Radium Contamination at Dalgety Bay, Fife

Probabilistic and Hazard Assessment: A Screening Assessment

Scottish Environment Protection Agency

May 2006

Dalgety Bay Radium Contamination Risk Assessment

1. Summary

Radioactive items have been detected on Dalgety Bay since at least 1990. Many surveys have been undertaken on the beach to determine the potential numbers of items present and possible implications for public health. This screening assessment attempts to draw together information on the number, activity and solubility of these items to address the concern expressed about the continuing presence of these items. This assessment does not attempt to determine the source of the contamination. However, in undertaking this assessment SEPA is unaware of any other possible sources of the contamination other than that originating from the former Ministry of Defence site at Dalgety Bay. This assessment is a screening assessment to determine whether a detailed assessment is required. The assessment is focused on the foreshore area around Dalgety Bay and does not specifically address the potential extent of the contamination.

This assessment contains a large number of assumptions giving significant uncertainties in the probability of exposure and the resultant effects. Assessment of the probability of encounter was undertaken to determine whether the probability of contact was negligible or otherwise. Based on the large number of assumptions made in this report, the assessment has shown that contact with a radioactive item could be around 1 in 900 per year for the beach as a whole (and around 1 in 90 in the area of greatest concentration). This has been calculated for 2000 hours spent on the beach. However, these estimates are likely to be based on a conservative assessment. The most probable effect of such an encounter, which lasts for a number of minutes, is a skin burn. The chance of ingestion of an item is highly unlikely around 1 in 500,000 per year. The effects of such an ingestion could be a committed dose of a few tens of millisieverts.

This screening assessment concludes that a detailed investigation is warranted on the grounds of public health protection. Such a detailed assessment should be capable of providing more precise information on the size, number and activity of the items on Dalgety Bay, together with further information on other areas of uncertainty.

However, in the absence of a detailed assessment, consideration should be given to the adoption of the precautionary principle at Dalgety Bay.

2. Introduction

2.1. Site Description

Dalgety Bay is located on the north side of the Firth of Forth, about 5 km east of the Forth rail bridge (Grid Reference NT 165 833). The nearest community is a relatively modern 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.

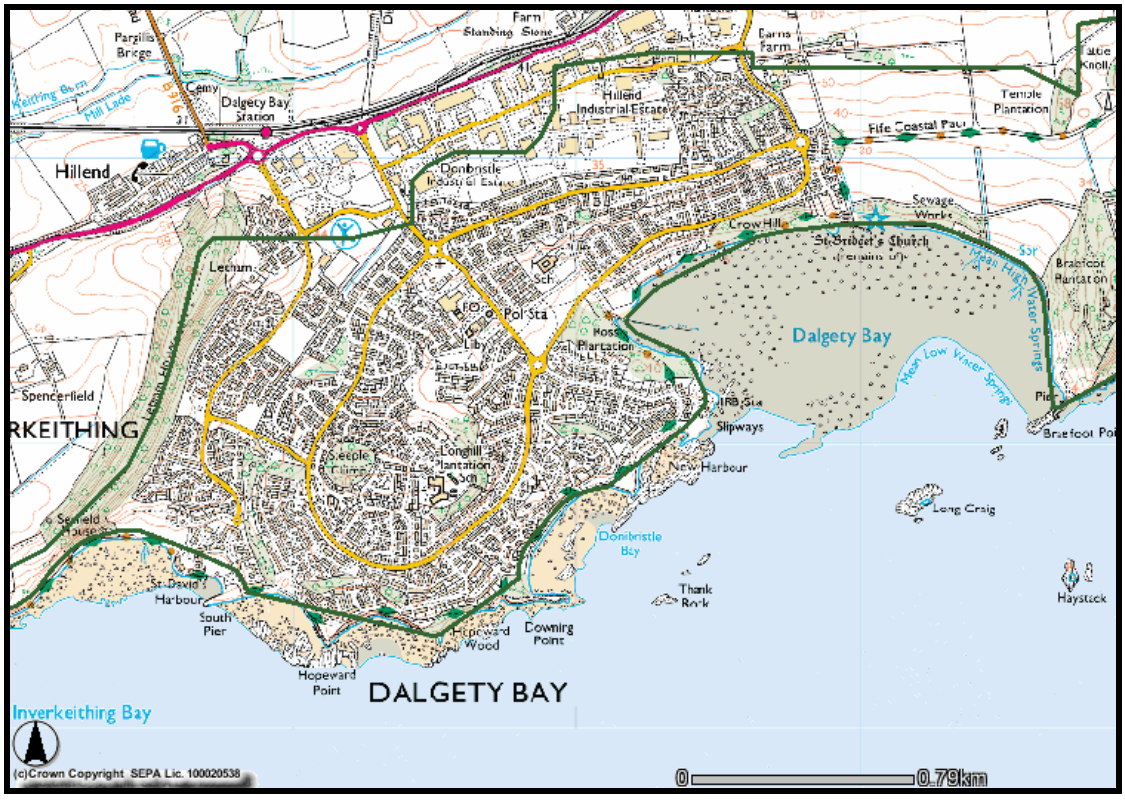


Figure 1: Dalgety Bay Map

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, asbestos sheeting), clinker, broken glass, pieces of broken plates, porcelain and general litter (Meehan, 2003). A foot path runs along the foreshore. Behind the beach is a wooded area (Ross Plantation) with grass, trees, shrubs and a network of paths. Further to the west, near the headland is Dalgety Bay Sailing Club, which has a clubhouse and slipways for launching boats. There is a boat park with several dozen boats and a car park; the latter used by both Sailing Club members and the general public. 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).

2.2. Brief History of Military Activities

Dalgety Bay is a site of a former Ministry of Defence (MoD) airfield (HMS Donibristle & HMS Merlin). Donibristle was used as a military airfield between 1917 and 1959. Throughout this time it played a role as an aircraft repair, re-fitting and salvage yard.

Donibristle airfield was opened in 1917 as a landing ground for 77 Squadron. It was then handed over to the Royal Navy Air Service to operate as an aeroplane base and salvage park. After 1918, it was operated by the RAF as a Fleet Aircraft Repair Depot. Its main work was the overhaul of aeroplanes for aircraft carriers, but it also rebuilt spotter planes and scrapped surplus engines and airframes. In 1921 the station was reduced to a care and maintenance basis. The site re-opened in 1925, principally as a shore base for disembarked carrier units.

A map from 1962 shows the location of the “Salvage Section” of the air base (Figure 2). A track is apparent near the headland leading to a refuse tip close to the New Harbour area. Also visible is a quarry area close to the Salvage Section and an additional refuse tip beside the coastal road/pond on the north side of the bay. Figure 3 shows an aerial photograph, taken during the time of MoD involvement with the area.

The history of the area between 1959 when the airfield was decommissioned and the building of the modern residential development is unclear. Modern maps have been overlayed on the 1962 map in Figure 4.

2.3. Monitoring History

In June 1990 environmental monitoring by Rosyth Nuclear Dockyard (carried out by Babcock Thorn) showed elevated radiation levels in the Dalgety Bay area. The monitoring was undertaken as part of the routine environmental monitoring programme carried out in accordance with the dockyard’s authorisation to dispose of liquid radioactive effluent to the Firth of Forth. Some material was removed for analysis, which indicated the presence of radium-226 (Ra-226). Further investigation confirmed that the contamination could not have originated from the dockyard and was most likely to be associated with past practices related to the nearby former HMS Donibristle/HMS Merlin military airfield. Since this initial discovery, there have been several monitoring exercises to determine the extent of this contamination.

In 1995, a local habits survey and detailed risk assessment was carried out by The University of Aberdeen and Auris Environmental Ltd on behalf of The Scottish Office. The survey of habits found that the area was mainly used by local people for recreational activities. No particular group was identified as being at greater risk than other groups. The report, published in 1996, concluded that there was an insignificant risk to members of the public from the contamination. However, the report recognised that the radioactive items may cause small skin burns if left in direct contact with skin for a prolonged period and that systematic monitoring should be carried out.

2.4. Previous surveys undertaken by the National Radiological Protection Board (NRPB)

Table 1 details the previous monitoring surveys at Dalgety Bay. A brief summary of each report is detailed in Appendix E.

	Report Reference	Title/Assessment	Author/Co.	Report Month/Year
1	NRPB/VR/4/1477	Foreshore Survey, Dalgety Bay.	NRPB	September 1990
2	NRPB/VR/4/1477	Radioactivity on Foreshore at Dalgety Bay	NRPB	December 1990
3	NRPB/VR/4/1488	Radioactivity at Dalgety Bay	NRPB	August 1991
4	NRPB/MR/4/2738	Two samples of Mint	NRPB	September 1991
5	NRPB/VR/4/1488 (Suppl)	Radioactivity at Dalgety Bay	NRPB	September 1991
6	NRPB/VR/4/1495	Radioactivity at Dalgety Bay	NRPB	December 1991
7	IPB/1/63 or MILM/GCJ/GR/122	Correspondence from NRPB to HMIPI (Supplementary to report NRPB/VR/4/1488)	NRPB	May 1992
8	NRPB/VR/4/1502	Radioactivity at Dalgety Bay	NRPB	June 1992
9	NRPB/VR/4/1513	Survey of Radioactive Contamination at Dalgety Bay	NRPB	October 1992
10	NRPB/VR/4/1531	Survey of Radioactive Contamination at Dalgety Bay	NRPB	July 1993
11	NRPB/VR/4/1538 (Amended)	Survey of Radioactive Contamination at Dalgety Bay	NRPB	November 1993
12	NRPB/VR/4/1563 (Amended)	Survey of Radioactive Contamination at Dalgety Bay.	NRPB	September 1994

Table 1: Previous NRPB Surveys

2.5. Garden/Car Park Surveys

(Information extracted from NRPB report NRPB/VR/4/1488 and supplementary correspondence detailed in Table 1 unless stated)

Figure 4 demonstrates that a modern residential development has been built on the area which previously included the salvage section of the MoD site. Radiological surveys of garden areas were undertaken by the NRPB on behalf of Her Majesty's Industrial Pollution Inspectorate (HMIPI) in 1991. Further details are provided in Appendix E. A review of the previous monitoring programmes and correspondence between NRPB and HMIPI has highlighted that contaminated material has been detected and removed in gardens in this area.

The NRPB carried out a survey during May and June of 1991 to monitor the beach, foreshore, the path behind the foreshore and areas of undeveloped land. Surveys were also carried out in 17 of the surrounding gardens – some of these measurements being conducted at the request of the householder. All gardens which were previously part of the Salvage Area have been surveyed (Figure 4). In one garden 2 m^3 of contaminated material was removed.

Of the areas surveyed, no activity was detected in the undeveloped land (including the quarry) behind the beach.

Elevated background levels were found in front of the clubhouse. A few items were removed, which indicated that any contaminated material was buried below a layer of topsoil of depth of, at least 10 cm. This material was deemed to be not readily accessible and, as such, no further efforts were made to remove contaminated material.

