98E-03	3.19E-04	1.39E-05
4 Fragment under fingernails	per visit	1.44E-08	5.16E-09	1.14E-09
	per year	2.88E-05	1.55E-06	3.42E-08
5 Fragment on clothes	per visit	1.27E-07	7.51E-08	3.55E-08
	per year	2.55E-04	2.25E-05	1.07E-06
6 Fragment in a shoe	per visit	3.35E-07	3.35E-07	3.35E-07
	per year	6.70E-04	1.01E-04	1.01E-05
Total probability	per visit	1.47E-06	1.48E-06	8.37E-07
	per year	2.94E-03	4.44E-04	2.51E-05

In terms of Chance

Exposure Pathway		Adult	Child	Infant
1 Inhalation of a fragment	per visit	64,855,072,464	466,145,833,333	1,356,060,606,061
	per year	32,427,526	1,553,795,866	45,203,248,292
2 Inadvertent Ingestion	per visit	5,966,666,667	2,983,333,333	596,666,667
	per year	2,983,335	9,944,445	19,888,889
4 Direct Skin Contact				
dry sand	per visit	51,436,782	47,886,570	110,086,101
	per year	25,719	159,622	3,669,537
wet sand	per visit	1,028,736	957,731	2,201,722
	per year	515	3,193	73,391
dry and wet sand	per visit	1,008,564	938,952	2,158,551
	per year	505	3,130	71,952
5 Fragment under fingernails	per visit	69,444,444	193,798,450	877,192,982
	per year	34,723	645,995	29,239,767
6 Fragment on clothes	per visit	7,850,877	13,318,452	28,144,654
	per year	3,926	44,395	938,156
7 Fragment in a shoe	per visit	2,983,333	2,983,333	2,983,333
	per year	1,492	9,945	99,445
Total probability	per visit	680,892	675,314	1,195,005
	per year	341	2,251	39,834

Following the methodology in RPD-EA-9-2005, this sheet details the results for the following area and detected fragments.

Number of fragments detected	Nf	6 fragments
Area Surveyed	As	6,525 m^2
Depth of monitoring	D	0.10 m
Adult Occupancy Rate	O_R	2000 $h\ y^{-1}$

__Note__: Occupancy values for Children and Infants remain at the generic rates stated in NRPB-W41. This will not be valid for assessments of adult habits (bait digging, bird watching etc.) - results for these columns should be treated with caution.

Results of Calculations — Survey Data

Exposure Pathway		Adult	Child	Infant
1 Inhalation of an item	per visit	2.36E-12	3.29E-13	1.13E-13
	per year	4.73E-09	9.86E-11	3.39E-12
2 Inadvertent Ingestion	per visit	2.57E-11	5.14E-11	2.57E-10
	per year	5.14E-08	1.54E-08	7.71E-09
3 Direct Skin Contact				
dry sand	per visit	2.98E-09	3.20E-09	1.39E-09
	per year	5.96E-06	9.60E-07	4.18E-08
wet sand	per visit	1.49E-07	1.60E-07	6.96E-08
	per year	2.98E-04	4.80E-05	2.09E-06
dry and wet sand	per visit	1.52E-07	1.63E-07	7.10E-08
	per year	3.04E-04	4.90E-05	2.13E-06
4 Fragment under fingernails	per visit	2.21E-09	7.91E-10	1.75E-10
	per year	4.41E-06	2.37E-07	5.24E-09
5 Fragment on clothes	per visit	1.95E-08	1.15E-08	5.45E-09
	per year	3.90E-05	3.45E-06	1.63E-07
6 Fragment in a shoe	per visit	5.14E-08	5.14E-08	5.14E-08
	per year	1.03E-04	1.54E-05	1.54E-06
Total probability	per visit	2.25E-07	2.27E-07	1.28E-07
	per year	4.50E-04	6.81E-05	3.85E-06

