Dalgety Bay Investigation Reports

The investigation of the nature, extent and hazards posed by radioactive contamination on the beach at Dalgety Bay is currently underway. This investigation is being undertaken by SEPA using the Radioactive Contaminated Land (Scotland) Regulations 2007 as a framework. This will require the production of a series of reports to assess the contamination in order to inform any necessary actions to ensure that the public and environment continue to be afforded an appropriate level of protection. The programme of reports is on our website, and includes reports that have been commissioned by both the MoD and SEPA. This report is part of this series and should be read in the context of all other related reports.

Whilst the full series of reports is being developed, a monthly monitoring and removal programme is being undertaken. This together with the signs providing advice to the public to wash their hands when leaving the beach and not to remove objects reduces the risks to the public from the radioactive contamination. The advice to avoid the demarcated area remains in place.

At present, providing the public follow the advice on the signs, the current risks to beach users are considered to be relatively low. In the event that the monitoring programme detects anything which requires further actions to protect the public this will be undertaken swiftly.

SEPA
30th April 2013.

Dalgety Bay

Radioactive Contaminated Land Risk Assessment

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Executive Summary

Radioactive sources (radium-226) present at Dalgety Bay continue to pose a significant hazard to public health. Many of the sources recovered continue to be in excess of the relevant criteria for The Radioactive Contaminated Land (Scotland) Regulations 2007 and the associated Statutory Guidance. The results of the physical investigation show that without remediation, the contamination of the beach will continue for many years to come.

The specific chance of one individual encountering a source e.g. by skin contact and inadvertent ingestion has been assessed using habits survey information for the foreshore which has been skewed following the initial signage and subsequent demarcation and supplementary signage on the foreshore. This has resulted in a reduced occupancy of the affected areas of the foreshore and a lowering of the potential for the public to encounter a radioactive source. Using habits data and source recoveries, current estimates for the chance that the most exposed person could come into contact with a radioactive source that could pose realistic harm is greatest around the slipway area at around 1 in 2200 per year. However, the possibility for any user of the beach area encountering a source which could realistically cause harm this is around 1 in 250 per year. It is noted that such estimates are the most realistic that can be performed at present and are not worst-case estimates. Such assessments do not consider preferential selection e.g. a child picking up a dial on the beach.

The most likely pathway is via direct skin contact. For most sources contact is very unlikely to result in a skin burn if people follow the advice to wash their hands when leaving the foreshore to minimise exposure times. Only small numbers of the higher activity sources recovered to date could give a skin burn to a beach user during their time on the beach. Lesser activity sources only pose a potential hazard if they remain on the skin for a number of hours, which can be avoided if people wash their hands when leaving the beach.

For inadvertent ingestion the possibility of this occurring for a source which could pose a realistic risk is currently significantly less than 1 in a million per year for the most exposed individual. For all users of the foreshore (i.e. the risk for all people using the area) the possibility of inadvertent ingestion is less than 1 in a million (currently around 1 in 700,000) for sources that pose a realistic hazard from ingestion.

Based on stochastic encounters, if the situation remains unaddressed there is almost certainty that an encounter will occur. This chance of accidental encounter is further compounded by the fact that some of the contamination is associated with physically attractive objects such as dials and levers that could be preferentially or deliberately selected. It is impractical to determine the probability of somebody choosing to pick up such an item with any suitable confidence. Other possible exposures could be a small child picking up a source and placing it into their mouth. For any encounter, the doses for children are typically greater than that for an adult.

Importantly, because of the heterogeneity of the contamination in terms of activity, solubility, size and distribution within the made ground, a retrospective risk assessment based solely on previous surface finds may not provide a suitable assessment of future risks. This was clearly demonstrated in 2011 when many more sources some with far greater activity were found on the beach at Dalgety Bay than had previously known to be the case. As no records of the amount of radioactivity brought onto the site are available, it is not possible to determine the activity remaining.

Applicability for designation as RCL

For ingestion, based on mean solubility a 3-month old child would receive 100 mSv from a 35 kBq source. For a 1-year old child this same dose is attributable to a source with an activity of 100 kBq, a number of such sources reported in the SEPA find data on our website have activities greater than this value and are of ingestible size[1]. For an adult this would be a source in the order of 700 kBq, however, the number of sources found to date with activities greater than this value is relatively low. Higher numbers of sources in excess of 35 kBq have been found in Areas C, D and E with fewer found outwith these areas (Figure 15). For skin doses, based on Charles 2008, sources of 10 MBq would deliver 10 Gy/h to the adult skin. Two such sources were found in 2011 which would deliver such a dose rate, although in all likelihood at least one further source was also found in this area in 1990, it is therefore reasonable to assume that further caches of such sources exist.

Sources which could deliver doses[2] of greater than 100 mSv are in greatest in numeric density in Areas C, D and E, (the current Demarcated Area, Boat Storage Area and the Slipways area). When sources are removed from these areas they are repopulated with similar activity sources, most likely as a result of coastal processes. For doses to the skin, sources which could deliver 10 Gy/h to an adult[3] skin have only been found in Area C.

SEPA considers that significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring on Area C, D and E at Dalgety Bay in line with the criteria set out in paragraph A.32 of the Statutory Guidance.

For Areas C, D and E current management arrangements, including signage demarcation and monitoring and removal, is reducing the risks to the public. However, the practicability, effectiveness and durability of these current measures are still to be assessed.

As the conditions set out in paragraph A.32 have been met the probability of a radiation dose in line with paragraph A.33 has not been assessed.

SEPA does not consider that it has sufficient information to determine whether a significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring at Areas B (Ross Plantation foreshore) and F (Headland foreshore) due to the uncertainties discussed in Part 5 of this Risk Assessment. SEPA will keep these areas under review and consider whether further inspections are required.

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[1] Assuming maximum size for ingestion of 20mm. From Litovitz Toby; Whitaker N, Clark L. (June 2010). "Preventing battery ingestions: an analysis of 8648 cases.". Paediatrics 125 (6): 1178–83.

[2] Assuming mean solubility

[3] It is noted that the dose rate to a child's skin has not been assessed.

Glossary of Terms

Artefact	a radioactive source which is different from the surrounding material e.g. a dial or gauge
Confidence of detection	The assessed value for which an observed effect will be recorded e.g. a 50% confidence of detection will mean there is an equal chance or detection and non detection
DBPAG	Dalgety Bay Particles Advisory Group a group of independent experts advising on the radioactive contamination at Dalgety Bay and its risks to health
DPAG	Dounreay Particles Advisory Group a group of independent experts advising on the radioactive contamination at Dounreay and its risks to health
ED50	ive dose (ED) is the dose or amount of drug that produces a response in some fraction of the subjects taking it. The median effective dose is the dose that produces an effect in 50% of the population abbreviated as the ED50, meaning effective dose, for 50% of people
FEPA	The Food and Environment Protection Act (FEPA) which allows orders to be made to prevent fishing
Gray	The gray (symbol: Gy) is the SI derived unit of absorbed dose, specific energy (imparted) and of kerma.
Particle	A physically small radioactive source which other than its radioactive properties is similar to that of the surrounding sediment
PRAG(D)	Particles Recovery Advisory Group (Dounreay) a group of independent experts advising on the recovery programme for Dounreay particles
Sievert	The sievert (symbol: Sv) is the International System of Units (SI) derived unit of equivalent radiation dose, effective dose, and committed dose.
Source	A radioactive objective which includes both particles and artefacts
Statutory Guidance	Environmental Protection Act 1990: Part iiA Contaminated Land Statutory Guidance: Edition 2, Paper SE/2006/44 as amended by Environmental Protection Act 1990: Part iiA Contaminated Land, Radioactive Contaminated Land (Scotland) Regulations 2007 Statutory Guidance 28 May 2009 SG/2009/87
TLD	A thermoluminescent dosimeter, or TLD, is a type of radiation dosimeter. A TLD measures ionizing radiation

Part 1. Scope of the issue

1.1. Introduction

Radioactive contamination has been detected since at least 1990 on parts of the foreshore at Dalgety Bay, Fife and on land adjacent to the foreshore and in garden land that was part of the former Donibristle airfield. The contamination is from the long lived radionuclide radium-226 which together with is decay products can pose a significant hazard to human health via skin contact, ingestion, inhalation or external irradiation. Physically it is in the form of solid radioactive sources of various shapes and physical sizes. The area considered as part of this assessment is shown in Figure 1 ("the Site").

Since 1990, episodic monitoring at Dalgety Bay has continued to recover radioactive sources/items from the beach. In the past, there have also been a number of investigations and remediation work has been undertaken to reduce the hazards in residential gardens, the most recent of which was performed by the MoD.

Work to characterise the extent of the contamination has been undertaken by the MoD and will be reported separately. However, the work showed that large areas of the coast had significant deposits of clinker/ash with associated radioactive sources which is consistent with the work undertaken by MoD in 2007 (Enviros, 2007). It is important to assess the hazard that such sources pose in light of that evidence as it suggests that, unless direct action is undertaken the effect of coastal action (AMEC 2013) will result in further sources being eroded out of these areas and becoming exposed on the beach.

SEPA has powers under the Radioactive Contaminated Land (Scotland) Regulations 2007 and the Environmental Protection Act 1990 to inspect land for the purpose of deciding whether land appears to be Radioactive Contaminated Land. Before SEPA can make the judgement that any land appears to be Radioactively Contaminated Land on the basis that Significant Harm is being caused by radioactivity possessed by any substance in, on or under the land or that there is a Significant Possibility of such harm being caused, SEPA must 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 Significant Possibility of such harm being caused by that radioactive contaminant to that receptor.

A determination that land is Radioactive Contaminated Land is made in respect of a specific area of land. In deciding what that area is, the primary consideration is the extent of land which meets the definition of Radioactive Contaminated Land.

SEPA should determine that land is Radioactive Contaminated Land on the basis that Significant Harm is being caused where:

(a) it has carried out an appropriate scientific and technical assessment of all the relevant and available evidence; and

(b) on the basis of that assessment, it is satisfied that Significant Harm is being caused.

SEPA should determine that land is Radioactive Contaminated Land on the basis that there is a Significant Possibility of Significant Harm being caused where:

i. it has carried out an appropriate scientific and technical assessment of all the relevant and available evidence;
ii. on the basis of that assessment, it is satisfied that there is a Significant Possibility of Significant Harm being caused; and
iii. there are no suitable and sufficient risk management arrangements in place to prevent such harm.

This risk assessment report is an appropriate scientific and technical assessment of all the relevant and available evidence.