Resuspension of material was considered in report NRPB/VR/4/1477. Additionally, in report NRPB/VR/4/1502 concern was raised over the increase in traffic (pedestrian and vehicular) over the summer months, giving rise to the increased risk of resuspension of material. NRPB noted that the material on the paths and the car parks appeared to be firmly embedded in the surface and that the possibility of resuspension was unlikely.

2.6. Current Status

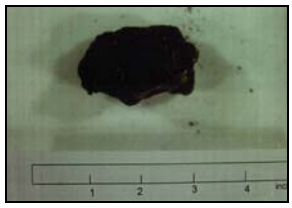
SEPA has been in discussions with The Scottish Executive, NHS Fife, Fife Council, the Health Protection Agency (formerly the National Radiological Protection Board) and the Ministry of Defence to address this issue. SEPA has undertaken limited monitoring to inform the development of a screening assessment to determine whether a detailed investigation is warranted.

This report provides the result of this screening assessment.

2.7. Form of Contamination

The photographs below show some of the typical contaminated items found at Dalgety Bay.

(Inches)

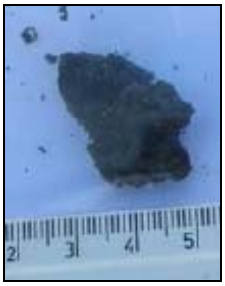


(Inches)

(cm)

The above photographs are taken from the 1996 Heaton report that was produced for The Scottish Office.

It had been assumed that all of the contaminated items were large and physically robust, however, the 2006 survey showed this assumption to be invalid. The following photographs are taken from the 2006 survey.



(cm)

(cm)

(cm)

2.8. Figures

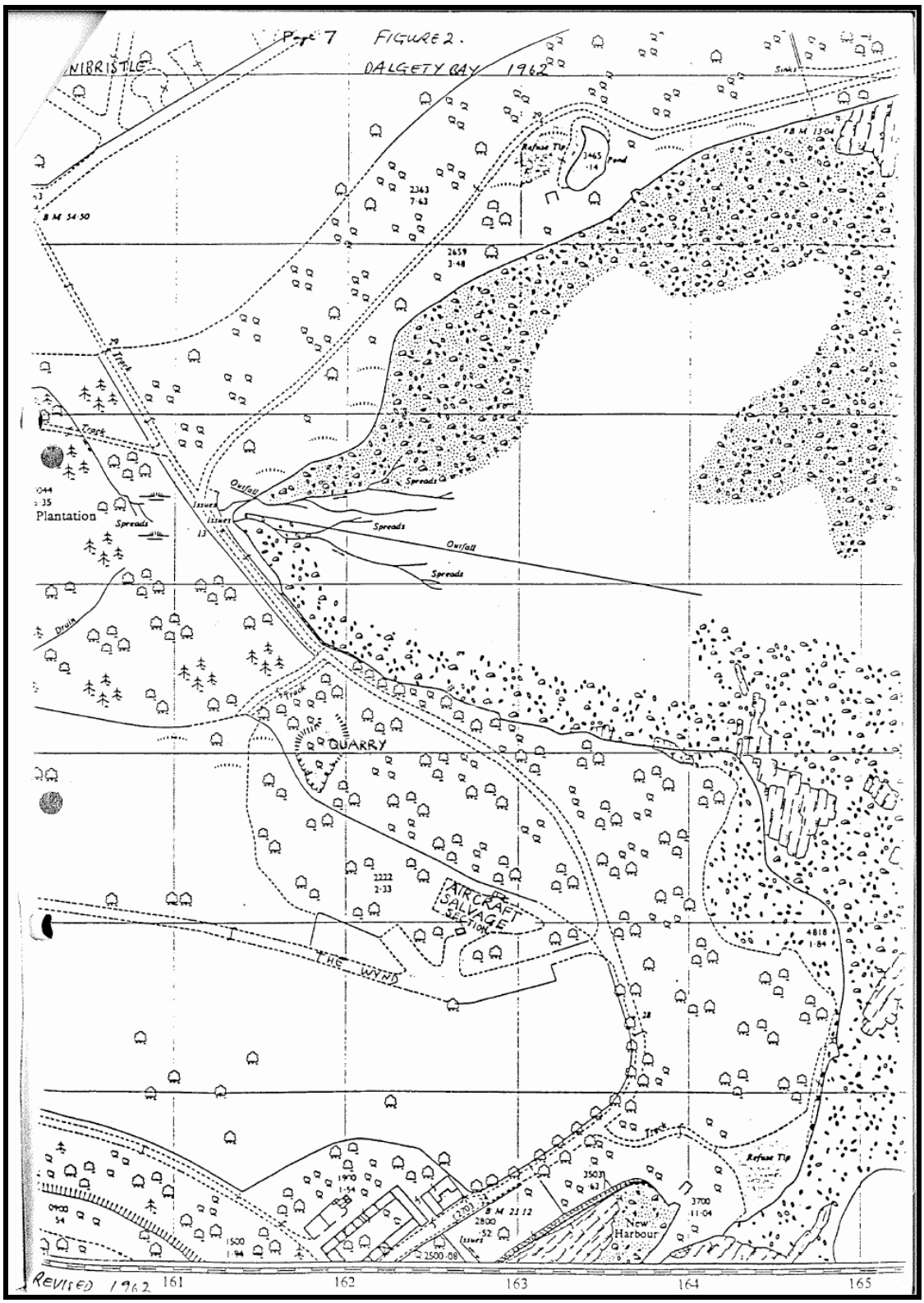


Figure 2: Dalgety Bay, 1962

Figure 3: Aerial Photograph of Dalgety Bay (during MoD occupation).

(The origin of the annotation is unknown)

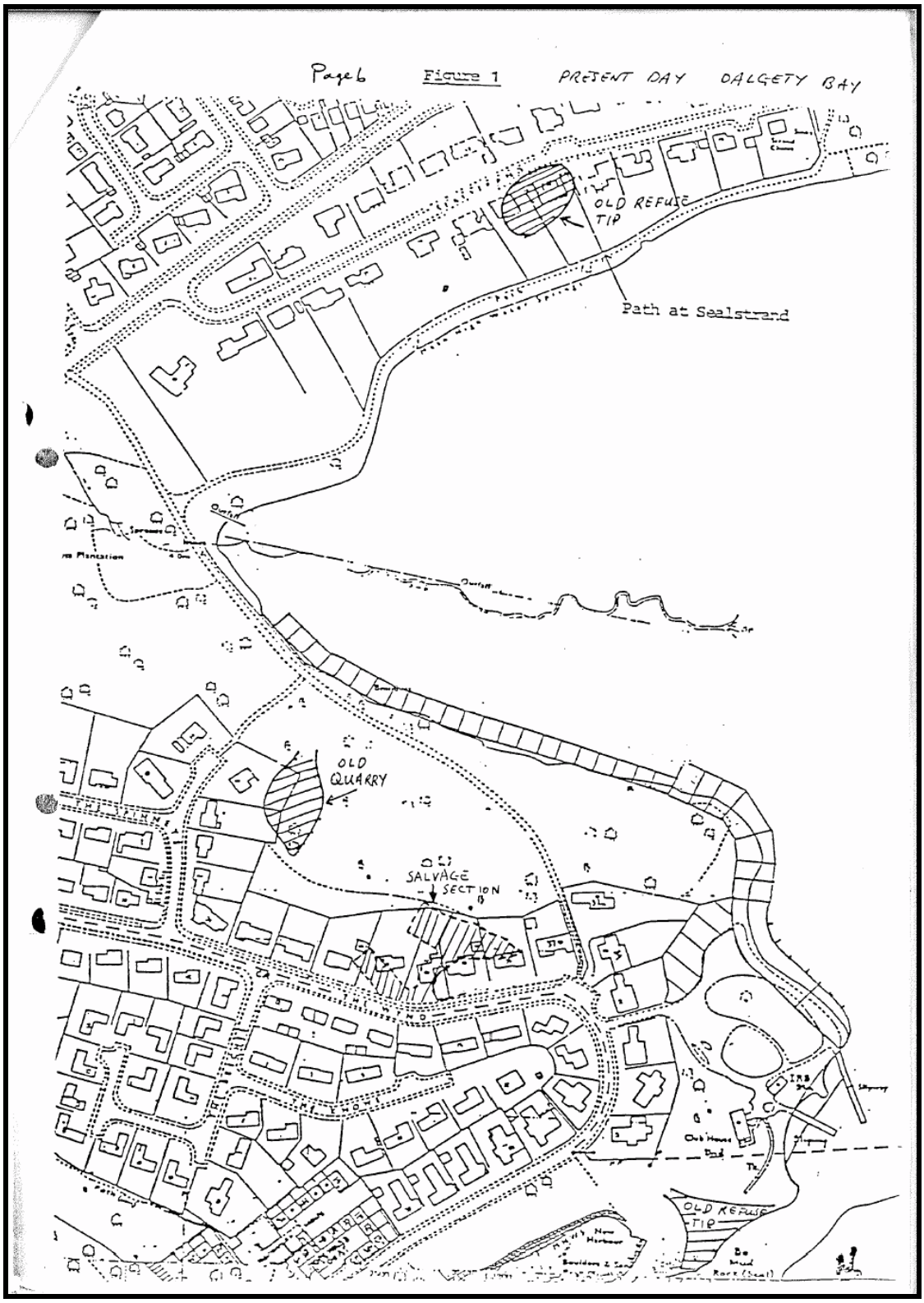


Figure 4: Overlay of old map on present day layout

3. 2006 Survey

SEPA commissioned RWE Nukem Limited to undertake a radiological survey to detect and remove any detected radium-226 contamination in the survey area. This survey was conducted in March 2006 and the report is available on the SEPA website (http://www.sepa.org.uk/pdf/radioactivity/rwe_hotspot_dalgety_bay_mar06.pdf). The survey area was limited to a small portion of Dalgety Bay. Contamination has been found outwith this area. The assessment assumes that the monitoring survey detected all of the radioactive items present on the survey area of the beach at the time of survey. The assessment does not address material which may be present at distance from the area surveyed, either in land, or on other areas of the beach.

3.1. Survey Area

The monitoring work comprised a surface radiation survey within a defined area (Figure 5) to identify and record the locations of radioactive items. Following detection of a radioactive hot spot, the item was retrieved for analysis and subsequent disposal.

The area of Dalgety Bay Beach and Foreshore surveyed, composed mainly areas of sandy beach. The area of the foreshore that was monitored was the section of foreshore between the entrance road and the slipways which serve the Dalgety Bay Sailing Club. This area monitored was consistent with that conducted in 2005.

Figure 5 shows the 2006 survey area.