In terms of Chance

Exposure Pathway		Adult	Child	Infant
1 Inhalation of a fragment	per visit	423,179,347,826	3,041,601,562,500	8,848,295,454,545
	per year	211,585,606	10,139,816,790	294,931,213,318
2 Inadvertent Ingestion	per visit	38,932,500,000	19,466,250,000	3,893,250,000
	per year	19,466,271	64,887,570	129,775,027
4 Direct Skin Contact				
dry sand	per visit	335,625,000	312,459,872	718,311,808
	per year	167,813	1,041,533	23,943,728
wet sand	per visit	6,712,500	6,249,197	14,366,236
	per year	3,357	20,831	478,875
dry and wet sand	per visit	6,580,882	6,126,664	14,084,545
	per year	3,291	20,423	469,485
5 Fragment under fingernails	per visit	453,125,000	1,264,534,884	5,723,684,211
	per year	226,563	4,215,116	190,789,424
6 Fragment on clothes	per visit	51,226,974	86,902,902	183,643,868
	per year	25,614	289,677	6,121,463
7 Fragment in a shoe	per visit	19,466,250	19,466,250	19,466,250
	per year	9,734	64,888	648,875
Total probability	per visit	4,442,822	4,406,421	7,797,406
	per year	2,222	14,688	259,914

Following the methodology in RPD-EA-9-2005, this sheet details the results for the following area and detected fragments.

Number of fragments detected	Nf	35 fragments
Area Surveyed	As	15,475 m^2
Depth of monitoring	D	0.10 m
Adult Occupancy Rate	O_R	2000 $h\,y^{-1}$

<u>Note</u>: Occupancy values for Children and Infants remain at the generic rates stated in NRPB-W41. This will not be valid for assessments of adult habits (bait digging, bird watching etc.) - results for these columns should be treated with caution.

Results of Calculations — **Survey Data**

Exposure Pathway		Adult	Child	Infant
1 Inhalation of an item	per visit	5.81E-12	8.09E-13	2.78E-13
	per year	1.16E-08	2.43E-10	8.34E-12
2 Inadvertent Ingestion	per visit	6.32E-11	1.26E-10	6.32E-10
	per year	1.26E-07	3.79E-08	1.90E-08
3 Direct Skin Contact				
dry sand	per visit	7.33E-09	7.87E-09	3.42E-09
	per year	1.47E-05	2.36E-06	1.03E-07
wet sand	per visit	3.66E-07	3.94E-07	1.71E-07
	per year	7.33E-04	1.18E-04	5.14E-06
dry and wet sand	per visit	3.74E-07	4.01E-07	1.75E-07
	per year	7.47E-04	1.20E-04	5.24E-06
4 Fragment under fingernails	per visit	5.43E-09	1.95E-09	4.30E-10
	per year	1.09E-05	5.84E-07	1.29E-08
5 Fragment on clothes	per visit	4.80E-08	2.83E-08	1.34E-08
	per year	9.60E-05	8.49E-06	4.02E-07
6 Fragment in a shoe	per visit	1.26E-07	1.26E-07	1.26E-07
	per year	2.53E-04	3.79E-05	3.79E-06
Total probability	per visit	5.54E-07	5.58E-07	3.15E-07
	per year	1.11E-03	1.67E-04	9.46E-06

In terms of Chance

Exposure Pathway		Adult	Child	Infant
1 Inhalation of a fragment	per visit	172,051,242,236	1,236,818,303,571	3,597,435,064,935
	per year	86,025,360	4,121,910,697	119,904,143,434
2 Inadvertent Ingestion	per visit	15,828,714,286	7,914,357,143	1,582,871,429
	per year	7,914,354	26,381,202	52,762,386
4 Direct Skin Contact				
dry sand	per visit	136,454,433	127,036,230	292,042,699
	per year	68,228	423,455	9,734,757
wet sand	per visit	2,729,089	2,540,725	5,840,854
	per year	1,365	8,470	194,696
dry and wet sand	per visit	2,675,577	2,490,906	5,726,327
	per year	1,338	8,304	190,878
5 Fragment under fingernails	per visit	184,226,190	514,119,601	2,327,067,669
	per year	92,114	1,713,733	77,568,922
6 Fragment on clothes	per visit	20,827,256	35,331,952	74,663,747
	per year	10,414	117,774	2,488,792
7 Fragment in a shoe	per visit	7,914,357	7,914,357	7,914,357
	per year	3,958	26,382	263,812
Total probability	per visit	1,806,310	1,791,511	3,170,177
	per year	903	5,972	105,673