The objective of this risk assessment report is to:

1. Establish whether there are significant pollutant linkages at the Site; and
2. If there is such a Significant Pollutant Linkage at the Site, whether it is resulting in Significant Harm to a receptor in the Pollutant Linkage or it presents a Significant Possibility of Significant Harm being caused to that receptor.
3. Establish whether the Site, or any parts of the Site, meets the definition of Radioactive Contaminated Land.

The Site has been assessed in respect of its current use in accordance with paragraph A.27 of the Statutory Guidance. This risk assessment does not consider any activities which occurred on the Site or any of the causes of the radium contamination. This risk assessment does not consider whether there are suitable and sufficient risk management arrangements in place to prevent any Significant Possibility of Significant Harm being caused.

SEPA is also required to consider whether any land appears to be Radioactive Contaminated Land on the basis that Significant Pollution of the Water Environment is being caused or that there is a Significant Possibility of such Pollution being caused. Since SEPA has not found any elevated radium contamination in the Water Environment at the Site to date, this risk assessment does not consider whether the Site, or any part of it, is Radioactive Contaminated Land on that basis.

Figure 1: Area of Dalgety Bay within scope of the current investigation

Part 2. Significant Pollutant Linkages

For land to be amenable to designation as Radioactive contaminated Land (RCL) there is a need for contamination to be present, together with a receptor and a pathway to exist to allow the receptor to encounter the hazard i.e. a pollutant linkage.

2.1. Radioactive Contamination

2.1.1. Sources recovered

Since the first radioactive find in June 1990 at Dalgety Bay, there have been at least 28 documented episodic monitoring surveys undertaken to date to remove sources on the beach area (appendix 9.1)[4]. The beach came under a regular monthly monitoring programme at the end of 2011 with specific criteria adopted in February 2012. This monitoring has shown that the numbers, activities and location of sources vary with time (Table 1 and Figure 2). Although some of this variation may reflect the detection capability of the equipment used and areas preferentially selected, it suggests that the occurrence of such sources is heterogeneous in temporal, physical, depth, hazard and spatial distributions. Such an effect on the beach is not surprising as the intrusive work conducted by MoD's contractors has revealed that the radioactive contamination in the made ground is heterogeneous.

Historical information on source finds is poorly characterised and the information on the number of monitoring surveys undertaken on the beach is incomplete along with the spatial extent of the surveys undertaken. However, it is clear that the extent of coverage has varied together with the nature and type of monitoring equipment deployed. These differences limit any meaningful comparison of historical data.

2.1.2. Population of sources

The number of sources recovered from the beach area at Dalgety Bay has varied with time (Figure 2). The true number of sources present on the beach is in all probability significantly greater than that number recovered during the survey. This is because no monitoring instrument is capable of detecting all of the sources present on the beach to a given depth. The difference is directly related to the distribution of sources both with activity and depths (as sources become more difficult to detect with lower activity and with greater depth). Further complications are introduced when very high activity, deeply buried sources, produce a significant radiation field rather than a localised source of radioactive contamination.

Between October and December 2011, SEPA found 459 sources over limited areas of the affected beach. SEPA recognised that its instrument was not capable of detecting all sources and thus it is likely that the true population was significantly greater than 459. In 2012, SEPA recovered 290 sources from January to May. Monitoring in both periods by SEPA did not cover all of the beach area in Figure 1, thus an adjustment should be applied to determine the potential number of sources present. For the SEPA 2011 data, it was estimated by SEPA that around 50% of the area in Figure 1 was monitored which would result in a potential population of around 1000 sources within the detectable depth, which is source activity dependent. If the

[4] It is noted that a number of surveys and programmes of radioactive waste removal have occurred on terrestrial areas of Dalgety Bay which is outwith the scope of this assessment.

limitations of detection capability were then considered this potential population would be further increased.

In 2012 the MoD contractor's monitoring recovered around 100 sources each month (850 over 9 months) having improved their monitoring technique. As this was the first time a specific monitoring objective had been utilised, it is problematic in making any comparisons to earlier monitoring data (in terms of find rates). When 2012 monitoring data are combined with the SEPA finds from January to May of the same year, the number rises to 1140 over the 9 month period. (SEPA has yet to receive data for the remainder of 2012). Thus current estimates for source populations are in the order of at least 125 detectable sources per month or around 1500 per year over a monitored area of about 3 hectares ($30,000m^2$). As the monitoring programme will not identify all of the sources present even within its limits of activity and depth detection criteria it would be reasonable to assume that the total population is greater than 1500. However, it is recognised that as detection efficiency diminishes rapidly with depth the true value for all sources present is likely to be significantly greater than this value.

Year	Number of sources removed
1990	190
1991	534
1992	76
1993	78
1994	45
1995	No monitoring data
1996	No monitoring data
1997	102
1998	11
1999	No monitoring data
2000	80
2001	No monitoring data
2002	93
2003	No monitoring data
2004	No monitoring data
2005	97
2006	37
2007	No monitoring data
2008	38
2009	76
2010	24
2011	478
2012	1151
Total	3110

Table 1: Beach monitoring finds

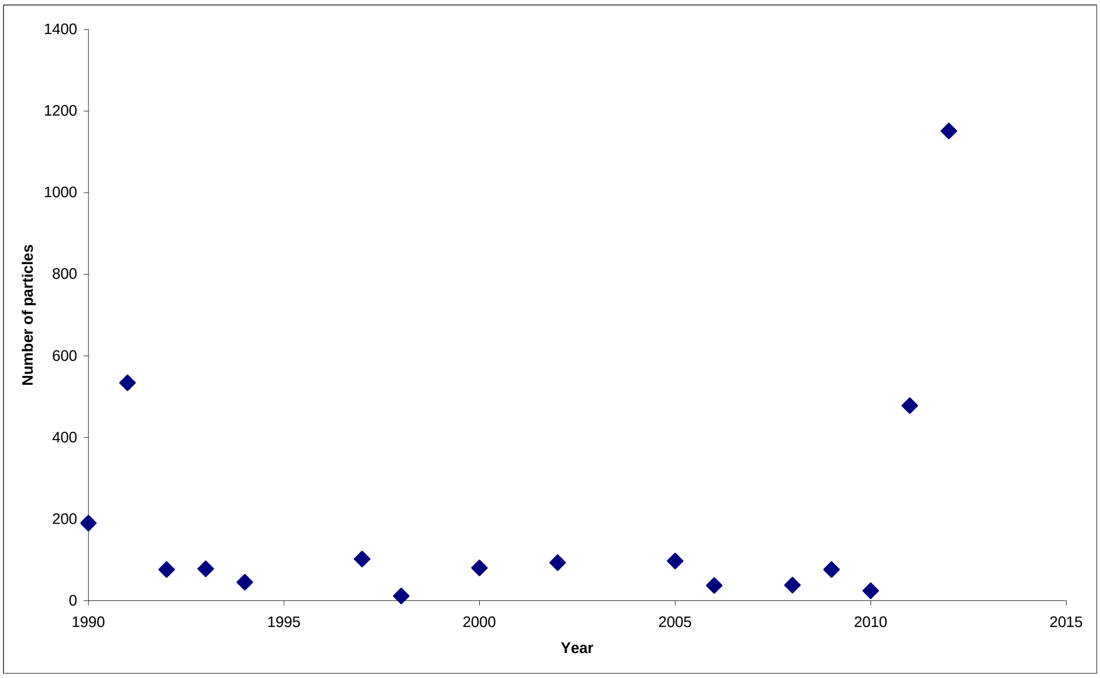


Figure 2: Numbers of sources reported to have been recovered on beaches by a variety of organisations (note in 1998 the area was greater than previous years and monitoring was not conducted in all years).

2.1.3. Distribution & Activity of sources

Historical information on the source activities is highly limited as are the details of where they were recovered on the beach. More recent monitoring, undertaken in 2006 and 2008, removed 38 and 39 sources, which had a total activity of 2.8 and 2.6MBq (respectively) (SEPA 2006, 2008). The activity distribution of the sources recovered in 2008 is shown in Figure 3 and ranged from a few hundred to 870,000 Bq. Classification of the sources into bands of activity 0-10 kBq, 10-100 kBq, 100 kBq - 1 MBq and > 1 MBq (Figure 4) shows similar numbers of sources in the first three classes and no sources in the greater than 1MBq class. The geographical distribution of the sources tended to be most concentrated (in number) in the slipway areas and in the upper regions of the adjacent beach. This work was reported in 2008 and a risk assessment performed on the data available at that time (SEPA, 2008).

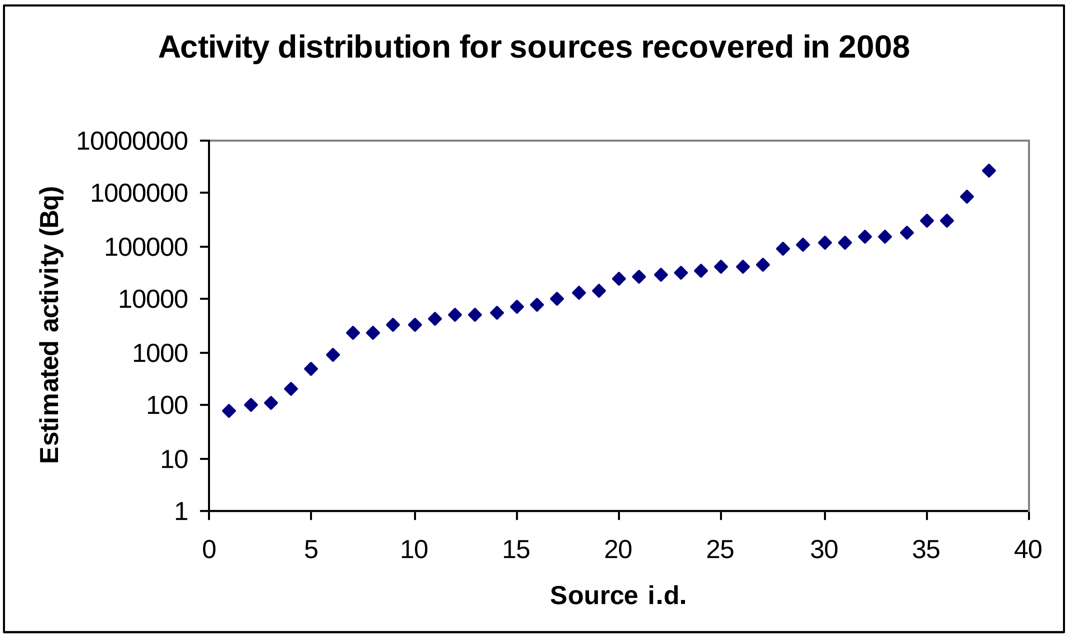


Figure 3: Activities of sources recovered in 2008.