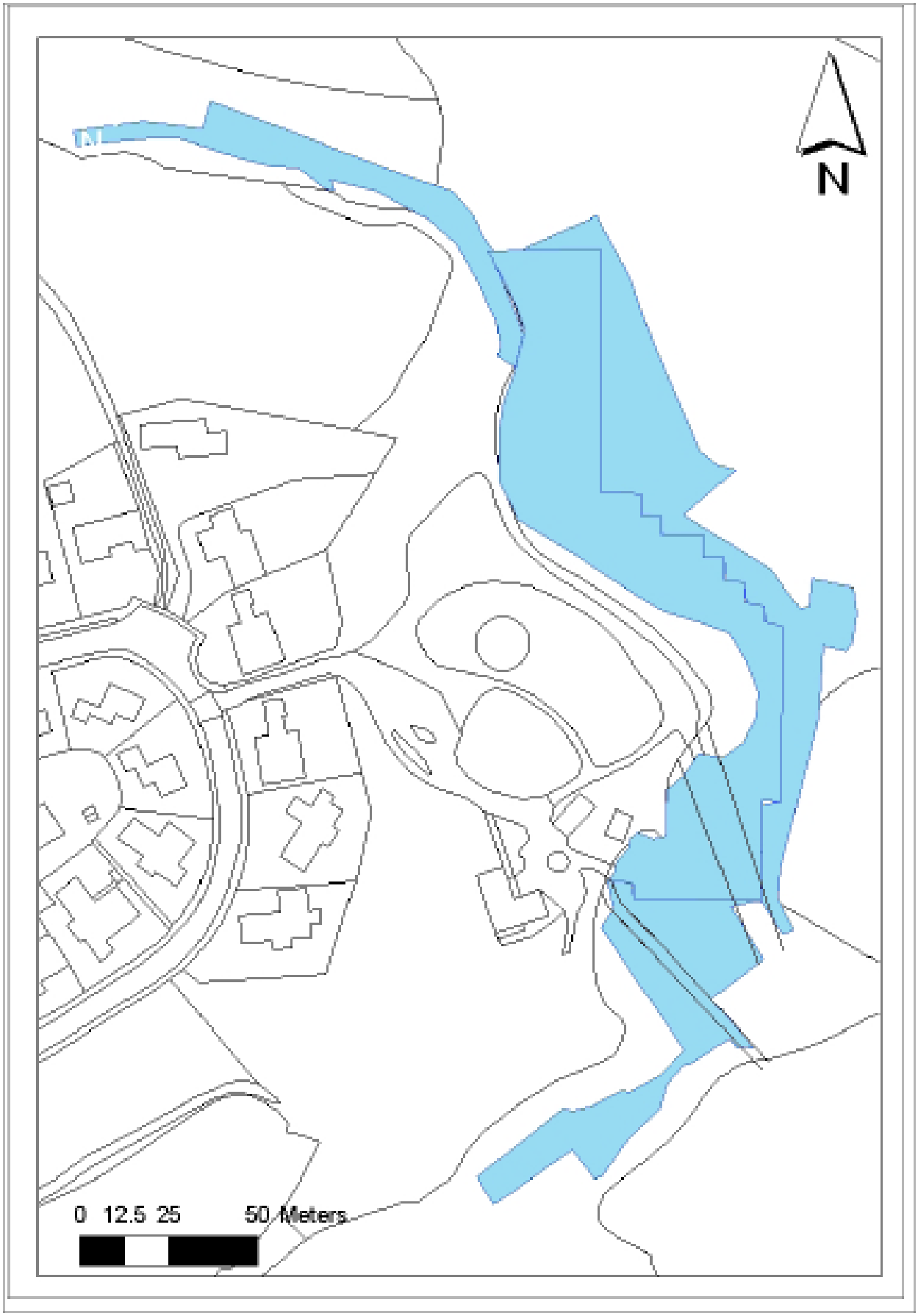


Figure 5: 2006 Survey Area

3.2. Survey Equipment & Methodology

3.2.1. Equipment

The monitoring equipment used for the surface radiation survey was the RWE Nukem Limited Groundhog detection system comprising a sodium iodide scintillation detector (76 mm diameter × 76 mm thickness) connected to a logger/ratemeter and a global positioning system (GPS). The probe is used for the detection of gamma emitting radionuclides.

Instrument response

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 counts per second (cps), and a threshold for positive identification of a radioactive item producing a count rate of 75 cps above background level, computer modelling has calculated minimum quantities of radium-226 detectable by the detector deployed 0.2m above the ground surface for a range of source depths. The depth range is shown in the table below:

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

Table 2: Groundhog detector response (from RWE Nukem)

Other instruments used during the survey

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

Mini Instruments 44B probe and Mini 900 Ratemeter
This probe has a thin beryllium end window (32 mm diameter) and the side of the probe is shielded with lead which makes the instrument highly suited for pinpointing gamma-emitting radioactive sources during excavation work.

NE Technology PDR1
The dose rate meter used was a NE Technology portable gamma dose rate meter PDR1. This instrument was used to measure dose rate from the recovered items.

3.2.2. Methodology

The Groundhog system is operated by traversing the survey area at a velocity of approximately 1 ms^{-1} on transects spaced around 1 metre distance, resulting in a survey resolution of one reading per square metre. On site, the data is uploaded to a computer and the data (radiation levels expressed as counts per second) is displayed in a Geographical Information System (GIS) as a graduated colour plot. However, the dataset supplied to SEPA showed that for significant areas of the beach, transects were spaced at distances greater than one metre. The resultant chance of detecting any item between such transects would be very poor.

When recovering identified items, areas with elevated count rate (e.g. hotspots) were located using a colour plot of the radiation survey result, a hand held GPS and the Groundhog detector. 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. Each excavated item was given a unique identification number and photographed and the following information recorded:

- Location (national grid reference to 8 figures)
- 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.

3.3. Survey Results

A total of 37 items were retrieved from 29 locations in the survey area. The depth at which these items were retrieved ranged from surface to 270 mm below ground level. The size of the recovered items varied from 1 mm to 120 mm, whilst the weight range was less than 1 g to 380 g. Information on the survey findings and comparative laboratory analysis are detailed in Table 3.

Four main clusters of hotspots were identified during the survey (Figure 6) and these areas are described below:

Area 1 was approximately 600 m^2 and contained 14 hotspot localities (16 contaminated items) in a relatively confined area immediately west of the northern-most slipway. The upper reaches of the area did not appear to be submerged during high tides as small boats were tied up at the location.

Area 2 was approximately 300 m^2 and contained 5 hotspots localities (10 contaminated items). The area of interest is immediately west of the northern most slipway and appeared to be affected by wave action/erosion.

Area 3 was approximately 350 m^2 and contained 6 hotspot localities (7 contaminated items) and is situated around the mid and southern slipways.

Area 4 was approximately 470 m^2 and contained 4 hotspot localities (4 contaminated items), two of which were located on the foreshore and two within the cliff section. The foreshore was much rockier than other parts of the survey area and numerous fragments of metallic items were identified.

Figure 6 shows the locations of the detected contamination.

3.4. Laboratory Analysis

To confirm indicative activities suggested by RWE Nukem, a number of samples were sent to Health Protection Agency – Radiation Protection Division (HPA-RPA) for empirical validation. Some of these samples were also tested to determine the potential effects of ingestion. The samples were leached by adding 100 ml of 1 M HCl (300 ml for the larger sample(s)) and allowing the flasks to stand for 8 hours at ambient temperature. The solutions were filtered and leachate analysed by gamma-ray spectrometry.

The results of the laboratory analysis are shown in Tables 4.1 and 4.2. This showed discrepancies between the RWE Nukem data and HPA data (Figure 7).

Dalgety Bay Inventory

No.	Depth Located (m)	Mass (g)	Physical Dimensions			Activity Ra-226 (kBq)		Area Located
			Length (mm)	Width (mm)	Depth (mm)	RWE Data [2]	HPA Data [3]	
1	0.1	0.5	8	4	2	224	660.00	1
2	0.05	4	18	15	8	3		1
3	0	<1	4	3	2	1	2.43	1
4	0.15	<1	7	6	4	4		1
5	0.03	<1	3	3	2	29	39.20	1
6	0	<1	3	3	2	18	55.00	1
7	0.05	<1	2	2	1	1	1.42	1
8	0.1	5	25	20	10	1	5.50	1
9	0.15	2	10	8	8	4		1
10	0.15	30	50	40	25	18		1
11	0.05	7	20	15	15	3		1
12	0	5	15	10	10	1	5.80	1
13	0.05	17	25	20	15	9	40.60	1
14	0.03	5	10	5	4	18	19.20	1
15	0.075	10	30	15	10	1		1
16	0.12	<1	2	2	1	224	620.00	1
17	0.27	167	85	70	50	449	520.00	3
18	0.1	<1	8	4	1	72	12.80	3
19	0.1	<1	4	4	3	4	730.00	3
20	0.05	<1	4	3	2	5	12.10	3
21	0.15	<1	1	1	1	18	3.75	3
22	0	86	85	50	25	359		4
23	0.05	10	20	15	15	13		4
24	0.1	10	25	20	10	269		3
25	0.15	<1	5	5	4	54	12.10	3
26	0.15	1	8	6	5	224	514.00	2
29	0.2	382	115	75	55	13		2
30	0.1	<1	1	1	1	18	17.00	2
31	0.15	32	55	30	20	18		2
32	0.15	36	45	35	25	45	311.00	2
33	0.2	319	120	90	50	45	1260.00	2
34	0.2	1	9	7	5	1		2
35	0.2	<1	7	5	5	4		2
36	0.2	<1	7	5	7	5	2.96	2
37	0.2	<1	10	7	1	3	3.62	2
27	0.075 [1]	61	60	40	30	27	199.00	4
28	0.1 [1]	21	fine material *	fine material *	fine material *	5	58.00	4

Notes

* Unable to segregate fine material

[1] Depth of contamination within cliff face

[2] Activity calculated by RWE Nukem

[3] Activity calculated by HPA-RPD

Table 3: Results of 2006 Survey

			Gamma-Ray Spectrometry of contaminated item			
			Ra-226		Pb-214	
No.	Found	ID No	kBq per item	Uncert (2σ)	kBq per item	Uncert (2σ)
1	HS_1	1_0.1m	660.00	140.00	282.00	57.00
3	HS_3	3_surface	2.43	0.49	1.07	0.22
5	HS_4	4_0.03	39.20	7.90	15.80	3.20
6	HS_5	5_0m	55.00	11.00	21.40	4.30
7	HS_6	6_0.05m	1.42	0.29	0.56	0.12
8	HS_6	6_0.1m	5.50	1.20	2.21	0.45
12	HS_10	10_0m	5.80	1.20	2.40	0.48
13	HS_11	11_0.05m	40.60	8.20	16.80	3.40
14	HS_12	12_0.03m	19.20	3.90	7.70	1.60
16	HS_14	14_0.12m	620.00	130.00	255.00	51.00
17	HS_15	15_0.27m	520.00	110.00	488.00	98.00
18	HS_16	16_0.1m_A	12.80	2.60	5.00	1.10
19	HS_16	16_0.1m_B	730.00	150.00	570.00	120.00
20	HS_17	17_0.05m	12.10	2.50	4.48	0.90
21	HS_18	18_0.15m	3.75	0.76	3.02	0.61
25	HS_22	22_0.15m	121.00	25.00	42.50	8.60
26	HS_23	23_0.15m	514.00	102.00	215.00	44.00
30	HS_25	25_0.1m	17.00	3.50	7.00	1.50
32	HS_26	26_0.15m_B	311.00	63.00	136.00	28.00
33	HS_27	27_0.2m_A	1260.00	260.00	520.00	110.00
36	HS_27	27_0.2m_D	2.96	0.60	2.35	0.48
37	HS_27	27_0.2m_E	3.62	0.73	1.57	0.32
27	CF_36	75mm[1]	199.00	40.00	157.00	32.00
28	CF_47*	100mm[1]	58.00	12.00	24.80	5.00