Appendix D. Ingestion doses from point sources recovered during 2008 monitoring

HPA Ref	Nuvia Ref	Bq/sample HPA								
		Ra-226	Rn-222	Po-218	Pb-214^	Bi-214^	Po-214	Pb-210#	Bi-210^	Po-210^
08-6301	DB/08/002	206			184.05	172.23		123.26	123.26	123.26
08-6303	DB/08/004	23			19.73	20.08		9.03	9.03	9.03
08-6304	DB/08/005	345			281.65	274.12		125.45	125.45	125.45
08-6305	DB/08/006	100			88.25	85.08		42.54	42.54	42.54
08-6317	DB/08/008	12510			10271.79	10071.95		4316.55	4316.55	4316.55
08-6319	DB/08/010	32			29.01	27.80		18.84	18.84	18.84
08-6322	DB/08/013	805			722.86	700.95		284.76	284.76	284.76
08-6341	DB/08/032	1.00			0.63	0.23		0.62	0.62	0.62
08-6342	DB/08/033	1.1			0.91	0.99		0.36	0.36	0.36
08-6343	DB/08/034	1.00			0.60	0.59		0.59	0.59	0.59
08-6344	DB/08/035	72			33.85	18.85		54.57	54.57	54.57
08-6345	DB/08/036	7			4.35	1.93		5.38	5.38	5.38
08-6346	DB/08/037	28			17.39	8.17		26.17	26.17	26.17
08-6347	DB/08/038	1.00			0.65	0.31		0.94	0.94	0.94
08-6348	DB/08/039	426			345.64	336.93		154.91	154.91	154.91
08-6348	DB/08/039	950			549.73	190.00		829.67	829.67	829.67

*	Assuming proportionate activity
#	Reported by HPA at SEPA's request (QA status not routine)
(yellow highlight)	Ra-226 result is at limit of detection (other data is assumed based on proportionate activity leached)
^	Assumes equilibrium with Pb-210

Appendix E. ICRP dose coefficients and resultant doses from ingestion for five age groups

Table E.1

Radionuclide	Ra-226	Rn-222	Po-218	Pb-214	Bi-214	Po-214	Pb-210	Bi-210	Po-210	Pb-206
Half-life	1600	3.8	3.05	26.8	19.9	0.00016	22.26	5	138.8	Stable
Unit	years	days	min	min	min	s	years	days	days	

Table E.2

ICRP Dose Coefficients for Ingestion Sv Bq^{-1}									
1 year old	9.60E-07			1.00E-09	7.40E-10		3.60E-06	9.70E-09	8.80E-06
5 year old	6.20E-07			5.20E-10	3.60E-10		2.20E-06	4.80E-09	4.40E-06
10 year old	8.00E-07			3.10E-10	2.10E-10		1.90E-06	2.90E-09	2.60E-06
15 year old	1.50E-06			2.00E-10	1.40E-10		1.90E-06	1.60E-09	1.60E-06
Adult	2.80E-07			1.40E-10	1.10E-10		6.90E-07	1.30E-09	1.20E-06

* Data from ICRP 72.

Table E.3 Doses calculated for the five age groups

	2008 Leachate Values										
	Ra-226	**Rn-222**	**Po-218**	**Pb-214**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Po-210**	**Total**	**Total**
HPA Ref	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Sv	mSv
08-6301	5.77E-05			2.58E-08	1.89E-08		8.51E-05	1.60E-07	1.48E-04	2.91E-04	0.29
08-6303	6.44E-06			2.76E-09	2.21E-09		6.23E-06	1.17E-08	1.08E-05	2.35E-05	0.02
08-6304	9.66E-05			3.94E-08	3.02E-08		8.66E-05	1.63E-07	1.51E-04	3.34E-04	0.33
08-6305	2.80E-05			1.24E-08	9.36E-09		2.94E-05	5.53E-08	5.10E-05	1.08E-04	0.11
08-6317	3.50E-03			1.44E-06	1.11E-06		2.98E-03	5.61E-06	5.18E-03	1.17E-02	11.67
08-6319	8.96E-06			4.06E-09	3.06E-09		1.30E-05	2.45E-08	2.26E-05	4.46E-05	0.04
08-6322	2.25E-04			1.01E-07	7.71E-08		1.96E-04	3.70E-07	3.42E-04	7.64E-04	0.76
08-6341	2.80E-07			8.80E-11	2.49E-11		4.28E-07	8.07E-10	7.45E-07	1.45E-06	0.00
08-6342	3.08E-07			1.28E-10	1.09E-10		2.51E-07	4.72E-10	4.36E-07	9.95E-07	0.00
08-6343	2.80E-07			8.38E-11	6.48E-11		4.06E-07	7.66E-10	7.07E-07	1.39E-06	0.00
08-6344	2.02E-05			4.74E-09	2.07E-09		3.77E-05	7.09E-08	6.55E-05	1.23E-04	0.12
08-6345	1.96E-06			6.09E-10	2.12E-10		3.71E-06	6.99E-09	6.46E-06	1.21E-05	0.01
08-6346	7.84E-06			2.43E-09	8.99E-10		1.81E-05	3.40E-08	3.14E-05	5.73E-05	0.06
08-6347	2.80E-07			9.04E-11	3.44E-11		6.48E-07	1.22E-09	1.13E-06	2.06E-06	0.00
08-6348	1.19E-04			4.84E-08	3.71E-08		1.07E-04	2.01E-07	1.86E-04	4.12E-04	0.41
08-6348	2.66E-04			7.70E-08	2.09E-08		5.72E-04	1.08E-06	9.96E-04	1.84E-03	1.84