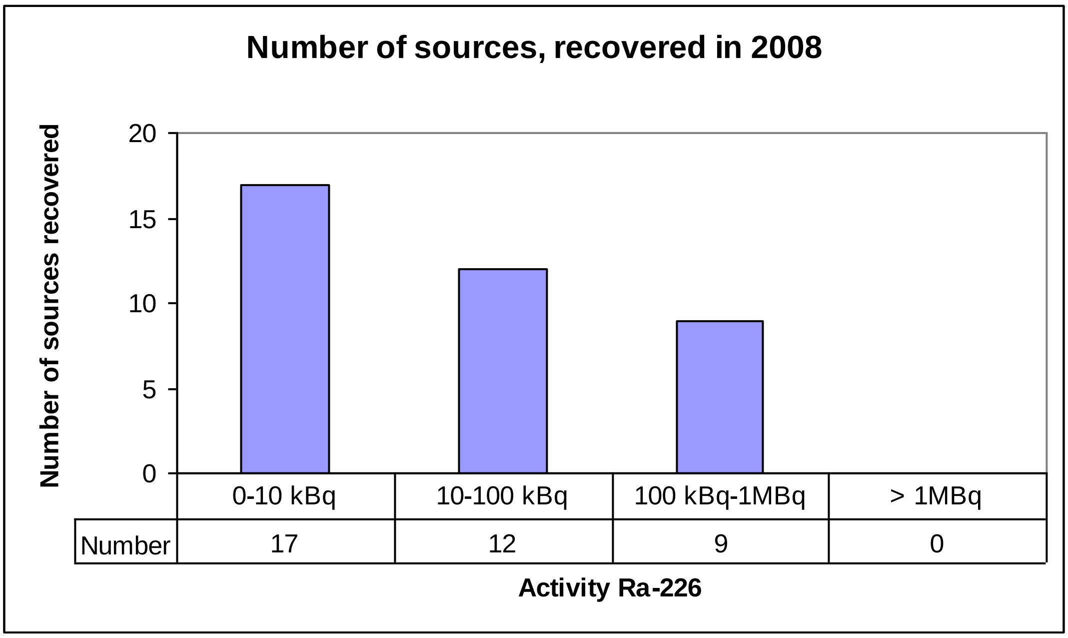


Figure 4: Source activities recovered in 2008 by class

In 2009 there was a change of contractor employed by MoD to undertake the work, resulting in a change of methodology used. In 2011 and 2012 sources were recovered by both the MoD contractor and SEPA, the organisations using differing instrumentation and differing deployment strategies. In 2012, following advice from DBPAG, the monitoring technique used by the MoD contractor changed from that used in 2011 to be capable of more confident detection of sources with activities greater than 20 kBq to a depth of 10 cm in the beach. Figures 5, 6 and 7 show the sources found in 2008, 2009, 2010, 2011 and for the first 9 months of 2012. It is clear from these figures that both the number of source finds and the activity composition of those finds changed over 2008 to 2012. The reason for these changes is unclear due to the change in frequency of monitoring and changes in technique used. However, irrespective of the technique used, had high activity sources been present within the top 10 cm of beach in previous years these should have been detected by previous monitoring regimes. Thus, the sources recovered in 2011 and 2012 will have either emerged onto the beach from erosion of the made ground or migrated to that location by surface movement since the previous monitoring was undertaken.

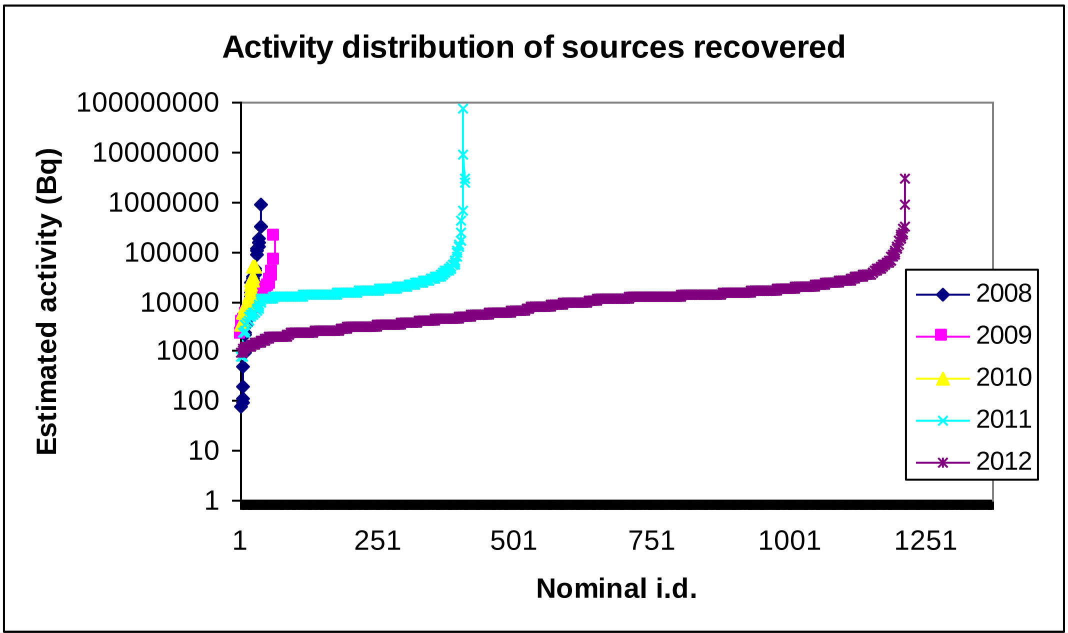
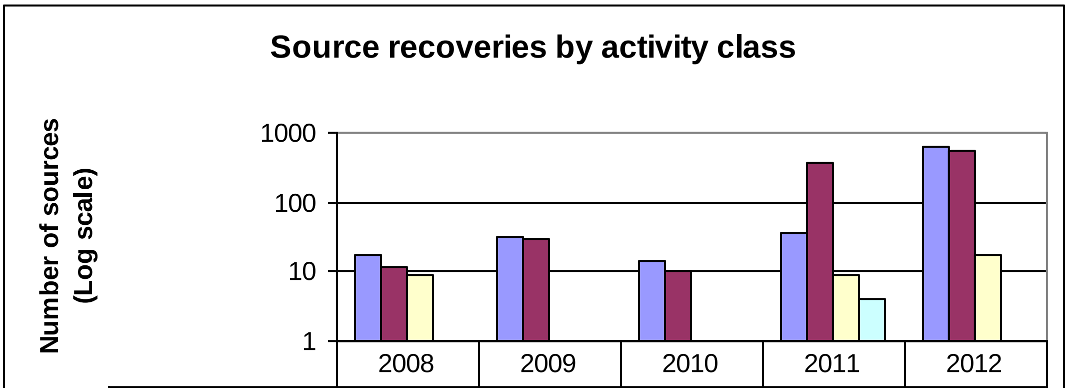


Figure 5: Source Activities found in 2008 – 2012



	2008	2009	2010	2011	2012
0-10 kBq	17	31	14	35	631
10-100 kBq	12	30	10	359	560
100 kBq -1 MBq	9	1	0	9	17
>1MBq	0	0	0	4	1

Year

Figure 6: Sources recovered classified by activity bands 2008 to 2012

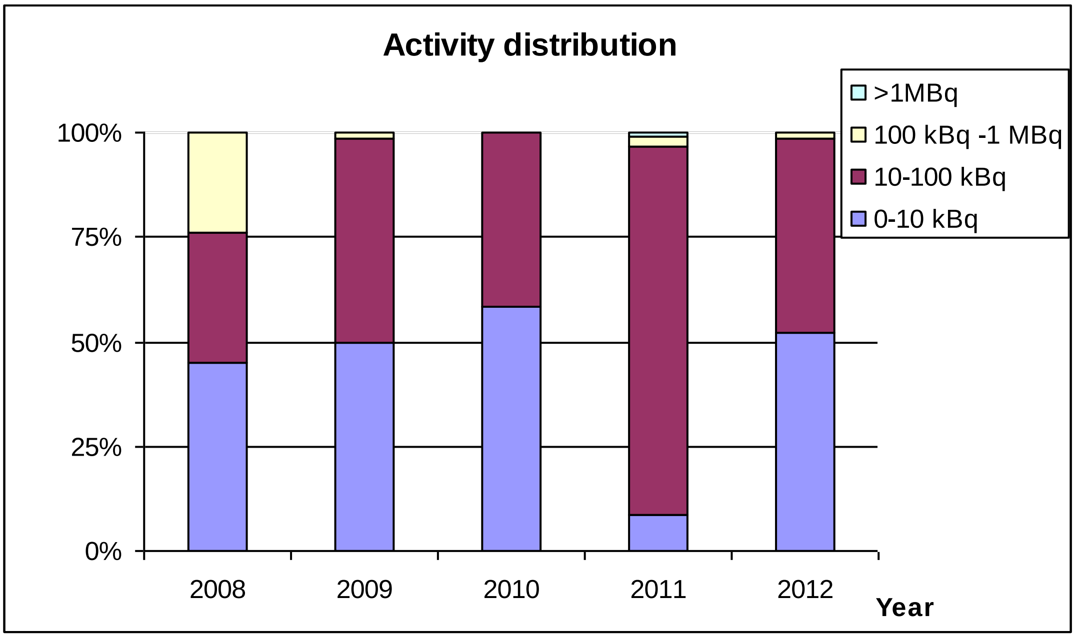


Figure 7: Source population composition by activity band

Although much of the monitoring data previous to 2006 does not contain information on individual source activities and locations, it does contain information on the likely number of sources recovered (See Figure 2). The large number and high activity of finds reported in 2011-2012 is not an isolated case. It should be noted that in 1991 540 sources were recovered by NRPB which also included sources with individual activities greater than 1 MBq. Between these dates, source recoveries fell to a few tens demonstrating the episodic nature of the contamination.

The sources are attributed to a particular activity classification on the basis of their assessed radioactive content. In 2008, the sources recovered were all analysed in laboratory conditions, which gave some confidence to the result[5]. Laboratory analysis was not used for all of the MoD's contractor and SEPA finds due to the large number of finds and the potential associated increase in laboratory worker doses. Thus a correction factor is applied to field measurements to assess the source activity. It is accepted that this factor will not be a completely accurate representation of the activity but an approximation. The number and relative proportions of sources in each classification recovered by the MoD's contractor and SEPA in 2011 and 2012 is shown in Figures 8 and 9. From an initial examination of these data, it appears that SEPA monitoring recovered greater numbers of higher (>10 kBq Ra-226) sources than the MoD's contractor's monitoring undertaken over the same period.

[5] It is noted that no standard is available for assessing activity from point sources.