Table 4.1: Results of Gamma-Ray Spectrometry

			Analysis of Leachates Ra-226	
No.	Found	ID No	Bq in leachate	Uncert (2σ)
1	HS_1	1_0.1m	393	38
5	HS_4	4_0.03	178	18
17	HS_15	15_0.27m	373	36
25	HS_22	22_0.15m	17900	1700
26	HS_23	23_0.15m	22.2	3.3
30	HS_25	25_0.1m	1170	120

Table 4.2: Results of Leachate Analysis

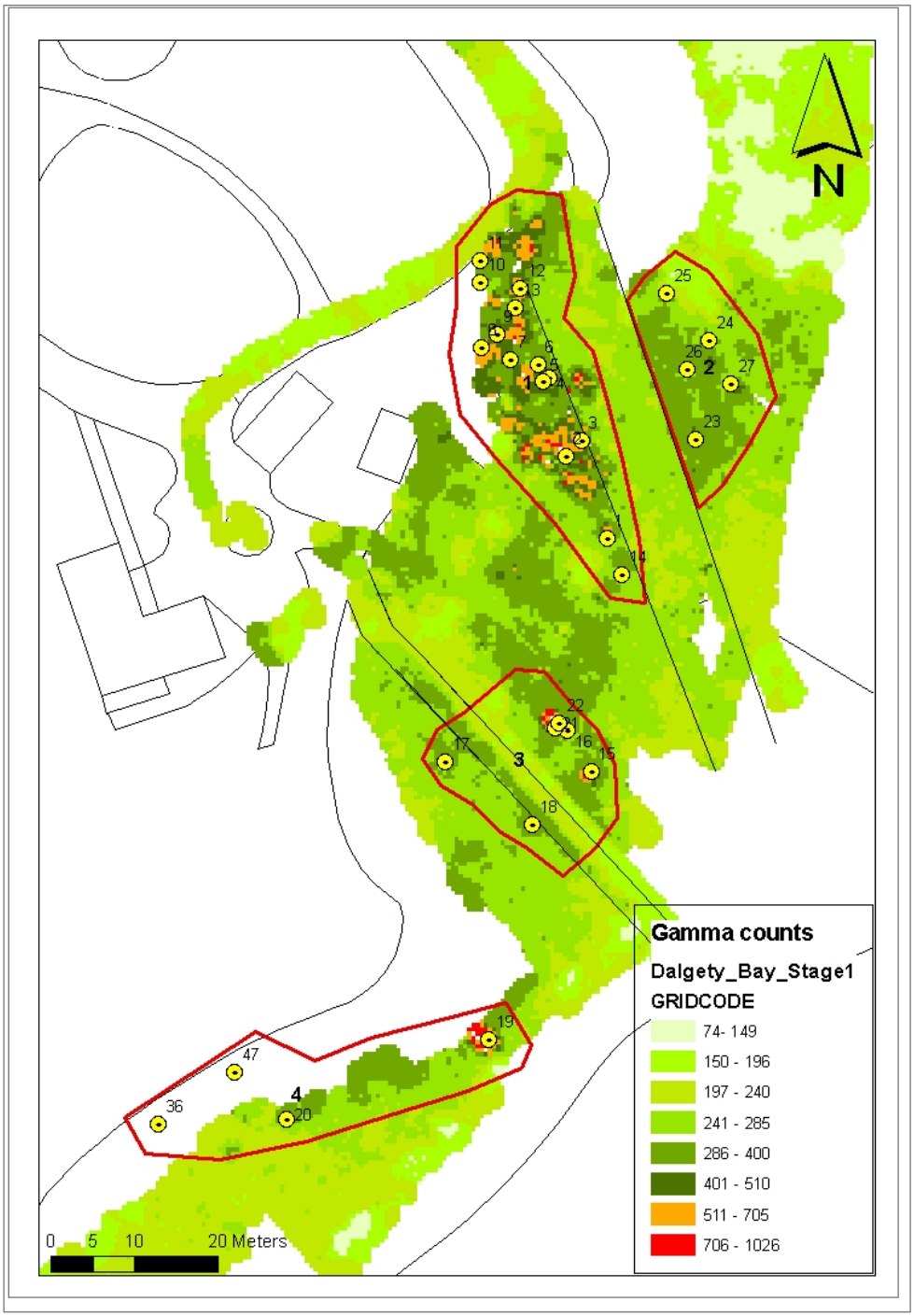


Figure 6: Results of 2006 Survey

4. Exposure Pathways

There are several potential exposure pathways to consider for the probability assessment. The following section will detail the methodology used for each pathway:

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 200µm i.e. 0.2mm (http://www.sepa.org.uk/pdf/radioactivity/dounreay/fragment_encounter_likelihood.pdf). As the recorded dimensions of the items recovered from the beach during the 2006 survey are greater than 0.2 mm this pathway is not further considered[1].

2. Ingestion
   It is possible that an individual could inadvertently ingest a radioactive item. Other ingestion pathways that were excluded from consideration were deliberate consumption and consumption of 'free' foods. The Heaton report (1996) states that the maximum diameter that can be ingested is 4 mm x 4 mm. For the purposes of this assessment it is assumed that this assumption is valid.

3. Skin Contact (inadvertent)
   It is possible that an item could come into contact with the skin. It is also possible that an item could get trapped under a nail. 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 items detected could be available for skin contact irrespective of the recovered depth.

4. An item under 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.

5. An item 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 in the air.

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

7. Food Pathways
   Potential exposure through ingestion of related foods is not considered due to known local conditions.

Assessment of these exposure pathways 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. Following this methodology allowed the development of a robust screening assessment as it follows a fully reviewed methodology. Although this methodology has been followed, the input parameters such as the contamination, nature of sediment and the habits are either generic or site specific to Dalgety Bay.

[1] It is noted that some "fine material" was removed during the recent survey, however the sediment size has not been determined. A nominal size of greater than 0.2 mm is assumed.

5. Habits Survey Data

In order to undertake a dose or probability assessment, habits survey data is required to assess the amount of time beach users spend in the area. From the habits survey data a critical group can be identified and the dose assessment can be targeted to the critical group.

The 1999 habits survey for Rosyth Dockyard and the 1995 local survey of usage were reviewed for applicability to the probability assessment. A brief summary of the review is detailed below.

5.1. Summary of 1996 Report – Survey of Usage

The 1996 report (University of Aberdeen and Auris Environmental Ltd.) included a survey of usage of the local area. The usage survey was carried out over a 6-week period in the summer of 1995 and involved both an observational survey of usage patterns in the area and also interviews with people on the beach. The most common activities found were watching boats (44%), walking (40%), dog walking (38%), sitting on the beach (33%) and sailing (29%). There were no data in that report that could be used in the screening assessment.

5.2. Rosyth Habits Survey, 1999

Dalgety Bay is located at the edge of the 5 km terrestrial survey area for the Rosyth Dockyard Habits Survey. The most recent habits survey was published in 1999. However, the information contained in the report does not provide enough detail to be of use for the Dalgety Bay screening assessment.

5.3. Generic Habits Data

In the absence of relevant site-specific habits data on occupancy and consumption rates, the NRPB publication "*NRPB-W41 Generalised Habit Data for Radiological Assessments*" was used in the probability assessment.

The data used from NRPB-W41 are detailed in Appendix B.

6. Probability Assessment

The assessment assumes that the monitoring survey detected all of the radioactive items present on the survey area of the beach at the time of survey.

The number of items recovered from the beach survey in March 2006 was 37. As the total area surveyed was 11,000 m^2 this gives an average distribution of 0.00336 items per m^2. However, given the coverage issues detailed in 3.2.2, the average distribution could be greater than this value. This value also assumes that all of the items present were detected and recovered. As no information is available on the remainder of the beach, it is assumed that this area is representative of the entire beach.

The methodology used to calculate the probability of encountering an item through the various exposure pathways is detailed in Appendix A. The assessment was undertaken to determine whether probability of a pathway existing is negligible or otherwise, and as such determine if a detailed assessment is warranted. Assumptions used to calculate each section have been listed.

The probability calculation for all exposure pathways has been based on the estimated total items (density) on the beach.

6.1. Total Surveyed Area

Following the methodology detailed in Appendix A of this report, this section provides the results of the probability assessment for the 2006 survey. Results are provided for the entire beach and for the area most likely to result in an encounter (Area 2). The assessment is based on the following input data:

Number of items detected	Nf	37 [2]	
Area Surveyed	As	11000	m^2
Area Description	Total Survey Area		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	9.40E-11	1.88E-10	9.40E-10
		per year	1.88E-07	5.64E-08	2.82E-08
2	Direct Skin Contact				
	dry sand	per visit	1.09E-08	6.30E-09	2.65E-09
		per year	2.18E-05	1.89E-06	7.95E-08
	wet sand	per visit	5.45E-07	3.15E-07	1.32E-07
		per year	1.09E-03	9.44E-05	3.97E-06
	dry and wet sand	per visit	5.56E-07	3.21E-07	1.35E-07
		per year	1.11E-03	9.63E-05	4.05E-06
3	Item under fingernails	per visit	8.07E-09	2.89E-09	6.39E-10
		per year	1.61E-05	8.68E-07	1.92E-08
4	Item on clothes	per visit	7.14E-08	4.21E-08	1.99E-08
		per year	1.43E-04	1.26E-05	5.98E-07
5	Item in a shoe	per visit	1.88E-07	1.88E-07	1.88E-07
		per year	3.76E-04	5.64E-05	5.64E-06

In terms of chance (1 in ….)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	10,643,243,243	5,321,621,622	1,064,324,324
		per year	5,321,624	17,738,735	35,477,479
2	Direct Skin Contact				
	dry sand	per visit	91,752,097	158,854,377	377,419,973
		per year	45,877	529,515	12,580,666
	wet sand	per visit	1,835,042	3,177,088	7,548,399
		per year	918	10,591	251,614
	dry and wet sand	per visit	1,799,061	3,114,792	7,400,392
		per year	900	10,383	246,680
3	Item under fingernails	per visit	123,873,874	345,694,532	1,564,722,617
		per year	61,937	1,152,316	52,157,422
4	Item on clothes	per visit	14,004,267	23,757,239	50,203,978
		per year	7,003	79,191	1,673,466
5	Item in a shoe	per visit	5,321,622	5,321,622	5,321,622
		per year	2,661	17,739	177,388