	2008 Leachate Values										
	Ra-226	**Rn-222**	**Po-218**	**Pb-214**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Po-210**	**Total**	**Total**
HPA Ref	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	Sv	mSv
08-6301	3.09E-04			3.68E-08	2.41E-08		2.34E-04	1.97E-07	1.97E-04	7.41E-04	0.74
08-6303	3.45E-05			3.95E-09	2.81E-09		1.72E-05	1.45E-08	1.45E-05	6.61E-05	0.07
08-6304	5.18E-04			5.63E-08	3.84E-08		2.38E-04	2.01E-07	2.01E-04	9.57E-04	0.96
08-6305	1.50E-04			1.77E-08	1.19E-08		8.08E-05	6.81E-08	6.81E-05	2.99E-04	0.30
08-6317	1.88E-02			2.05E-06	1.41E-06		8.20E-03	6.91E-06	6.91E-03	3.39E-02	33.88
08-6319	4.80E-05			5.80E-09	3.89E-09		3.58E-05	3.02E-08	3.02E-05	1.14E-04	0.11
08-6322	1.21E-03			1.45E-07	9.81E-08		5.41E-04	4.56E-07	4.56E-04	2.20E-03	2.20
08-6341	1.50E-06			1.26E-10	3.18E-11		1.18E-06	9.93E-10	9.93E-07	3.67E-06	0.00
08-6342	1.65E-06			1.83E-10	1.38E-10		6.90E-07	5.81E-10	5.81E-07	2.92E-06	0.00
08-6343	1.50E-06			1.20E-10	8.25E-11		1.12E-06	9.42E-10	9.42E-07	3.56E-06	0.00
08-6344	1.08E-04			6.77E-09	2.64E-09		1.04E-04	8.73E-08	8.73E-05	2.99E-04	0.30
08-6345	1.05E-05			8.71E-10	2.70E-10		1.02E-05	8.61E-09	8.61E-06	2.93E-05	0.03
08-6346	4.20E-05			3.48E-09	1.14E-09		4.97E-05	4.19E-08	4.19E-05	1.34E-04	0.13
08-6347	1.50E-06			1.29E-10	4.38E-11		1.79E-06	1.50E-09	1.50E-06	4.79E-06	0.00
08-6348	6.39E-04			6.91E-08	4.72E-08		2.94E-04	2.48E-07	2.48E-04	1.18E-03	1.18
08-6348	1.43E-03			1.10E-07	2.66E-08		1.58E-03	1.33E-06	1.33E-03	4.33E-03	4.33