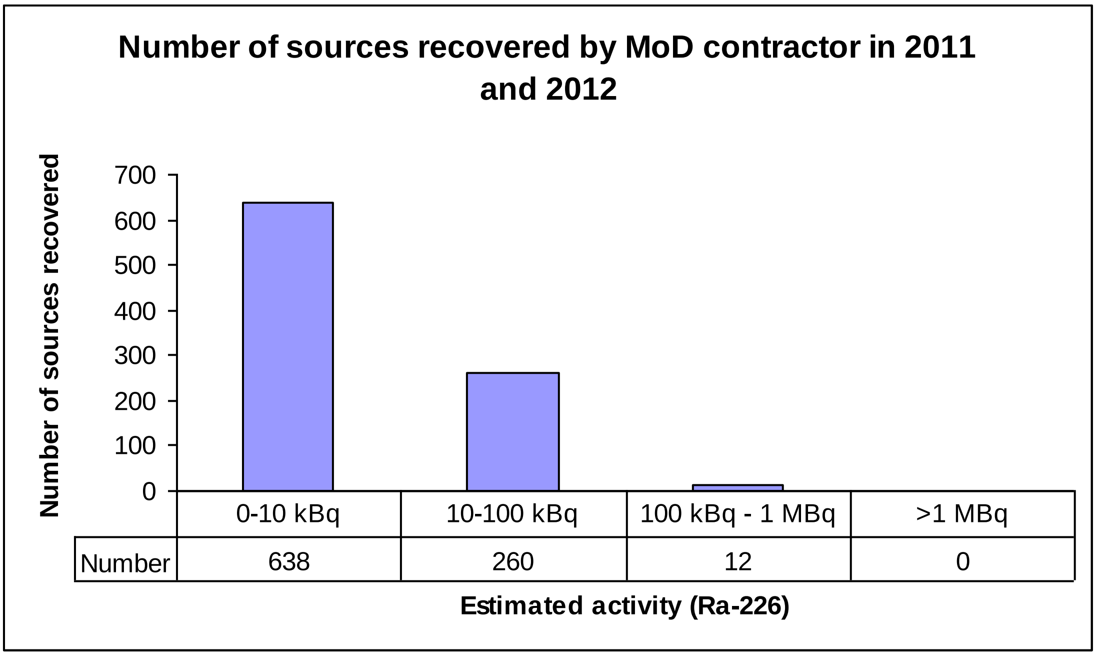


Figure 8: Sources recovered by MoD's contractor allocated according to estimated activity.

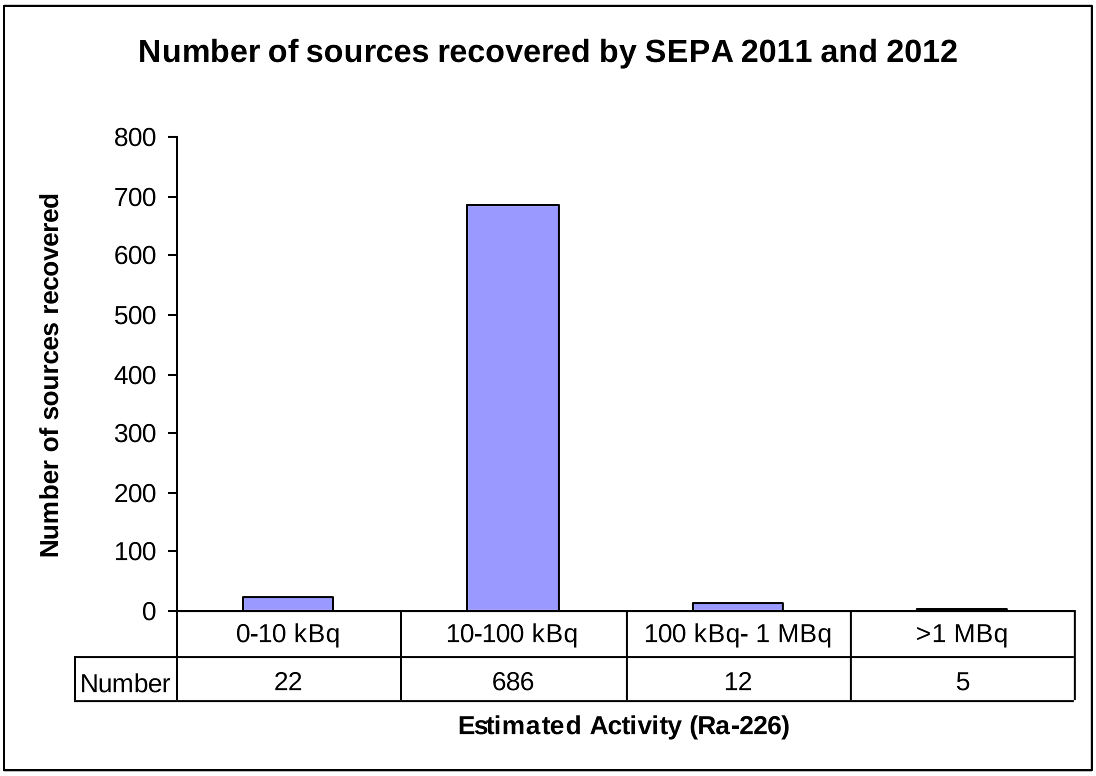


Figure 9: Sources recovered by SEPA in 2011 and 2012

The reason for the difference between the relative proportions could be attributable to a number of factors:

I. SEPA surveys removed the higher activity sources from the beach before the MoD's contractors monitoring occurred. *This is unlikely to be the case as initial SEPA monitoring followed the September 2011 survey of the beach carried out by the MoD contractor*.

II. The MoD contractor's monitoring system had a greater physical volume and was thus more able to detect lower activity sources closer to the surface. *This may explain the greater number of lower activity (0-10 kBq)* sources *it would not explain the absence of higher number of* sources *with activities greater than 10 kBq as these should also have been detected by this system.*

III. Monitoring of differing areas skewed the dataset. *The MoD contractor's monitoring data included all of the affected area, whilst the SEPA monitoring sampled parts of the area (for the purpose of determining the areas of greatest concern). It is possible that the SEPA sampling was not fully representative of all of the area: for example, all of the slipway areas were monitored whilst only a proportion of the beach in front of Ross Plantation was monitored. Thus areas where greater numbers of higher activity sources were present may have been targeted by the SEPA monitoring, thereby skewing the data.*

IV. A cache of sources were released in 2011 which were detected by SEPA monitoring. *This would explain the relatively high proportions of sources with activities >10kBq. However, as in the case of I above, the MoD's contractor monitored all of the beach prior to SEPA monitoring.*

V. The absence of specified methodology at that time meant that different 'action' levels were being set. *This may be a likely explanation for the discrepancy and means that source find data prior to implementation of a criteria for monitoring (2012) is likely to be an underestimate of the true source numbers present on the beach.*

VI. Calibration factors used by SEPA and the MoD's contractor for conversion from field readings to activities are not a reflection of true activity. *Selection of a calibration factor will significantly affect the entire range of source activities. This is discussed further in the estimation of activity section 1.2.6.*

The sources recovered have had differing levels of activity within them and present differing hazards to the public. In late 2011, SEPA detected and recovered a series of multi-MBq sources from the now demarcated area of the beach. At that time, it was believed that these finds were significantly greater than anything previously detected on the beach at Dalgety Bay. However, a comprehensive review of records has now indicated that in October 1990 a survey from the Directorate of Fisheries Research (Camplin, W. 1990) detected and recovered what was described as "a particularly hot" source from a depth of 15-20 cm. This source had a dose rate of > 28 mSv/h and resulted in a recommendation that access should be restricted until a full radiological survey had been undertaken. In August 1991, the then National

Radiological Protection Board (NRPB) (subsequently part of the Health Protection Agency (HPA) and now part of Public Health England (PHE)) detected a source which at a distance of 4 cm had a beta/gamma dose rate of 4.5 mSv/h (450 µSv/h gamma). It is difficult to determine the activity of these two sources accurately due to potential uncertainties in the measurement geometry and precision of the distance, together with knowledge of the equipment and its operation. However, it is likely to have been at least 10 and 4 MBq respectively but could have been higher than these estimates (using the RadPro calculator).

Since those finds in 1990 and 1991, no further multi-MBq sources were believed to have been recovered from the beach until September 2011 when 4 such sources were recovered. However, from the mid 1990's until 2006 monitoring data did not provide detailed information on the activity of each source, thus caution is needed in the interpretation of those data. In 2006, the maximum activity reported was 1.2 MBq, in 2008 it was 0.87 MBq and in 2010 it was 0.5 MBq. In 2011, 4 sources were recovered with activities in excess of 1 MBq, the maximum of which was 76 MBq[6,7]. In 2012, a further source of 2 MBq was recovered in front of the headland area.

It is highly likely that the sources which continue to be removed from the beach at Dalgety Bay were all deposited before the first find in 1990. As erosion of the beach occurs they can be identified and recovered. As sources become closer to the surface of the beach they are more likely to be detected while even higher activity sources buried at depths of greater than 60 cm are highly unlikely to be detected.

It would be reasonable to assume that, following the recovery of at least two multi-MBq sources in the 1990s, further sources in 2011 and a source from in front of the headland area in 2012 further multi-MBq sources remain in the beach and coastline at depths at which they cannot currently be detected. Importantly, there is no inventory of the total amount of radium handled during historic operations at the Site. Thus, it is impossible to determine the amount of radium remaining in the environment at Dalgety Bay. With the presumption that the distribution of the activities of recovered sources informs about the distribution of the activity of the remaining population then further such sources with higher activities can be expected. However, ICRP 64 noted that the observed frequency may not necessarily be repeated in the future and the assumed symmetry may be false.

As erosion of the coastline at Dalgety Bay can move significant volumes of material, it is not possible to determine with certainty when further high activity sources remaining in the environment may emerge using the monitoring data alone.

It is also important to note that children can dig in beaches to depths of 60 cm or greater and move large amounts of sand, thus a source currently buried at depth could be unearthed by a child digging on the beach and mobilized in the surface environment. Further assessment of pathways is presented in Section 4.

2.1.4. Source Break-up

Some sources detected and recovered from Dalgety Bay beach have been co-located with other sources, whilst others have, on recovery, broken into smaller sources. Some of these breakdowns result in two or more active sources whilst others result in active and inactive components (Appendix 2). Over time these

[6] Detector limitations make assessment of the precise activity of this source difficult as the dose rate is so large.
[7] It is important to note that such particles represent a small fraction of those sources recovered to date

processes of breakdown will also occur naturally through weathering and erosion to produce increasingly smaller but more numerous sources over time. This could mean that a large, highly active source could break down into many smaller sources resulting in a large number of physically small sources. This would significantly increase the potential for encounter and, as sources became physically smaller, the possibility of ingestion, skin contact and inhalation (Section 3).