[2] Assumes all finds irrespective of depth

6.2. Area 2

Number of items detected	Nf	10 [3]	
Area Surveyed	As	300	m^2
Area Description	Area 2		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	9.31E-10	1.86E-09	9.31E-09
		per year	1.86E-06	5.59E-07	2.79E-07
2	Direct Skin Contact				
	dry sand	per visit	1.08E-07	6.24E-08	2.63E-08
		per year	2.16E-04	1.87E-05	7.88E-07
	wet sand	per visit	5.40E-06	3.12E-06	1.31E-06
		per year	1.07E-02	9.35E-04	3.94E-05
	dry and wet sand	per visit	5.51E-06	3.18E-06	1.34E-06
		per year	1.10E-02	9.54E-04	4.02E-05
3	Item under fingernails	per visit	8.00E-08	2.87E-08	6.33E-09
		per year	1.60E-04	8.60E-06	1.90E-07
4	Item on clothes	per visit	7.08E-07	4.17E-07	1.97E-07
		per year	1.41E-03	1.25E-04	5.92E-06
5	Item in a shoe	per visit	1.86E-06	1.86E-06	1.86E-06
		per year	3.72E-03	5.59E-04	5.59E-05

In terms of chance (1 in ….)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	1,074,000,000	537,000,000	107,400,000
		per year	537,001	1,790,000	3,580,000
2	Direct Skin Contact				
	dry sand	per visit	9,258,621	16,029,851	38,085,106
		per year	4,630	53,433	1,269,504
	wet sand	per visit	185,172	320,597	761,702
		per year	93	1,069	25,391
	dry and wet sand	per visit	181,542	314,311	746,767
		per year	91	1,048	24,893
3	Item under fingernails	per visit	12,500,000	34,883,721	157,894,737
		per year	6,250	116,280	5,263,158
4	Item on clothes	per visit	1,413,158	2,397,321	5,066,038
		per year	707	7,992	168,868
5	Item in a shoe	per visit	537,000	537,000	537,000
		per year	269	1,790	17,900

[3] Assumes all finds irrespective of depth

7. Hazard Assessment

7.1. Form

The radium contamination at Dalgety Bay is believed to have originated from historic MoD operations. The radium used by the MoD was primarily through the use of radium 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. The form of the radium paint is likely to be radium sulphate. However, other common forms of radium include radium chloride and radium bromide, both of which are very soluble (Ferguson, 1999).

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. Hence, it is possible that radium chloride or radium bromide may be present.

7.2. The effect of burning

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.

7.3. Dose Implications

There are two primary ways in which exposure to radium may occur; through external exposure or internal exposure.

External exposure

Due to the difficulties of estimating skin contact doses the approach used by NCRP 1989 has been followed. This assumes for every 10^{10} high energy beta particles around 5 Grays are received per cm^2. Radium-226 has three such high energy beta-emitting daughters: Pb 214, Bi 214 and Bi 210. Thus for 1.0 MBq of Ra-226 and exposure time of 1 hour, 3.6×10^9 betas will have been received which will give 1.8 Gray per hour from each energetic beta and for all three energetic betas gives 5.4 Grays per hour. It has been assumed that the gamma-dose rate which is around 1-1.5 % that of the beta dose rate, is negligible and the low energy betas of Pb-210 gives no significant contribution.

Description	Particle No.	Activity Ra-226 (kBq)	Activity [4] Pb-214, Bi-214, Bi-210 (kBq)	Contact Dose Rate (Gyh^{-1})	Approximate time to deliver 2Gy
Max. Activity of Pb-214	16	730	570	3.1	40 min
Max. activity of Ra-226	33	1260.0	520.0	2.8 [5]	45 min [6]
Min. Activity of Ra-226	7	1.4	0.56	3.0E-03	4 weeks
Mean Activity of Ra-226	-	217.3	115.9	0.6	3.5 hours
Max. Specific Activity of Ra-226 [7]	1	660.0	282	1.5	80 min

Table 5.1: Contact Doses for Ra-226 contaminated items (based on measured activities)

Note: Poor resolution of specific mass has made estimations of specific activity subject to high levels of uncertainty.

The assessments are based on a skin thickness of 70 μm, which is not valid for the thinner areas of skin such as that on the face where the thickness could be around 50 μm. At this thickness the high-energy alpha particles (around 7-8 MeV) could have a contributing affect on the dose and should be considered in any subsequent detailed assessment of hazard.

[4] Activities of Bi-214 and Bi-210 assumed to be in equilibrium with measured activities of Pb-214
[5] Calculated dose rate is probably over-estimated due to physical size of this item
[6] Calculated duration is probably under-estimated due to physical size of this item
[7] Maximum specific activity of items of (actual) known mass, i.e. omits items listed in Table 3 as ' <1g '

Internal exposure

Dose per unit intake by ingestion for Ra-226 was calculated using committed effective dose coefficients listed in ICRP 72. For the purposes of this screening assessment the use of ICRP 72 dose coefficients was considered valid, however any detailed assessment will need to consider the applicability of ICRP 72. Further consideration of local doses to the gut may be needed due to the high surface dose rates from some of the contaminated items recovered. Table 5.2 shows an assessment of the potential doses which could be received if an item, irrespective of physical size, were ingested.

	Activity (kBq)		Committed effective dose (mSv)				
Description (Item No.)	**Ra-226**	**Pb-210 & Po-210[8]**	**Ra-226**	**Pb-210**	**Po-210**	**Total (100% Solubility)[9]**	**Total (15% Solubility)[10]**
Max. Activity (33)	1260.0	520.0	352.8	358.8	624.0	1336 [11]	200 [12]
Min. Activity (7)	1.4	0.56	0.4	0.4	0.7	1.5	0.2
Mean Activity (-)	217.3	115.9	60.8	80.0	139.1	280	42
Max. Specific Activity [13] (1)	660.0	282.0	184.8	194.6	338.4	718	108

Table 5.2: Committed Effective Doses from Ingestion of Ra-226 contaminated items

Note: Poor resolution of specific mass has made estimations of specific activity subject to high levels of uncertainty.

Ra-226 ($SvBq^{-1}$)	Pb-210 ($SvBq^{-1}$)	Po-210 ($SvBq^{-1}$)
2.8E-07	6.9E-07	1.2E-06

Table 6: Committed Effective Dose Coefficients (ICRP 72)

7.4. Survey findings

The 2006 monitoring survey showed that none of the items detected was small enough to be inhaled. From the items detected, it was found that the maximum activity that could be ingested was 620 kBq[14] of Ra-226. There was no correlation between volume and activity of detected items. The range of activities that can be ingested is shown in Table 6.1. All items detected have the ability to give external exposure, though the probability of this occurring is dependent on the physical size of the item.

Figure 7 shows the results of a comparison between RWE Nukem on-site calculated activity and HPA laboratory measured activity. This shows significant discrepancies between the RWE Nukem data and the HPA data. The reason for these differences

[8] Activities of Pb-210 and Po-210 assumed to be in equilibrium with measured activities of Pb-214
[9] Total committed effective dose based on maximum solubility of items of 100%
[10] Total committed effective dose based on maximum solubility of items of 15%
[11] Calculated committed effective dose is probably an over-estimate due to physical size of item
[12] Calculated committed effective dose is probably an over-estimate due to physical size of item
[13] Maximum specific activity of items of (actual) known mass, i.e. omits items listed in Table 3 as ' <1g '
[14] The maximum ingestible activity was based on the equivalent diameter of a spherical particle.

is unknown. It has been assumed for the purposes of this assessment that the laboratory HPA data are valid.

No.	Ref	Equivalent Diameter (mm)	Activity Ra-226 (kBq) – HPA Data
21	HS_18	1.24	3.75
30	HS_25	1.24	17.00
28	CF_47*	1.24	58.00
7	HS_6	1.97	1.42
16	HS_14	1.97	620.00
5	HS_4	3.25	39.20
6	HS_5	3.25	55.00
3	HS_3	3.58	2.43
20	HS_17	3.58	12.10
18	HS_16	3.94	12.80

Table 6.1: Ingestible items detected during 2006 survey

The equivalent diameter is defined as the diameter of a sphere that has the same volume as the non-spherical item of concern.

8. Uncertainty

This screening assessment was undertaken to determine whether there is a need for a detailed assessment of the hazard and risk from radioactive items detected at Dalgety Bay, Fife. As such it contains a large number of assumptions which if considered appropriate could be tested. The primary assumptions which are likely to have greatest effect on the output of this screening assessment relate to the number of items present and the hazard.

8.1. Hazard

The assessment of hazard has been based on activity data provided by the Health Protection Agency – Radiological Protection Division (HPA-RPD). It is noteworthy that large discrepancies exist between the data provided by HPA-RPD and that from RWE Nukem which undertook the monitoring (Figure 7). Given the absence of any relationship between the two data sets and that not all of the recovered and monitored by RWE Nukem were analysed by HPA-RPD, it is possible that items recovered by RWE Nukem could have had greater or less activity than the range reported by HPA-RPD.

The assessment has assumed that the items recovered in 2006 have activities and form which are representative of the entire population. Given the heterogeneity in the items recovered, it is possible that the full extent of the activity and form of these items has yet to be fully defined.

A committed dose from ingestion of items was assessed on the basis of a very basic leaching experiment conducted on a very small number of randomly selected items. This experiment has shown large variation in the potential activity that could be absorbed if an item were ingested. Examination of further items and using a methodology that more closely represents the GI tract could improve understanding of the potential doses. It is possible that a detailed assessment using the ICRP HAT model could be undertaken to provide a more robust understanding of the potential resultant doses from ingestion. However, as the objective was to provide basic screening assessment, it was considered inappropriate for this study. In this assessment of ingested doses it has been assumed that the items recovered in 2006 have activities and form which are representative of the entire population of radioactive items.

Specific measurements on individual items could be conducted which would provide a more robust methodology for assessing doses from skin contact. As in the consideration of ingested doses, in the assessment of contact doses it has been assumed that the items recovered in 2006 have activities and form which are representative of the entire population.

8.2 Number of items

In assessing the potential risk of encountering an item at Dalgety Bay, it was assumed that the number of items detected in 2006 was temporally representative. However, three factors mean that this is potentially a significant underestimate. The monitoring methodology has, in all likelihood, omitted areas of the beach and the limited ability of the system to detect items at or below the limit of detection may have meant that items were undetected. Further, following removal of any item the area was not resurveyed with the same methodology to determine if a further item was present.