	2008 Leachate Values										
	Ra-226	**Rn-222**	**Po-218**	**Pb-214**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Po-210**	**Total**	**Total**
HPA Ref	10 yr old	10 yr old	10 yr old	10 yr old	10 yr old	10 yr old	10 yr old	10 yr old	10 yr old	Sv	mSv
08-6301	1.65E-04			5.71E-08	3.62E-08		2.34E-04	3.57E-07	3.20E-04	7.20E-04	0.72
08-6303	1.84E-05			6.12E-09	4.22E-09		1.72E-05	2.62E-08	2.35E-05	5.91E-05	0.06
08-6304	2.76E-04			8.73E-08	5.76E-08		2.38E-04	3.64E-07	3.26E-04	8.41E-04	0.84
08-6305	8.00E-05			2.74E-08	1.79E-08		8.08E-05	1.23E-07	1.11E-04	2.72E-04	0.27
08-6317	1.00E-02			3.18E-06	2.12E-06		8.20E-03	1.25E-05	1.12E-02	2.95E-02	29.45
08-6319	2.56E-05			8.99E-09	5.84E-09		3.58E-05	5.46E-08	4.90E-05	1.10E-04	0.11
08-6322	6.44E-04			2.24E-07	1.47E-07		5.41E-04	8.26E-07	7.40E-04	1.93E-03	1.93
08-6341	8.00E-07			1.95E-10	4.76E-11		1.18E-06	1.80E-09	1.61E-06	3.59E-06	0.00
08-6342	8.80E-07			2.83E-10	2.07E-10		6.90E-07	1.05E-09	9.45E-07	2.52E-06	0.00
08-6343	8.00E-07			1.85E-10	1.24E-10		1.12E-06	1.71E-09	1.53E-06	3.45E-06	0.00
08-6344	5.76E-05			1.05E-08	3.96E-09		1.04E-04	1.58E-07	1.42E-04	3.03E-04	0.30
08-6345	5.60E-06			1.35E-09	4.05E-10		1.02E-05	1.56E-08	1.40E-05	2.98E-05	0.03
08-6346	2.24E-05			5.39E-09	1.72E-09		4.97E-05	7.59E-08	6.81E-05	1.40E-04	0.14
08-6347	8.00E-07			2.00E-10	6.56E-11		1.79E-06	2.72E-09	2.44E-06	5.03E-06	0.01
08-6348	3.41E-04			1.07E-07	7.08E-08		2.94E-04	4.49E-07	4.03E-04	1.04E-03	1.04
08-6348	7.60E-04			1.70E-07	3.99E-08		1.58E-03	2.41E-06	2.16E-03	4.50E-03	4.50