To assess whether a large number of low activity sources were present on the beach which would not be detected by the current monitoring regimes, a series of sediment samples from a depth up to 2-3 cm were taken across the affected area of the beach (See Figure 10). Control samples were obtained from an area to the east and west of the site. Fifteen surface grab samples of 2-3 kilograms of beach material were removed and analysed to determine the amount of radium present. Only one sample contained radium-226 above 50 Bq per sample. This material was separated to determine whether it was homogeneous activity or discrete radium sources; it was homogeneous. Thus, it is unlikely that currently there is a large population of 50 Bq - 1 kBq particles on the beach.

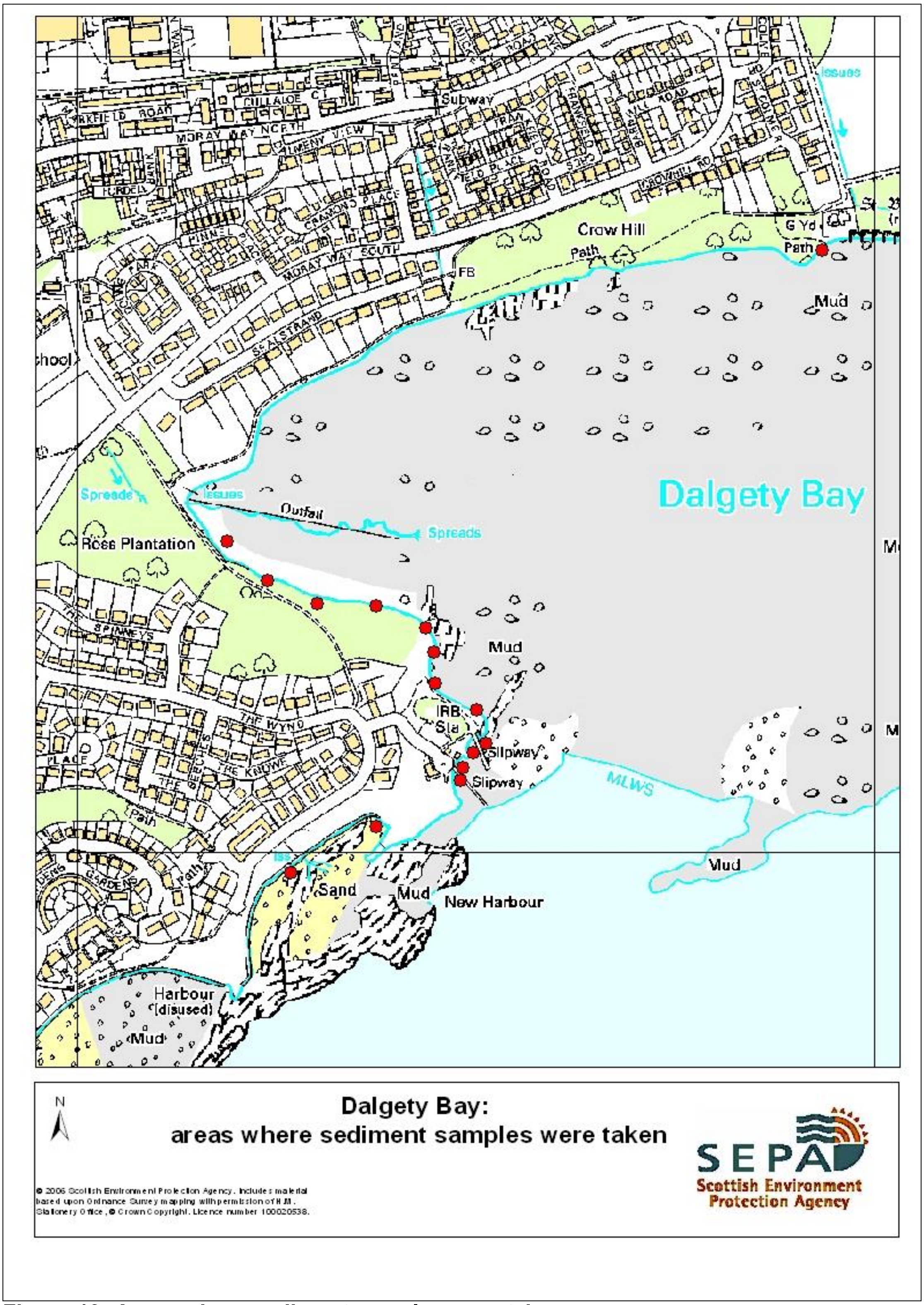


Figure 10: Areas where sediment samples were taken

2.1.5. Source activity estimation

The assessment of source activity is a key parameter in order to assess the potential hazards and the risks to a beach user. At present the current MoD contactor recovers sources within a matrix of inert beach material and the source activity is estimated using a correction factor. Importantly, the source is not routinely fully isolated from its matrix and thus there could be an over or under estimate of the source's true activity due to the effect of shielding (see 3.1.2) and the proximity of the source to the detector. In contrast, SEPA recoveries tend to isolate the individual source from the matrix. Plotting of the relationship between these two variables (Figures 11 and 12) shows that typically the SEPA field estimate of data tends to over-estimate lower activity sources typically by around a factor of 2 which is likely to be a reflection that background count rates have not been subtracted from field estimates. However for the sources of greater than 100 kBq the field estimate is largely consistent with the laboratory estimates and is a slight over estimate of the true activity. The R^2 value for the SEPA data is high representing a good relationship.

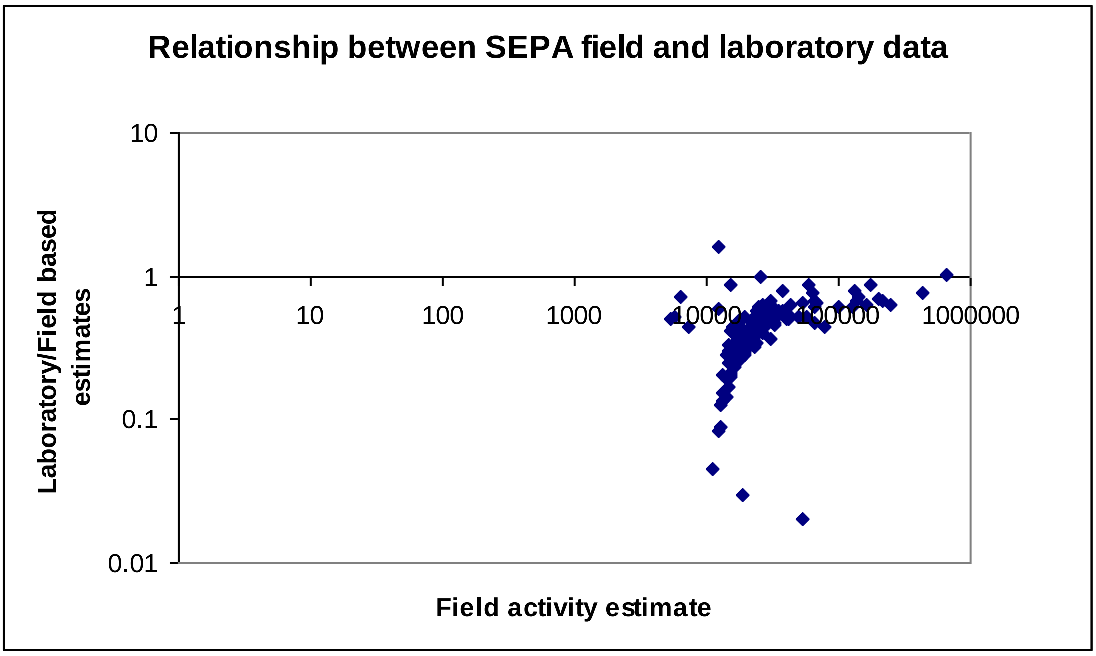


Figure 11: Relationship between field estimated and laboratory derived activity data.

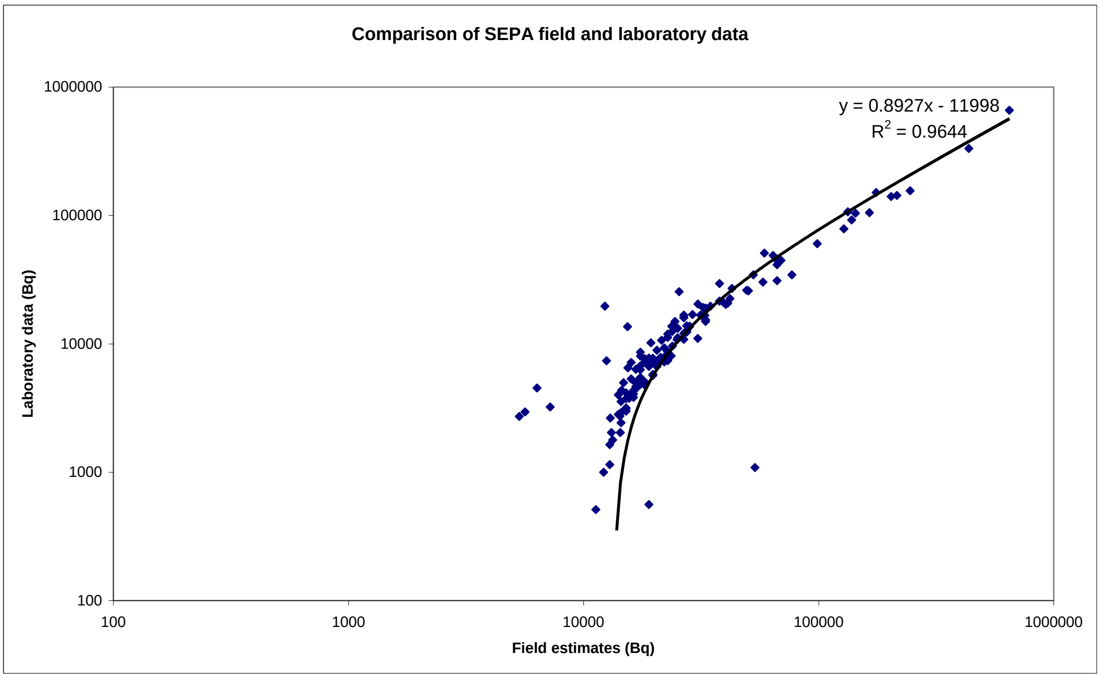


Figure 12: Direct activity comparison between field and laboratory activity estimation.