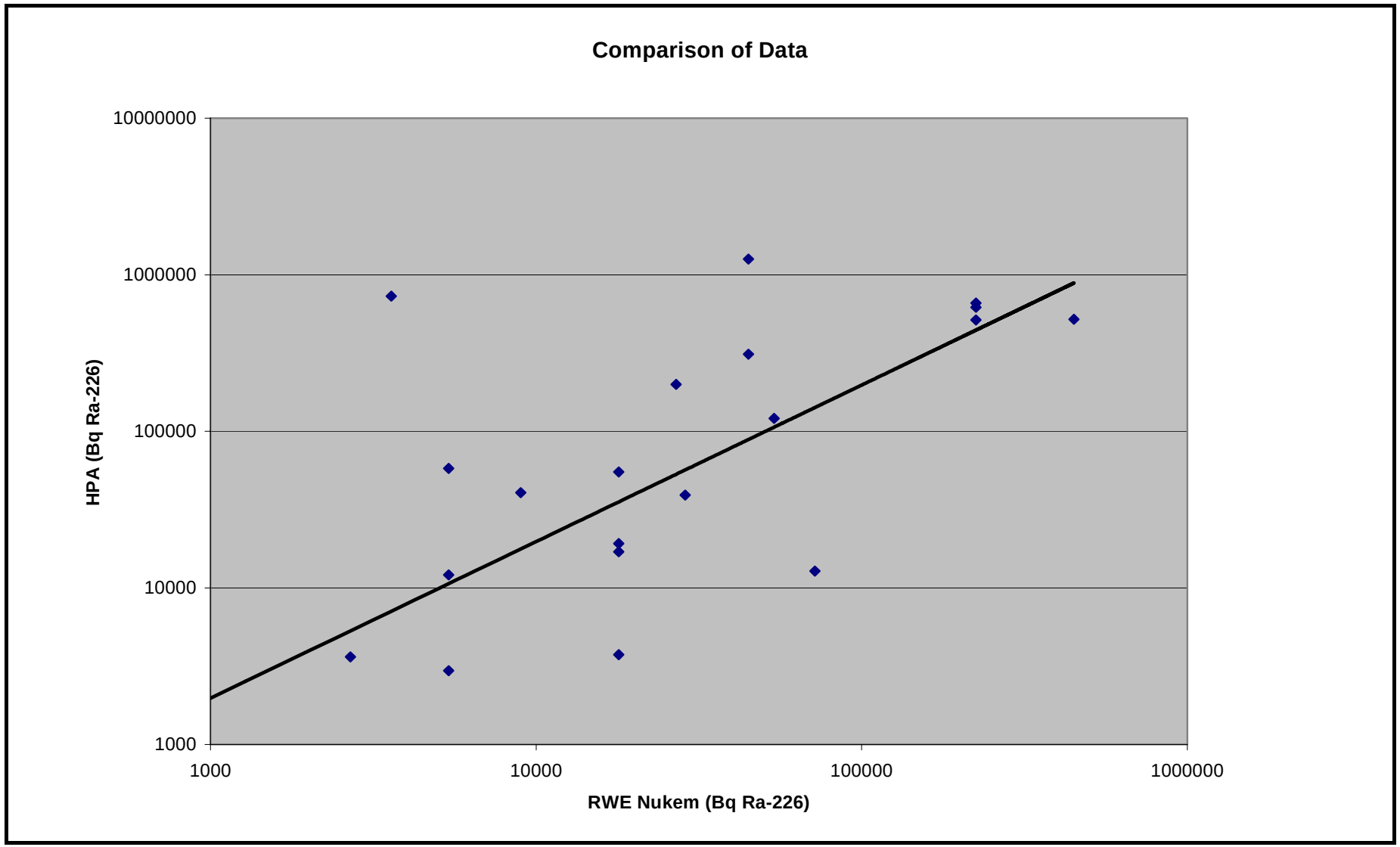


Figure 7: Comparison of HPA Analysis Data and RWE Nukem Data

9. Discussion

Radium contaminated items continue to be detected on Dalgety Bay foreshore whenever the foreshore is surveyed. The number and form of these items are poorly understood. This screening assessment is based on the assumption that the data collected in March 2006 are representative of the entire foreshore area; SEPA has no data to support or reject this assumption. It is likely that a large number of items reside in the environment and it is likely that that these will continue to be deposited on the inter-tidal area around Dalgety Bay should no remedial action be taken. SEPA is aware that some remedial work to reinforce the rock armour has recently taken place at Dalgety Bay. The implications of this work on the rate of deposition of items and likelihood of encountering such items are unknown.

Items with activities typical of that detected in 2006 on Dalgety Bay could give rise to short-term observable effects with contact periods that would be credible for people spending time on the beach. This screening assessment has shown that the possibility of a member of the public encountering such items cannot be ruled out. Further work is needed to determine whether the assumptions detailed in this assessment are valid. Until such assumptions are tested and more information becomes available, the application of the precautionary principle should be considered to ensure that the public are adequately protected.

In terms of Ra-226 activity, the most active item detected in the 2006 study on the beach at Dalgety Bay contained about 1,260,000 Bq. The activities of a number of the items recovered from the beach show that contact with these items could give rise to observable effects if they were to remain completely stationary for less than one hour.

On the basis of the existing monitoring data and current assumptions about the occupancy and usage of the beach, the estimated probability of an individual, who spends 2000 hours on the beach, coming into contact with such an item is about 1 in 900 per year. For the highest concentration of items detected in the survey, the probability of contact rises to 1 in 91 per year ($p = 0.011$). Alternatively, this can be expressed as for every 2000 hours spent on the beach there is around a 1 in 90 chance of at least one encounter. The probability of a member of the public ingesting a radioactive item is around one in 5 million. The likely consequence of such ingestion is a committed dose of a few tens of millsieverts. For the highest concentration of items detected in the survey, the probability of ingestion rises to 1 in around 500,000 per year.

The purpose of this screening assessment was to determine whether a detailed assessment of the radioactive contamination at Dalgety Bay is warranted, not to provide precise information on the risks. This assessment has made a large number of assumptions on the number, distribution and effects of the contamination which could be tested. This assessment has indicated that a further detailed assessment is warranted and in the absence of such assessment consideration should be given to the adoption of the precautionary principle.

10. Conclusions

Further investigation and characterisation of the distribution, number, activity and solubility of Ra-226 items on Dalgety Bay are required. Specific information on the habits practised in the Dalgety Bay area should be sought to provide a more detailed risk assessment.

This screening assessment has shown that:

1. The continued presence of radioactive items poses a realistic hazard to public health.
2. The probability of encountering a radioactive item for the entire area surveyed is around 1 in 900 per year for an adult occupancy of 2000 hours. For the area showing the greatest concentration of radioactive items this probability rises to around 1 in 90.

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Appendices

A. Methodology for probability assessment
B. Generalised Habits Data
C. 2006 Survey Probability Calculation
D. 2006 Survey Probability Results
E. Review of Previous Surveys (Tables)
F. Review of Previous Babcock Surveys (Maps)

Appendix A

Appendix A

Methodology used to determine probability of encountering a radioactive item on Dalgety Bay.

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

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.

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

4. Direct Skin Contact

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

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.

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.

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.

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}
S_n amount of sand trapped under nails per visit to the beach, g

Assumption: Amount of sand trapped is assumed to be valid.

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: Sand Loading Rate is assumed to be valid.

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: Amount of sand trapped is assumed to be valid.

Appendix B

Appendix B: Generalised Habit Data.

Inadvertent ingestion rates of soil and sand

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

Representative critical group for Beach/Intertidal areas Occupancy Data

Age	Beach/ Intertidal Occupancy *(h y^{-1})*
Adult	2000
Child	300
Infant	30

Appendix C

Appendix C – 2006 Survey Probability Calculation

Refer to separate sheet

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Appendix D

Appendix D: 2006 Survey Probability Results for All Areas

Probability of encountering radioactive items from Dalgety Bay - 2006 Survey

Following the methodology detailed in Appendix A of this report, this section provides the results of the probability assessment for the 2006 survey. The assessment is based on the following input data:

Number of items detected	Nf	37	
Area Surveyed	As	11000	m^2
Area Description	Total Survey Area		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	9.40E-11	1.88E-10	9.40E-10
		per year	1.88E-07	5.64E-08	2.82E-08
2	Direct Skin Contact				
	dry sand	per visit	1.09E-08	6.30E-09	2.65E-09
		per year	2.18E-05	1.89E-06	7.95E-08
	wet sand	per visit	5.45E-07	3.15E-07	1.32E-07
		per year	1.09E-03	9.44E-05	3.97E-06
	dry and wet sand	per visit	5.56E-07	3.21E-07	1.35E-07
		per year	1.11E-03	9.63E-05	4.05E-06
3	Fragment under fingernails	per visit	8.07E-09	2.89E-09	6.39E-10
		per year	1.61E-05	8.68E-07	1.92E-08
4	Fragment on clothes	per visit	7.14E-08	4.21E-08	1.99E-08
		per year	1.43E-04	1.26E-05	5.98E-07
5	Fragment in a shoe	per visit	1.88E-07	1.88E-07	1.88E-07
		per year	3.76E-04	5.64E-05	5.64E-06

In terms of chance (1 in …)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	10,643,243,243	5,321,621,622	1,064,324,324
		per year	5,321,624	17,738,735	35,477,479
2	Direct Skin Contact				
	dry sand	per visit	91,752,097	158,854,377	377,419,973
		per year	45,877	529,515	12,580,666
	wet sand	per visit	1,835,042	3,177,088	7,548,399
		per year	918	10,591	251,614
	dry and wet sand	per visit	1,799,061	3,114,792	7,400,392
		per year	900	10,383	246,680
3	Fragment under fingernails	per visit	123,873,874	345,694,532	1,564,722,617
		per year	61,937	1,152,316	52,157,422
4	Fragment on clothes	per visit	14,004,267	23,757,239	50,203,978
		per year	7,003	79,191	1,673,466
5	Fragment in a shoe	per visit	5,321,622	5,321,622	5,321,622
		per year	2,661	17,739	177,388

Probability of encountering radioactive items from Dalgety Bay - 2006 Survey

Number of items detected	Nf	16	
Area Surveyed	As	600	m^2
Area Description	Area 1		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	7.45E-10	1.49E-09	7.45E-09
		per year	1.49E-06	4.47E-07	2.23E-07
2	Direct Skin Contact				
	dry sand	per visit	8.64E-08	4.99E-08	2.10E-08
		per year	1.73E-04	1.50E-05	6.30E-07
	wet sand	per visit	4.32E-06	2.50E-06	1.05E-06
		per year	8.60E-03	7.48E-04	3.15E-05
	dry and wet sand	per visit	4.41E-06	2.55E-06	1.07E-06
		per year	8.77E-03	7.63E-04	3.21E-05
3	Fragment under fingernails	per visit	6.40E-08	2.29E-08	5.07E-09
		per year	1.28E-04	6.88E-06	1.52E-07
4	Fragment on clothes	per visit	5.66E-07	3.34E-07	1.58E-07
		per year	1.13E-03	1.00E-04	4.74E-06
5	Fragment in a shoe	per visit	1.49E-06	1.49E-06	1.49E-06
		per year	2.98E-03	4.47E-04	4.47E-05