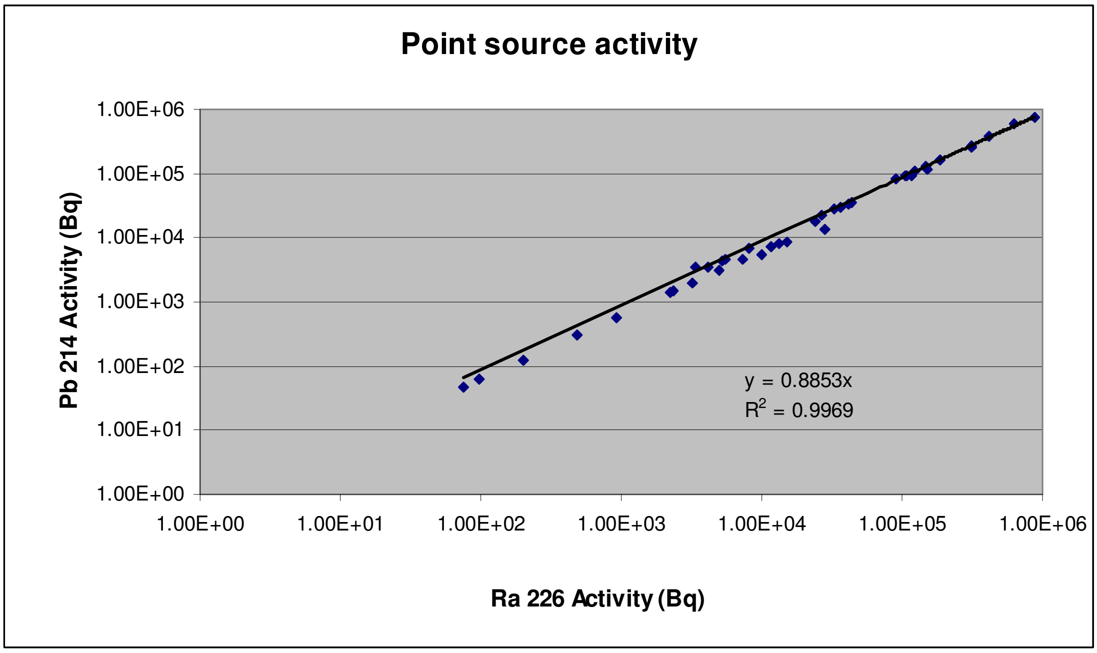
	2008 Leachate Values										
	Ra-226	**Rn-222**	**Po-218**	**Pb-214**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Po-210**	**Total**	**Total**
HPA Ref	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	Sv	mSv
08-6301	1.28E-04			9.57E-08	6.20E-08		2.71E-04	5.92E-07	5.42E-04	9.42E-04	0.94
08-6303	1.43E-05			1.03E-08	7.23E-09		1.99E-05	4.34E-08	3.97E-05	7.39E-05	0.07
08-6304	2.14E-04			1.46E-07	9.87E-08		2.76E-04	6.02E-07	5.52E-04	1.04E-03	1.04
08-6305	6.20E-05			4.59E-08	3.06E-08		9.36E-05	2.04E-07	1.87E-04	3.43E-04	0.34
08-6317	7.76E-03			5.34E-06	3.63E-06		9.50E-03	2.07E-05	1.90E-02	3.63E-02	36.28
08-6319	1.98E-05			1.51E-08	1.00E-08		4.15E-05	9.05E-08	8.29E-05	1.44E-04	0.14
08-6322	4.99E-04			3.76E-07	2.52E-07		6.26E-04	1.37E-06	1.25E-03	2.38E-03	2.38
08-6341	6.20E-07			3.27E-10	8.16E-11		1.37E-06	2.98E-09	2.73E-06	4.72E-06	0.00
08-6342	6.82E-07			4.75E-10	3.55E-10		7.99E-07	1.74E-09	1.60E-06	3.08E-06	0.00
08-6343	6.20E-07			3.11E-10	2.12E-10		1.30E-06	2.83E-09	2.59E-06	4.51E-06	0.00
08-6344	4.46E-05			1.76E-08	6.78E-09		1.20E-04	2.62E-07	2.40E-04	4.05E-04	0.41
08-6345	4.34E-06			2.26E-09	6.94E-10		1.18E-05	2.58E-08	2.37E-05	3.99E-05	0.04
08-6346	1.74E-05			9.04E-09	2.94E-09		5.76E-05	1.26E-07	1.15E-04	1.90E-04	0.19
08-6347	6.20E-07			3.36E-10	1.13E-10		2.07E-06	4.51E-09	4.13E-06	6.83E-06	0.01
08-6348	2.64E-04			1.80E-07	1.21E-07		3.41E-04	7.44E-07	6.82E-04	1.29E-03	1.29
08-6348	5.89E-04			2.86E-07	6.84E-08		1.83E-03	3.98E-06	3.65E-03	6.07E-03	6.07