A similar comparison was undertaken by the Defence Science and Technology Laboratory (DSTL) which compared the field estimates of activity compared to its laboratory analysis. This is shown in Figure 13[8]

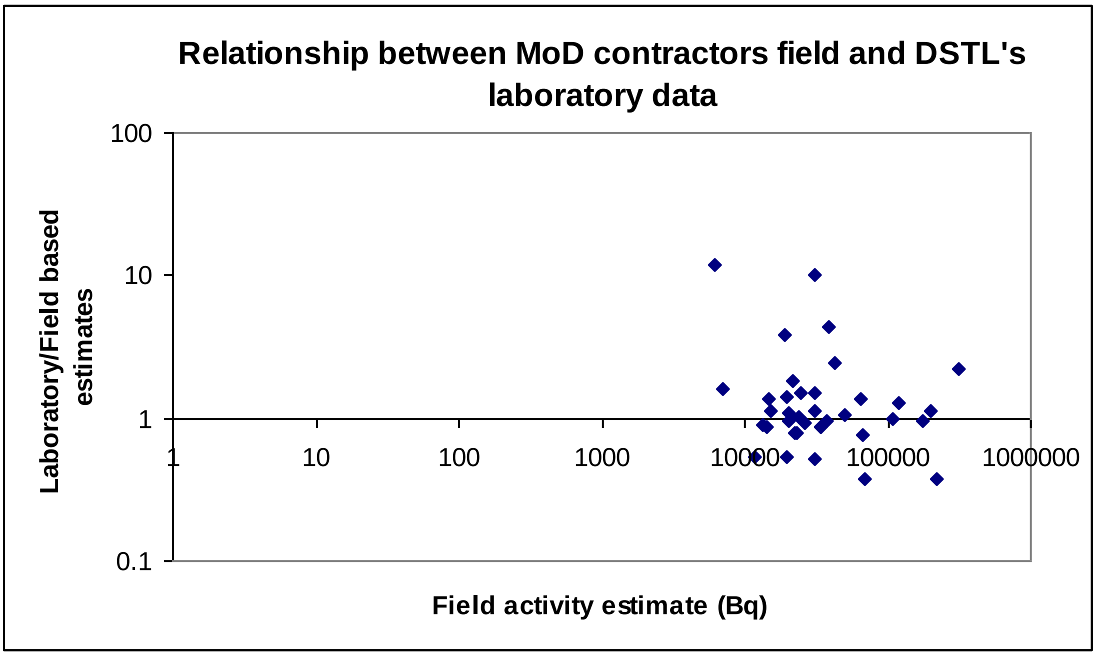


Figure 13: Relationship between field estimated and laboratory derived activity data

This comparison showed that the MoD contractor's field data tends to underestimate the true activity data, especially for the higher activity sources. Using a regression equation of the line gives an R^2 value of less than 0.6 representing a poor relationship between these two datasets.

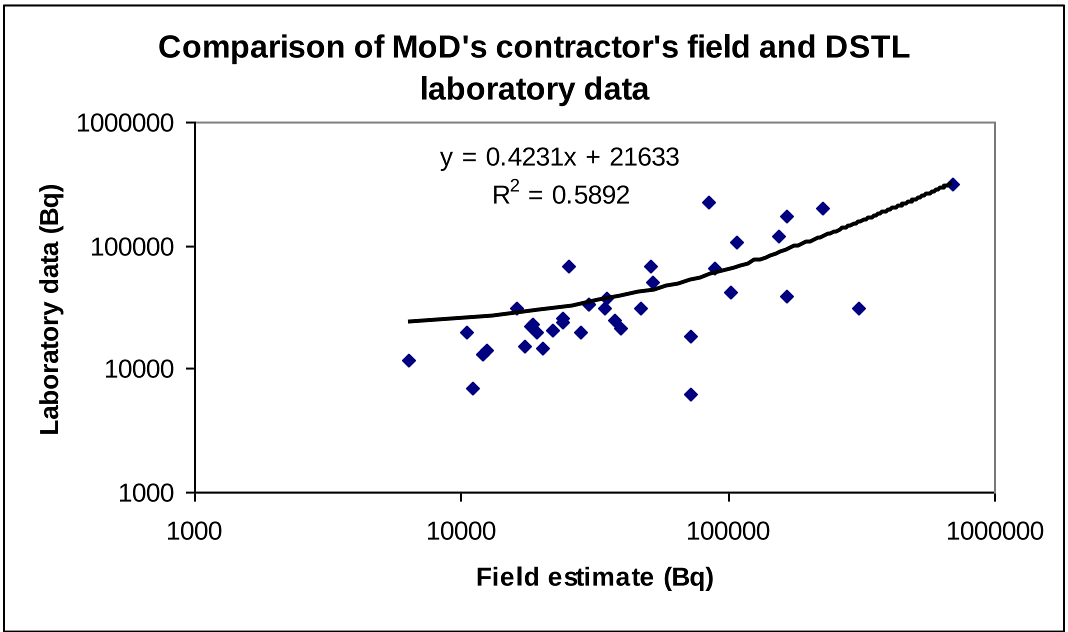


Figure 14: Direct activity comparison between field and laboratory activity estimation

[8] Figure developed using data from DSTL

On average the dataset suggests that the MoDs contractor’s field measurement overestimates the activity of low activity sources up to around 30kBq, while underestimating higher activity sources. As a result, for the dataset overall the total laboratory activity was around 2.9 MBq whilst the estimated field activity was 2 MBq. Thus, the potential for underestimation of the activity of the sources needs to be considered for higher activity sources when assessing the potential hazards and risks when using the MoD contractor’s dataset. The SEPA estimates tend to slightly overestimate activity.

In practice this could mean that the numbers of sources which had activities around 100 kBq or greater has been underestimated.

2.2. Dalgety Bay Receptors

2.2.1. Introduction

Before SEPA can establish the existence of a Significant Pollutant Linkage with respect to land, it must identify a Receptor with respect to that land. The Statutory Guidance provides that, for the purposes of the Radioactive Contaminated Land (Scotland) Regulations 2007, a Receptor is "(a) a human being which is being, or could be, harmed by a Radioactive Contaminant; or (b) a water environment which is being, or could be, polluted by a Radioactive Contaminant."

As indicated above, since SEPA has not found any elevated radium contamination in the Water Environment at the Site to date, this risk assessment does not consider whether the Site, or any part of it, is Radioactive Contaminated Land on the basis that Significant Pollution of the Water Environment is being caused or that there is a Significant Possibility of such Pollution being caused.

In order to assess the people who may be receptors, as well as the pathways by which they may become exposed to radioactivity in the environment, SEPA has undertaken a habits survey. This habits survey identifies the numbers of people using an area and their likely exposure pathways, thereby informing the risk assessment process.

2.2.2. Foreshore Areas

The habits survey report showed that the foreshore area at Dalgety Bay as a whole is used for many purposes including walking, bird watching, boat launching, and children playing (Heaton 1996, CEFAS 2013). Some activities are exclusive to specific areas of the foreshore e.g. sailing activities are limited largely to the slipway area and people walking dogs tend to currently use the foreshore in front of Ross Plantation rather than in front of the headland. Thus it is appropriate to consider the potential risks across the foreshore differently for different areas as a person walking a dog will have different potential exposures to a child digging, a sailor launching a boat or a horse rider. For this purpose the foreshore area has been divided into eight discrete areas as shown in Figure 15 according to the potential for different uses of those areas. The terrestrial aspects of the survey are not considered further in this report as the pathways are not currently considered viable.

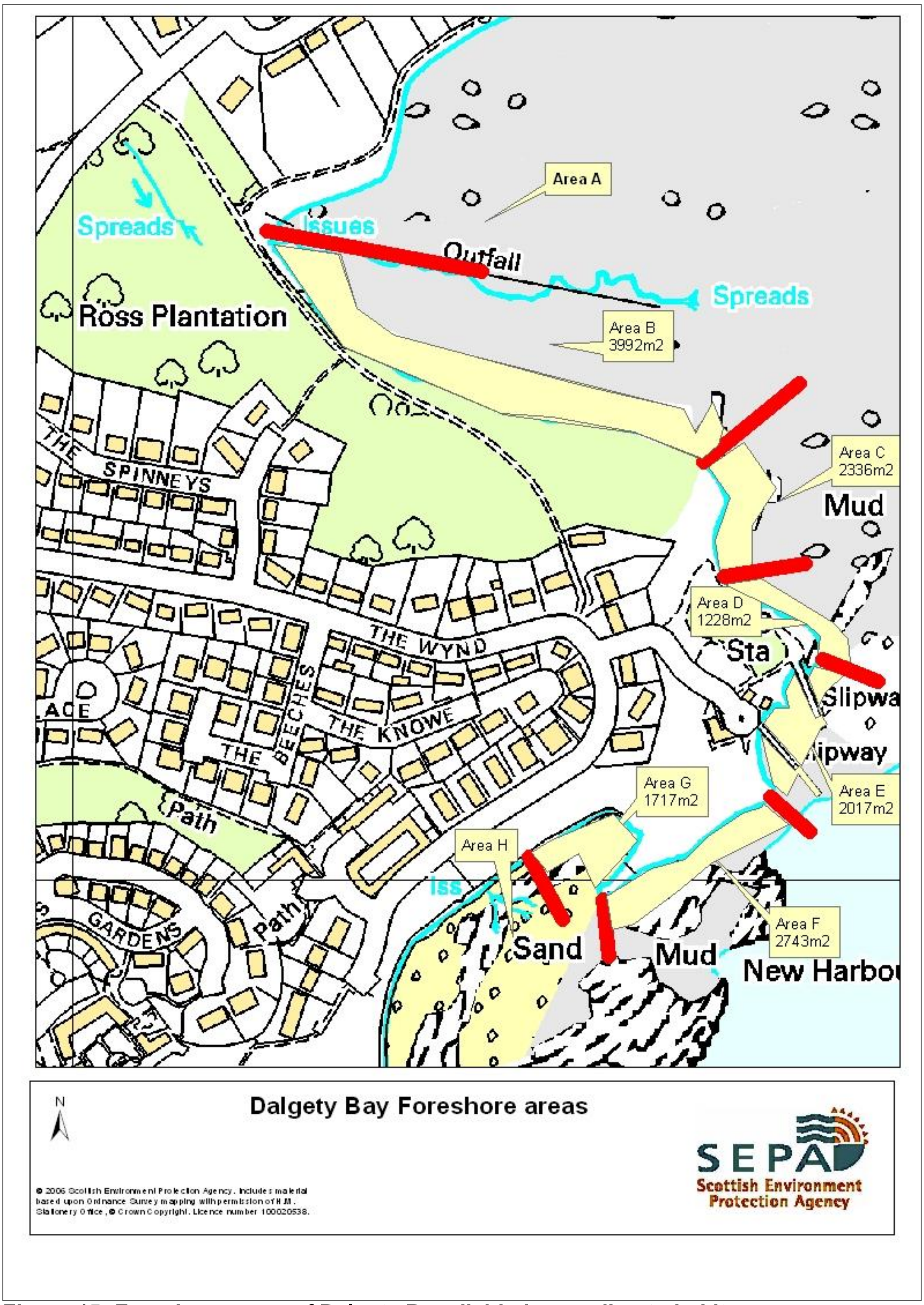


Figure 15: Foreshore areas of Dalgety Bay divided according to habits.