In terms of chance (1 in …)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	1,342,500,000	671,250,000	134,250,000
		per year	671,251	2,237,501	4,475,000
2	Direct Skin Contact				
	dry sand	per visit	11,573,276	20,037,313	47,606,383
		per year	5,787	66,792	1,586,880
	wet sand	per visit	231,466	400,746	952,128
		per year	116	1,336	31,738
	dry and wet sand	per visit	226,927	392,888	933,458
		per year	114	1,310	31,116
3	Fragment under fingernails	per visit	15,625,000	43,604,651	197,368,421
		per year	7,813	145,349	6,578,948
4	Fragment on clothes	per visit	1,766,447	2,996,652	6,332,547
		per year	884	9,989	211,085
5	Fragment in a shoe	per visit	671,250	671,250	671,250
		per year	336	2,238	22,375

Probability of encountering radioactive items from Dalgety Bay - 2006 Survey

Number of items detected	Nf	10	
Area Surveyed	As	300	m^2
Area Description	Area 2		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	9.31E-10	1.86E-09	9.31E-09
		per year	1.86E-06	5.59E-07	2.79E-07
2	Direct Skin Contact				
	dry sand	per visit	1.08E-07	6.24E-08	2.63E-08
		per year	2.16E-04	1.87E-05	7.88E-07
	wet sand	per visit	5.40E-06	3.12E-06	1.31E-06
		per year	1.07E-02	9.35E-04	3.94E-05
	dry and wet sand	per visit	5.51E-06	3.18E-06	1.34E-06
		per year	1.10E-02	9.54E-04	4.02E-05
3	Fragment under fingernails	per visit	8.00E-08	2.87E-08	6.33E-09
		per year	1.60E-04	8.60E-06	1.90E-07
4	Fragment on clothes	per visit	7.08E-07	4.17E-07	1.97E-07
		per year	1.41E-03	1.25E-04	5.92E-06
5	Fragment in a shoe	per visit	1.86E-06	1.86E-06	1.86E-06
		per year	3.72E-03	5.59E-04	5.59E-05

In terms of chance (1 in …)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	1,074,000,000	537,000,000	107,400,000
		per year	537,001	1,790,000	3,580,000
2	Direct Skin Contact				
	dry sand	per visit	9,258,621	16,029,851	38,085,106
		per year	4,630	53,433	1,269,504
	wet sand	per visit	185,172	320,597	761,702
		per year	93	1,069	25,391
	dry and wet sand	per visit	181,542	314,311	746,767
		per year	91	1,048	24,893
3	Fragment under fingernails	per visit	12,500,000	34,883,721	157,894,737
		per year	6,250	116,280	5,263,158
4	Fragment on clothes	per visit	1,413,158	2,397,321	5,066,038
		per year	707	7,992	168,868
5	Fragment in a shoe	per visit	537,000	537,000	537,000
		per year	269	1,790	17,900

Probability of encountering radioactive items from Dalgety Bay - 2006 Survey

Number of items detected	Nf	7	
Area Surveyed	As	350	m^2
Area Description	Area 3		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	5.59E-10	1.12E-09	5.59E-09
		per year	1.12E-06	3.35E-07	1.68E-07
2	Direct Skin Contact				
	dry sand	per visit	6.48E-08	3.74E-08	1.58E-08
		per year	1.30E-04	1.12E-05	4.73E-07
	wet sand	per visit	3.24E-06	1.87E-06	7.88E-07
		per year	6.46E-03	5.61E-04	2.36E-05
	dry and wet sand	per visit	3.31E-06	1.91E-06	8.03E-07
		per year	6.59E-03	5.73E-04	2.41E-05
3	Fragment under fingernails	per visit	4.80E-08	1.72E-08	3.80E-09
		per year	9.60E-05	5.16E-06	1.14E-07
4	Fragment on clothes	per visit	4.25E-07	2.50E-07	1.18E-07
		per year	8.49E-04	7.51E-05	3.55E-06
5	Fragment in a shoe	per visit	1.12E-06	1.12E-06	1.12E-06
		per year	2.23E-03	3.35E-04	3.35E-05

In terms of chance (1 in …)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	1,790,000,000	895,000,000	179,000,000
		per year	895,000	2,983,334	5,966,667
2	Direct Skin Contact				
	dry sand	per visit	15,431,034	26,716,418	63,475,177
		per year	7,716	89,055	2,115,840
	wet sand	per visit	308,621	534,328	1,269,504
		per year	155	1,782	42,317
	dry and wet sand	per visit	302,569	523,851	1,244,611
		per year	152	1,747	41,488
3	Fragment under fingernails	per visit	20,833,333	58,139,535	263,157,895
		per year	10,417	193,799	8,771,930
4	Fragment on clothes	per visit	2,355,263	3,995,536	8,443,396
		per year	1,178	13,319	281,447
5	Fragment in a shoe	per visit	895,000	895,000	895,000
		per year	448	2,984	29,834

Probability of encountering radioactive items from Dalgety Bay - 2006 Survey

Number of items detected	Nf	4	
Area Surveyed	As	470	m^2
Area Description	Area 4		

Results of Probability Calculations

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	2.38E-10	4.75E-10	2.38E-09
		per year	4.75E-07	1.43E-07	7.13E-08
2	Direct Skin Contact				
	dry sand	per visit	2.76E-08	1.59E-08	6.70E-09
		per year	5.52E-05	4.78E-06	2.01E-07
	wet sand	per visit	1.38E-06	7.96E-07	3.35E-07
		per year	2.75E-03	2.39E-04	1.01E-05
	dry and wet sand	per visit	1.41E-06	8.12E-07	3.42E-07
		per year	2.81E-03	2.44E-04	1.03E-05
3	Fragment under fingernails	per visit	2.04E-08	7.32E-09	1.62E-09
		per year	4.09E-05	2.20E-06	4.85E-08
4	Fragment on clothes	per visit	1.81E-07	1.07E-07	5.04E-08
		per year	3.61E-04	3.20E-05	1.51E-06
5	Fragment in a shoe	per visit	4.75E-07	4.75E-07	4.75E-07
		per year	9.50E-04	1.43E-04	1.43E-05

In terms of chance (1 in …)

	Exposure Pathway		Adult	Child	Infant
1	Inadvertent Ingestion	per visit	4,206,500,000	2,103,250,000	420,650,000
		per year	2,103,251	7,010,833	14,021,667
2	Direct Skin Contact				
	dry sand	per visit	36,262,931	62,783,582	149,166,667
		per year	18,132	209,279	4,972,223
	wet sand	per visit	725,259	1,255,672	2,983,333
		per year	363	4,186	99,445
	dry and wet sand	per visit	711,038	1,231,051	2,924,837
		per year	356	4,104	97,495
3	Fragment under fingernails	per visit	48,958,333	136,627,907	618,421,053
		per year	24,480	455,427	20,614,035
4	Fragment on clothes	per visit	5,534,868	9,389,509	19,841,981
		per year	2,768	31,299	661,400
5	Fragment in a shoe	per visit	2,103,250	2,103,250	2,103,250
		per year	1,052	7,011	70,109

Appendix E

Appendix E: Review of Previous Surveys

Dalgety Bay – Review of Previous Surveys

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
1	Extensive survey of the foreshore and the shingle banking.	Mini-Instruments Meter Type 6-80	Yes, no number given. However, 14 areas of 'high activity' present. Material present at or near high spring tide markings on beach Total activity removed 0.2 MBq of Ra-226	Spectrometric evidence suggests that the material to have been chemically separated rather than natural in origin.	There are no radiological implications for the population in the vicinity. The beach is unattractive, odiferous area and is unlikely to attract more than the occasional pedestrian. No evidence of bait digging and a complete absence of wading birds. The mud is also unlikely to harbour lugworms. Radioactivity is associated with heavy, relatively large items which are unlikely to become airborne.	No further action need be taken (from a radiological protection perspective). However, a grid survey could delineate the extent of the contamination, although this would not detect items at significant depth.

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
2	Beach Area divided into blocks of 100 m^2. Beach area to Yacht Club and grassy area to North of beach.	Sodium Iodide Detector	212 in 1300 m^2 All items removed	Material varied in size from large pieces (5 cm diameter) to small pieces no bigger than a pin head. Activity range: 2 – 380 kBq Dose rate: Beta-Gamma: 5-2000 $\mu Sv\ h^{-1}$ Gamma: 15-100 $\mu Sv\ h^{-1}$	Dose Rate measurements from material at 1 m not different from the surrounding area. Higher dose rates more localised and randomly distributed throughout the beach. Skin contact doses would require continuous contact for observable effects. Breaching of dose limit would be unlikely for inhalation. Ingestion unlikely – appear insoluble & bound to clinker/glass	NRPB concerned that very small, highly active items could become lodged under the fingernails and deliver high doses. Inhalation/Ingestion pathways considered unlikely pathways. If the pathway did occur, doses would be low. Survey should assess extent of contamination. Measurement of radon should be undertaken in housing development surrounding the area. Repeat surveys at 3 or 6 monthly intervals.

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
3	Measurement of Radon in Houses. Beach, foreshore and the path behind the foreshore were monitored from the point that the November 1990 Survey (December 1990 report) terminated. The headland and Sailing Club were included. The area was divided into blocks. Direct radon measurements were made in the basement of the Sailing Club and in the downstairs areas of 24 private houses. 4 householders requested to be included in the monitoring. Dalgety Bay Primary School was also monitored for radon. Surveys were carried out in 17 gardens. Some were carried out in conjunction with measurements, some as a result of requests and some as a result of information gathered during the survey. One garden was surveyed at the request of the owner who associated the clinker/ash material with that cleared from the site of his house during the	Sodium Iodide Detectors. Unshielded detectors to detect contamination – Shielded detectors to isolate individual items. Radon Decay Product Monitors.	All items detected were removed for disposal. Total Activity removed was 35 MBq (excludes 100 MBq from one garden). In the repeat survey area (block 9, December Report). 4 items were detected – this is compared to 16 items in the previous survey. The four items were of lower activity than those found previously. All were at, or near the, surface of the beach	Contaminated material was found in two gardens. In one, discrete items were found; both were buried under about 10 cm of topsoil – neither were associated with accumulations on clinker material. In the other garden about 2 m^3 of contaminated clinker and ash were removed from a small area of garden. The activity was uniformly distributed and could not be separated out. Total activity removed was around 100 MBq. Radon (Bq m^{-3}) *Sailing Club: 32* *Private Houses: 1 – 24. Avg – 10.* *Primary School: 16-33. Avg – 23.* Beach/Foreshore: Beta-Gamma: 4.5 mSv h^{-1}. Gamma: 450 μSv h^{-1}.	The results of this survey support the assessment made in the previous report. Material appears to be insoluble and large item size.	Beach and foreshore should be resurveyed every 6 months. Two areas should be surveyed to determine if replenishment is occurring. Sailing Club headland and path at Sealstrand should be left undisturbed.

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
	early construction phase. The path at Sealstrand was included due to evidence suggesting that material may removed during the construction of the Sailing Club Clubhouse had been relocated to that area. This survey also resurveyed a section of the December report survey area for efficacy purposes.					