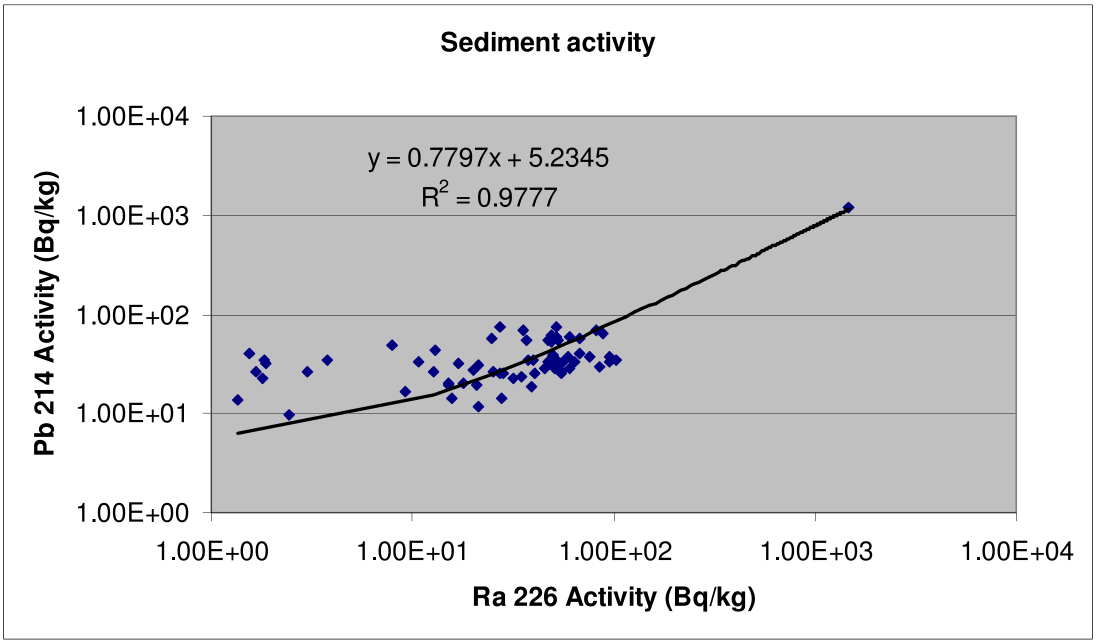
	2008 Leachate Values										
	Ra-226	**Rn-222**	**Po-218**	**Pb-214**	**Bi-214**	**Po-214**	**Pb-210**	**Bi-210**	**Po-210**	**Total**	**Total**
HPA Ref	1 yr old	1 yr old	1 yr old	1 yr old	1 yr old	1 yr old	1 yr old	1 yr old	1 yr old	Sv	mSv
08-6301	1.98E-04			1.84E-07	1.27E-07		4.44E-04	1.20E-06	1.08E-03	1.73E-03	1.73
08-6303	2.21E-05			1.97E-08	1.49E-08		3.25E-05	8.76E-08	7.95E-05	1.34E-04	0.13
08-6304	3.31E-04			2.82E-07	2.03E-07		4.52E-04	1.22E-06	1.10E-03	1.89E-03	1.89
08-6305	9.60E-05			8.83E-08	6.30E-08		1.53E-04	4.13E-07	3.74E-04	6.24E-04	0.62
08-6317	1.20E-02			1.03E-05	7.45E-06		1.55E-02	4.19E-05	3.80E-02	6.56E-02	65.59
08-6319	3.07E-05			2.90E-08	2.06E-08		6.78E-05	1.83E-07	1.66E-04	2.65E-04	0.26
08-6322	7.73E-04			7.23E-07	5.19E-07		1.03E-03	2.76E-06	2.51E-03	4.31E-03	4.31
08-6341	9.60E-07			6.29E-10	1.68E-10		2.23E-06	6.02E-09	5.46E-06	8.66E-06	0.01
08-6342	1.06E-06			9.13E-10	7.30E-10		1.31E-06	3.52E-09	3.20E-06	5.57E-06	0.01
08-6343	9.60E-07			5.98E-10	4.36E-10		2.12E-06	5.71E-09	5.18E-06	8.27E-06	0.01
08-6344	6.91E-05			3.39E-08	1.39E-08		1.96E-04	5.29E-07	4.80E-04	7.46E-04	0.75
08-6345	6.72E-06			4.35E-09	1.43E-09		1.94E-05	5.22E-08	4.73E-05	7.35E-05	0.07
08-6346	2.69E-05			1.74E-08	6.05E-09		9.42E-05	2.54E-07	2.30E-04	3.52E-04	0.35
08-6347	9.60E-07			6.46E-10	2.31E-10		3.38E-06	9.11E-09	8.27E-06	1.26E-05	0.01
08-6348	4.09E-04			3.46E-07	2.49E-07		5.58E-04	1.50E-06	1.36E-03	2.33E-03	2.33
08-6348	9.12E-04			5.50E-07	1.41E-07		2.99E-03	8.05E-06	7.30E-03	1.12E-02	11.21

F. Relationship of radium to its daughters

There is uncertainty that the measured laboratory data may not be a true representation of the field conditions for daughters of ^{226}Ra.

In Figures E1 and E2, ^{214}Pb activity is plotted versus ^{226}Ra activity for point sources counted in laboratory conditions and sediment measured by in-situ (field) gamma spectrometry, respectively.





For the point sources and sediment the R^2 value is 0.997 and 0.978 respectively. There appears to be a direct correlation between radium-226 and its daughter with around a 10:9 ratio for the point sources and 10:8 for the sediment (for Ra-226 activities greater than 10 Bq kg^{-1}). We suggest that the difference for these ratios is due to the physical size of the sediment allowing greater release of the daughters. As a result we have assumed the data of daughter activity for point sources to be valid.