For each of the areas the physical sizes are (noting that Areas A and H are unlimited, not currently routinely monitored and assuming that the areas continue seaward for up to 10-15 metres) detailed in Table 2.

B[9] Ross Plantation	3992m^2
C Demarcated Area	2336m^2
D Boat Park	1228m^2
E Slipways	2017m^2
F Headland	2743m^2
G New Harbour	1717m^2 (currently not routinely monitored)
Total	14033m^2

Table 2: Areas of Dalgety Bay

The current monitoring programme undertaken by the MoD is significantly greater than these areas as it includes a greater area seaward. However, as the area is mud flats, few people use this area and relatively few sources are found in the mud flats. From the MoD physical findings 2013 report and AMEC 2013 it is speculated that sources that have been found in this area have originated further up the beach.

2.2.3. Habits Observed

Walking / Dog walking

The Habits Survey reported that there were many access points to the survey area and that dog walkers and walkers variously walked through part or all of the area. Many local walkers and dog walkers followed a regular route while others preferred to vary their route from day to day. Although most dog walkers and walkers reportedly stayed predominantly on the paths and grass areas above the shore, approximately 60% of the dog walkers and 30% of the walkers regularly visited one or more of the beaches as part of their walk.

The beach most frequently visited by dog walkers and walkers more generally was in the Ross Plantation area, but they tended to pass through this area quite quickly. Some dog walkers kept their dogs on leads but many let the dogs run free and exercised them by throwing balls, sticks and stones for the dogs to chase. A few encouraged their dogs to go into the sea by throwing objects into the water. It was noted that small quantities of sand and sediment often adhered to the balls and sticks when the dogs retrieved them to the dog walkers. Several dog walkers used plastic sticks with a moulded grip in the end to throw the balls with, and although the primary reason for their use was to save the dog walker bending down to pick up the ball, their use also resulted in the dog walker handling the ball less. Dogs frequently had sediment on their paws and fur and were subsequently petted by the dog walkers. Occasionally small dogs were picked up and carried. It was noted that dogs had been digging in the sand on the beach at one location.

Other beach activities

Several families spent time on the small sand beach to the West of New Harbour, engaged in activities such as playing and building sandcastles or rock pooling in the rocks nearby. They reported that they also visited this beach in the summer time, when they took picnics and paddled or swam in the sea. A few families also played and paddled on the small sand beach at New Harbour and one family was identified that spent a small amount of time playing on the shore at the Slipways. Most of the shore in front of the Headland is large stones, which are difficult to walk on. However, one family was identified that spent a small amount of time climbing on the

[9] Areas not currently routinely monitored have not been included

rocks at the south-west end of the Headland zone. This was the only activity recorded taking place on the upper shore in this zone.

A few individuals that were walking, dog walking or playing picked up shells or stones from the beaches at Ross Plantation, the Slipways, New Harbour and the West End. Some people took the stones and shells home with them. One family identified that picked up broken crockery from the beaches at Ross Plantation and the Slipways but did not take it home. One person occasionally collected driftwood from the beaches at West End and New Harbour for use in their garden. No one was identified that was deliberately searching for old aircraft artefacts on the shore at the time of the survey, although it is known that this has occurred (pers. comm.. C. McPhail).

A few of the walkers were engaged in other activities while out on their walks, such as taking photographs. A small number of runners and joggers were recorded and they took similar routes through the survey area as the walkers. A few cyclists passed through all or part of the survey area and they stayed on the paths and grass areas above the shore. Horse riders were observed on the Fife Coastal Path but were not interviewed. Four bird watchers were interviewed. They mainly used the beach at Ross Plantation since it provided a good vantage point out across the mudflats of the bay, which attracted many birds. The bird watchers also spent time on the grass areas and paths above the shore at the Headland and in other zones.

Several people commented that the sand beach at West End could be very busy with families having days out on the beach in the summer, and that the Fife Coastal Path attracted more walkers in the summer months. Importantly, no sources have been found to the West of New Harbour to date, although it is accepted that the monitoring undertaken at this location is very limited.

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

The club keep a raft, which is used for lifting and inspecting moorings. The main boating activities relevant to the survey were launching boats, carrying out boat maintenance on or close to the shore, inspecting moorings and spending time on the water. Most boats were launched from the slipways in the Slipways zone (area E) but boats were also launched down the ramp and across the beach at New Harbour. Keelboats were launched from trailers using a tractor. Most keelboats that were being used were launched in the spring, kept moored offshore through the summer, and bought out of the water for the winter. During the summer they were reached by tenders that were kept ashore. Dinghies and RIBs were kept ashore and launched each time that they were used. Dinghies and tenders were generally launched from hand towed trolleys. On race days, other people sometimes helped sailors by returning the trolleys up the slipway for them after a boat had been launched. Most people that launched small craft from the slipways kept on the concrete surface as much as possible, but they also sometimes stood on the surrounding sediment, particularly at congested times. It was noted that small amounts of sand and stones could be deposited on the concrete slipways by the tide. Boats could be launched quite quickly, with the sailors only spending a couple of minutes in the intertidal area, but it could also take much longer, particularly if the launching area was congested. Individuals were observed standing in shallow water holding boats for several minutes while waiting for crew to dispatch trolleys or fetch items of gear etc.

Boat maintenance

Boat maintenance was identified taking place on the land close to the shore in the Boat Area zone, on the fringe of the upper shore near the main slipway and on the beach at New Harbour. Boat maintenance included work carried out on the club raft as well as on boats. Keelboats were kept moored offshore of the sailing club and most boat owners lifted their moorings once or twice a year to check the condition of the chains and shackles. Moorings were usually lifted using the club raft. Usually three or four boat owners would work together to help each other lift the moorings. One individual was identified who kept his boat moored closer inshore and he walked out at low spring tide across the mud and sand in the Slipways zone to inspect his moorings, rather than use the raft. The moorings for the club's marker buoys were also lifted and inspected periodically. The moorings could have sediments adhering to them when lifted. Most people said that they wore gloves when handling moorings.

Bait digging and shellfish collection

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

Other beach activities

It was reported that a group of people had a barbeque on the beach in the Ross Plantation/demarcated area zone during the summer and that an individual occasionally cleared seaweed from the shore at New Harbour, but details of these activities could not be obtained. It was also reported that children and teenagers frequently played in the woods and on the shore in the Ross Plantation zone during the summer.

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

Further observations

It was noted that sediment adhered to the footwear and clothing of people on the shore and to items picked up from the shore. Sediment also adhered to the fur of dogs. One lady who kept her dog's ball in her pocket when it was not being used reported that she frequently had sand in her pocket that had brushed off the ball. People were often observed leaving the shore with sediments still adhering to their footwear and to their dogs. It was reported that towels and other possessions laid on the beach at West End in the summertime picked up sand from the beach, and although most of this was generally shaken or brushed off when people left the beach, small amounts remained attached. Sediments removed from the beach in this way could be transferred to people's vehicles and homes. A few people deliberately collected stones and shells or wood to take to their homes and these could have small amounts of sediments adhering to them. It has previously been reported to SEPA and the Dalgety Bay Forum that people have removed objects especially artefacts from the beach, although some of these have proven to be inert, dials have been recovered from the beach which remain radioactive.

The consumption of foods by people on the shore could potentially lead to the inadvertent ingestion of sediments adhered to foodstuffs as Individuals were reported to consume picnics on the beach at West End in the summertime and a group of people had a barbeque on the beach in the Ross Plantation/Fenced Area zone during the summer. Infants and children were reported to spend time playing on sand at the beaches at West End and New Harbour, and conducting activities involving the handling of sediments such as building sandcastles and playing with handfuls of sand. This could potentially lead to direct contact with radioactive sources and irradiation from close proximity together with potential inadvertent ingestion of sediments by hand to mouth transfer.

Activities that have changed due to the current mitigation measures
Many walkers and dog walkers reported that they now kept to the paths above the shore and did not go onto any of the beaches, although they used to in the past. Others said that they now avoided the beaches in the Ross Plantation zone and the Slipways zone although they still used the beach in the West End zone. Few people reported that they had ever used the shore in the Boat Area zone or the Fenced Area zone but one individual was interviewed who had previously regularly walked all along the shore between the Slipways and the Ross Plantation, but no longer did so. Many people reported that they now did not let their children or dogs go onto the beaches. Several people said that they still used the shore but did not pick things up, or that they still picked things up to look at or play with, (for example shells and stones) but no longer took them home.

One person reported that they had previously collected small quantities of mussels for their own consumption from the shore in the Slipways zone and the Headland zone but that they had stopped doing this when the FEPA restriction was introduced.

A representative of the sailing club reported that the club had not hosted any regattas at Dalgety Bay for visiting sailors in 2012 although it had usually done so in the past. The club had installed sinks outside the clubhouse so that people could wash off any sediment before entering the clubhouse. The club has advised members, particularly children, to stay on the concrete slipways when launching and recovering boats. Previously, one of the activities in youth training had been a swim from an offshore barge to the shore. This had been stopped, although capsize drill was still practised in deeper water offshore. Although reportedly in a minority compared to the people who had adapted their behaviour, several people said that they were not concerned about the radioactivity and had not changed any of their activities. They continued to visit the shore, throw sticks and balls for their dogs, and pick up or take home items from the shore such as shells and stones.

Survey Limitations
The habits survey was conducted at Dalgety Bay in October 2012 and involved the interviewing of people using the beach area. As the survey was undertaken in the Autumn of 2012 it may have missed the higher occupancies over the summer months e.g. a scout troop that was known to have visited the beach once but for a duration of two days. However, to address this questionnaires and interviews were conducted which asked people about their habits over the summer months and events that were held during the year which drew people from outwith the survey area e.g. a sailing regatta.

The action by SEPA in erecting the fence and providing additional signage (together with the existing signage) has skewed the habits that would normally be present on the site, e.g. the Sailing regatta was cancelled in 2012. In an attempt to mitigate this, the habits survey asked people about areas they used in the area prior to the demarcation being installed in 2011. However, even addressing for this we are aware that the permanent signs present had already been widely known about and may have skewed the data, e.g. a concert was reportedly cancelled in 2009.