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
4	This measurement report concerns two samples of mint collected from two areas – 1 garden in Dalgety Bay and the other a garden in Edinburgh.			Ra-226 concentration dry weight: Dalgety Bay: 0.32 ± 0.05 Bq kg $^{-1}$ Edinburgh: 0.06 ± 0.02 Bq kg $^{-1}$		
5	This survey was a follow up survey to determine the extent of contamination at one of the gardens in Dalgety Bay.			0.7 m^3 of contaminated material – consisting of clinker and ash on compacted clay. Total activity was approximately 4 MBq		
6	This survey was to follow up recommendations of previous reports. Two areas were selected for a survey – a reference site to be surveyed on each monitoring visit, and a block to be selected on rotation from the original survey. The aim of this is to enable the replenishment rate of the reference area to be monitored and also for the whole beach to be re-monitored over time. There was also an additional area surveyed – this was the beach away from the sailing club (a distance of 30 m from the end of the reference area and extended 10 m down the beach)	Sodium Iodide Detectors (as per previous surveys)	28 items were found and removed during the survey. This cannot be compared directly with 115 items found in the same area in a previous survey because included different areas in the survey. However, an examination of the survey notes indicates that 100 items were detected previously in this area. Two areas were excavated to a depth of 0.5 m. A layer of clinker and ash was found, causing an elevated background reading.	Lower activity, smaller items may be present and outwith the Limits of detection.		This survey confirms the conclusions from previous reports. The beach and foreshore approximately every 6 months. Reuse the reference area to determine replenishment rates. Re-Monitoring previously surveyed areas (in rotation) so that the whole beach can be resurveyed over time).

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
7	This letter provided supplementary information from NRPB survey report August 1991.		NRPB provide clarification on some of the points raised by their report: The survey included gardens in the 'Salvage Area' - The one garden where 2 m^3 of material was found was in this salvage area. The addresses of these premises were kept confidential for the protection of the householders.			
8	This survey was a second follow up survey. A grid system was used which mirrored the previous survey. The reference area was monitored to track replenishment rates of the area. Other areas included in this survey: a. An area of beach measuring approx 40 x 10 m on the Sailing Club side of the reference area.	Sodium Iodide Detectors.	All detected radioactive material was isolated and removed for disposal. When elevated background (twice normal) was registered and no discrete items could be isolated, samples were taken for analysis. 3 samples were taken (clinker/ash) from 10cm below the surface of the beach. 2 samples (compacted material) were taken from the car park.	The discrete items found were of lower activity than previously monitored. Beach finds were buried well below the surface. As with previous surveys, a number of areas of increased background were identified. The Boat/Car Park Area material finds can be classified as follows: *3 discrete items removed* *5 areas where discrete items appeared to be*	Material from the Boat/Car Park Area was compacted and firmly embedded. It is therefore considered that the ingestion and inhalation pathways are an extremely low probability. The dose rate of 0.2 $\mu Sv\ h^{-1}$ measured at the surface of one of the higher areas of raised background confirms that there is no significant external hazard.	The beach and foreshore area should continue to be surveyed at approximately six month intervals. The reference area should be surveyed on each occasion, together with additional areas, selected in rotation, so that over a period of time the whole area would have been resurveyed.

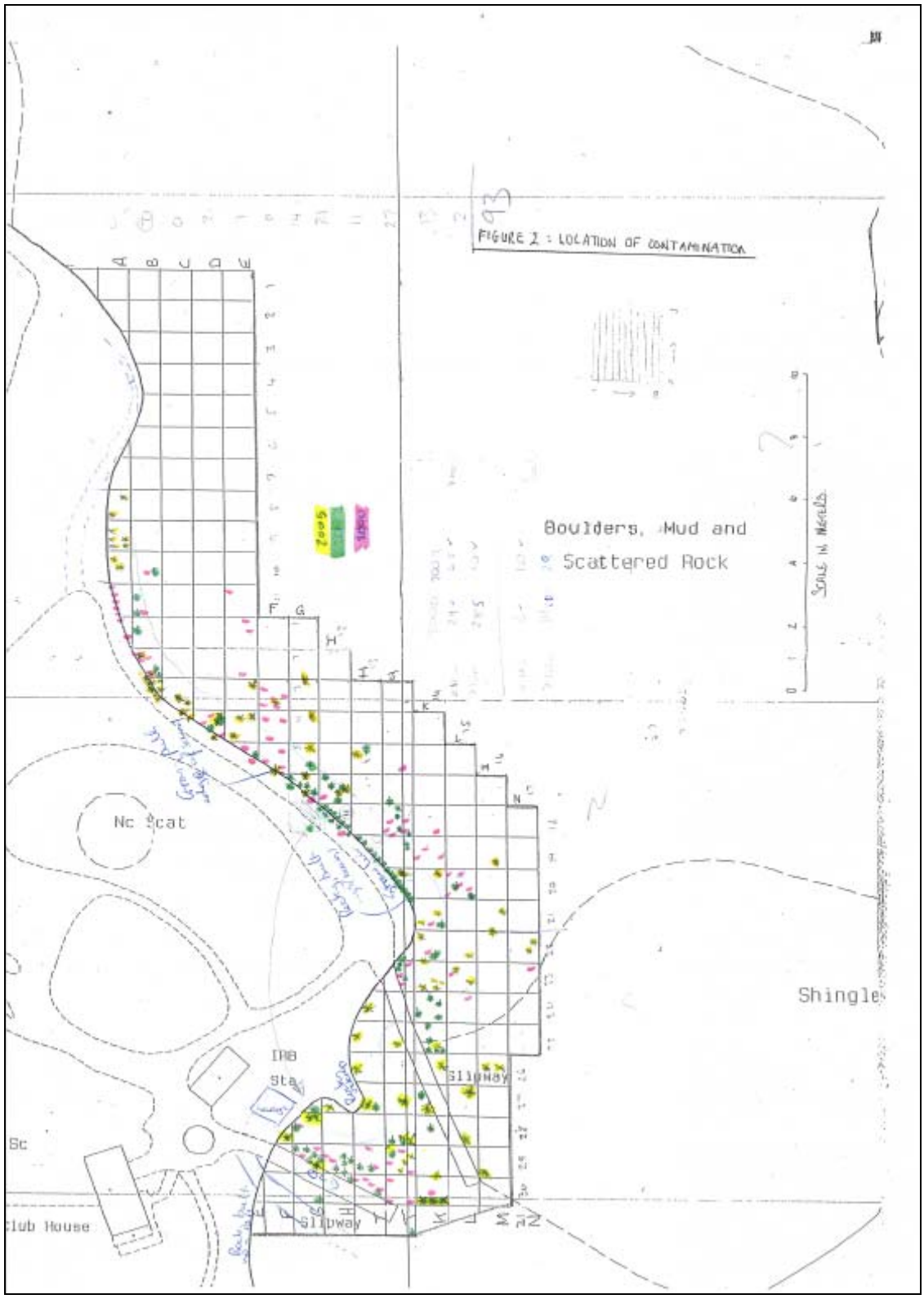
	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
	b. A section of the boat/car park		9 discrete items were found in the reference area. This can be directly compared with the previous find of 28 items, and the 100 items detected in the 1991 May/June Survey.	*incorporated into the compacted material* *2 small areas (60 x 60 cm) of 3-4 times background – material associated with a layer of clinker and ash. Average Specific Activity of 300 Bq kg $^{-1}$. Dose Rate: 0.2 μSv h^{-1}.* Beach: 23 discrete items were isolated and removed. This compares with 60 discrete items from the same area in May/June 1991. 3 samples of increased background gave specific activities of 90 Bq kg $^{-1}$.		

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
9	This survey was the third follow up survey. The reference area was monitored to track replenishment rates of the area. Other areas included in this survey: a. An area of beach measuring approx 20 x 15 m on the Sailing Club side of the reference area. b. An area of beach measuring approximately 40 x 12 m	Sodium Iodide Detectors	Where increased radiation levels were detected, the source of the radiation was isolated and removed for disposal. One sampled sample was taken where radiation background elevated to about three times the average surface background count rate at a depth of about 50 cm. No discrete items could be isolated from the ash layer.	Items removed from the areas surveyed varied in physical size from a pinhead to pieces of clinker of irregular shape up to about 7 cm in dimension. Number of items found in reference area: 11. This is about the same as previous survey (9). They were located at least 10 cm below the surface and were generally of low activity. 76 items were isolated during this survey. 14 were detected above high water. 41 were detected between the tidal marks. 21 were detected below the tidal marks.		At least one further survey should be undertaken in about six months time. The survey should include the reference area and the remaining part of the beach not already resurveyed. If possible the next survey should identify the locations of the items found in relation to the tidal marks.

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
10	This is the fourth repeat survey. The reference area was monitored to track replenishment rates of the area. Other areas included in this survey: a. An area consisting of the full width of the Sailing Club access road adjacent to the dinghy park and approx. 20 m of the road adjacent to the foreshore b. An area of beach measuring approximately 10 x 15 m	Sodium Iodide Detectors	Discrete, isolated items were removed for analysis and disposal with the exception of those located on the access road. The items located on the access road were apparently incorporated into the road construction material. Removal was not considered practicable or necessary.	A total of 48 items were detected – 9 above high water mark, 9 on the access road on the sailing club and the remainder between the tidal marks. 26 of the items were recovered from areas that had been previously surveyed by equipment which was not a sensitive as was used in this survey. Two items were found in the reference area. This is significantly fewer than the eleven items found previously. They were located either on or near to the surface and were generally of low activity. Total activity of removed items = 522 kBq.	Removal of the items located on the road surface was not considered necessary due to the fact that the items were immobile.	At least one further survey should be undertaken in about six months time. The survey should include the reference area and areas that were originally surveyed with less sensitive equipment than that now used.

	Survey Method	***Probe Type***	***Items Detected/Removed***	***Findings/Analysis***	***Radiological Assessment***	***Report Conclusions/ Recommendations***
11	This was the fifth repeat survey. The whole beach and part of the Sailing Club Car Park have now been re-surveyed at least once.	Sodium Iodide Detectors.	Detected material was removed where appropriate.	Total activity (approx) of removed items = 560 kBq. Seven items were detected in the reference area. Six items had been detected during the previous monitoring. Most were at or near the ground surface. 23 items were removed from other areas. Total items: 30 items removed.		Consideration could be given to reducing the frequency of the repeat surveys to annually.
12	This was the sixth repeat survey. The reference area was monitored to track replenishment rates of the area. Nine other areas included in this survey: a. Areas to the left and right of the reference area b. The areas around the two slipways and the boat park	Sodium Iodide Detectors.	Detected material was isolated and removed for disposal. Discrete/isolated items were removed for analysis and disposal.	Total Activity removed: 397.6 kBq 7 items were detected in the reference area. 7 items had been detected there previously. Total items: 34. 7 detected above high water mark, of this, 4 were found in the boat park.		At least one further survey should be undertaken in about 12 months. The survey should be included the reference area and areas not surveyed within the last 12 months.

Appendix F



Appendix F: Map of all items detected during 2000, 2002 and 2005 Babcock surveys