2.3. Pathways

In order for radioactive material to pose any risk to the public, there is a need for a pathway to exist between the source and the public (receptor). These pathways are the route by which members of the public can become exposed to the source and thereby harm can occur. Whilst a radioactive source will present a hazard, it cannot pose a risk to the public without the existence of a pathway.

This risk assessment considers the following potential Pathways; ingestion, inhalation, skin contact and external gamma doses.

2.3.1. Ingestion

The hazard posed from ingestion of a radioactive source is a product of the energy deposited (irradiation) of the gut wall as the source moves through the body and the amount of the source which is retained in the body. The amount of the source which is retained is generally related to the solubility of the source in the gut thus absorbing it into the blood stream. Typical solubility values (f_1) for ^{226}Ra and its daughters have been collated and reported in various ICRP documentation. The radium containing sources at Dalgety Bay have clearly been subject to burning or incineration and this affects their physicochemical form (Wilson et al. submitted). Therefore direct determination of their gut solubility has been undertaken in order for radiation doses to be correctly assessed.

2.3.2. Inhalation

The inhalation pathway is the mechanism whereby particulate matter can enter the respiratory tract. This can range from fine particulates in the air to dust sized fractions which are only airborne in windy conditions or mobilised by physical actions e.g. kicking or throwing of material. The capability of radioactive contamination to cause harm via the respiratory tract is dependent upon the physical size of the source and its aerodynamic equivalent as this will dictate the position in the tract where the material is deposited. Once deposited in any given location within the respiratory tract, the activity of the source will dictate the harm occurring at that location.

In general terms the further any radioactive source can move into the respiratory tract (deeper into the lung) the more potential harm it poses, i.e. a 1kBq source poses more hazard if deposited on the deep lung than if it were in the upper trachea. Thus, any assumptions made about any relationship between physical size and radiological activity would have a significant effect on the assessment made. However, for the sources recovered from the site there is no currently established relationship between physical size and radioactive content.

2.3.3. Skin contact

The effect of a radium source on the surface of the skin can either be through a long term increase in the possibility of a stochastic effect (e.g. a cancer) or a more immediate deterministic effect (e.g. a radiation burn). Charles et al (2008) discussed both the stochastic and deterministic effects of Dalgety Bay sources on the skin and concluded that a source on the skin of any given activity will produce a deterministic effect of concern far more quickly than a stochastic effect of concern.

2.3.4. External gamma dose rates

People using the area of Dalgety Bay shown in Figure 1 could potentially receive a dose from sources present on the foreshore by being in close proximity to the source rather than having any direct contact with it. However, the further a person is away from the source the lower the dose rate becomes. This is further reduced by the effects of shielding via burial in the foreshore, together with exposure times.

2.3.5. Preferential selection

Part 3 assesses the potential hazard that sources of a given activity pose to human health via the primary exposure pathways of ingestion, inhalation and skin contact. In using those data together with the data on habits, assessments can be made on the potential risks that people encounter when using the foreshore. This type of assessment typically assumes that one grain of sand is no more likely to be contacted than another, which is true if those sources behave like the surrounding media and there is nothing unique about them. However, some of the objects recovered from Dalgety Bay are likely to be visually attractive to foreshore users, such as luminised aircraft dials and levers which have been found on the foreshore. These items are likely to ‘stand out’ from the other items on the foreshore and also be attractive to members of the public, especially inquisitive children. As the population of such potentially visually attractive sources is unknown, as is the tendency of any individual to act or collect materials, it is therefore impossible to determine the potential chance of somebody sighting and collecting such an object on the foreshore in the future. It is also unknown whether a cache of such objects could be released onto the foreshore following a storm. In terms of the hazard such sources would pose, this is detailed in Part 3. Issues relating to pica, a rare condition where someone is compelled to ingest substances of limited nutritional value such as soil, have not been addressed specifically but would increase the possibility of ingestion.

Part 3. Hazard

3.1. Introduction

The radioactive sources present at Dalgety Bay pose a hazard[10] to human health, although this is often incorrectly expressed as a risk and it is important to differentiate between these two terms:

- Hazard is the potential for a source to do harm whereas;
- A risk is the reflection of both the hazard and the pathways for that hazard to be encountered[11].

All radioactive sources present at Dalgety Bay pose a hazard, however if they were to remain buried at depth where people could not encounter them they would not pose a realistic risk. Equally, if the radioactive sources had a short half-life such that they would decay quickly to an inert material, sources buried at depth would not pose a risk as the time taken for them to emerge may be greater the time taken for the source to become inert.

At Dalgety Bay the radioactive contamination is from the radionuclide radium-226 which has a half life[12] of 1600 years. Thus, future changes to the site such as coastal erosion (AMEC 2013) (over a time scale of up to 16,000 years, ten half lives) mean that hazards currently buried may become a realistic risk to foreshore users over time e.g. from future habits or the impacts of climate change within the context of current use as defined in Paragraph A.27 Statutory Guidance. The potential for encountering a source is detailed in Part 4.

Radium-226 decays into other daughter radionuclides that are also radioactive and pose a hazard to human health. Thus, in assessing the total hazard from a radium source, the effects of these daughter radionuclides need to be included. Figure 16 shows the radium-226 decay chain together with the associated radioactive emissions. In this context, the primary radionuclides for consideration for health effects are: Radium-226, Lead-214, Lead-210, Bismuth-214, Polonium-214 and Polonium-210, and for inhalation only Radon-222.

The consequence of an exposure is dependent on the nature of the exposure e.g. how long a source remains on the skin or under the fingernail, or how much of it is absorbed into the body if ingested. It is clear from SEPA 2006 and 2008 reports that sources recovered from Dalgety Bay are highly heterogeneous in nature, both in terms of physical properties (size, mass, solubility) and radioactive content, with no apparent direct relationship between these variables.

A number of studies have been undertaken on the potential hazard that Dalgety Bay sources present (Heaton 1996; Charles 2008, HPA 2012, SEPA 2006, 2008, 2011, 2012). These reports focus on the three potential mechanisms whereby a hazard could become realised at Dalgety Bay, namely inadvertent[13] ingestion, skin contact and inhalation.

[10] Following the principle of linear no threshold effect
[11] It is not always appropriate to express risk as a multiple of hazard and probability
[12] The time required for half the nuclei in a sample of a specific isotopic species to undergo radioactive decay
[13] The possibility of preferential selection of artefacts e.g. picking up a dial is not considered within this type of mechanism, as it is impractical to provide any meaningful assessment.

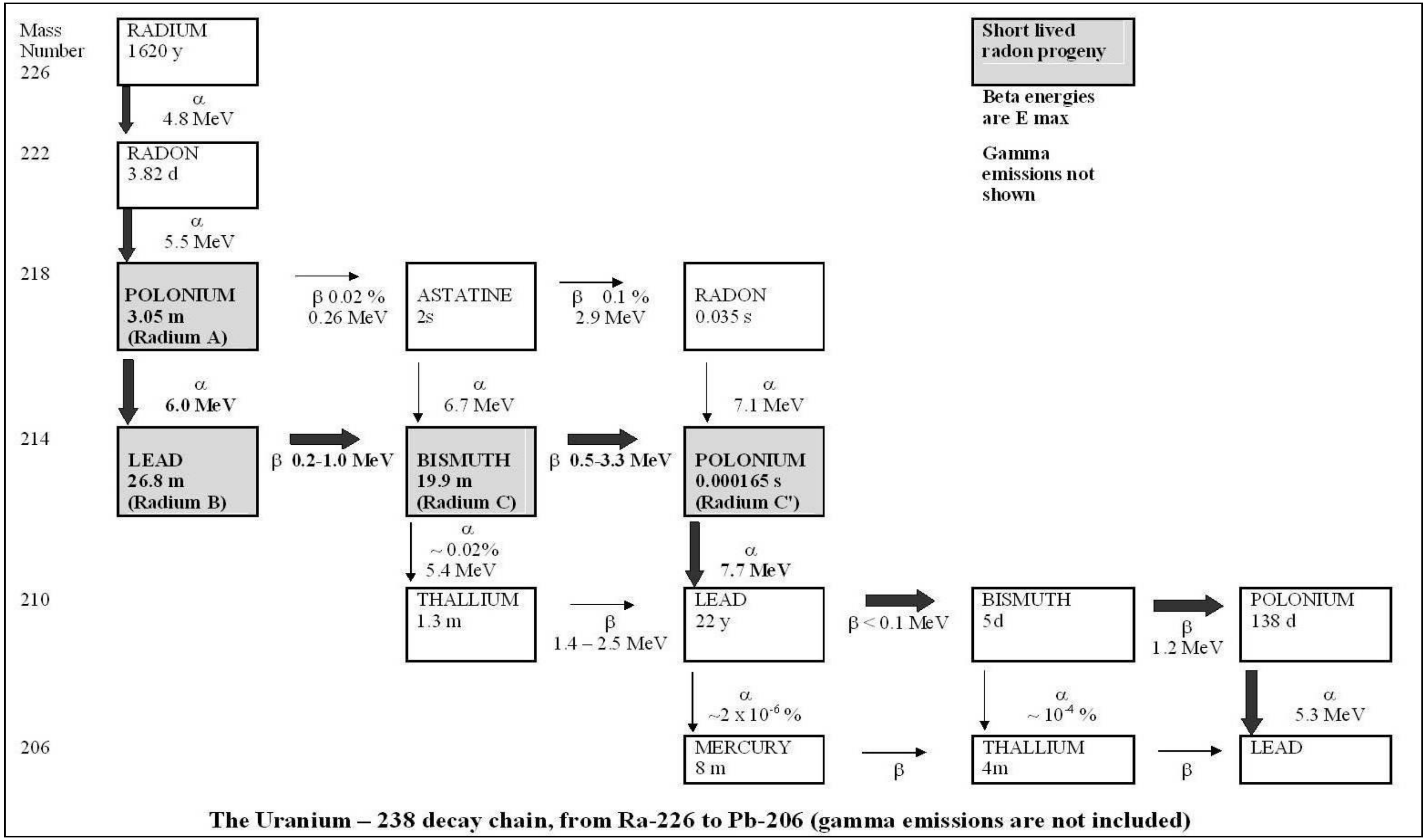


Figure 16: The Radium decay series from Charles 2008

3.2. Radium activity concentrations

One gram of radium has an activity of 37 GBq. Thus the amount of radium present in the 76 MBq source is around 2 mg, which in its pure elemental form has a density of 5.5 g/cm^3 and would have a volume of less than 1 mm^3. Such a source would be easily ingestible and if such an encounter occurred would in all likelihood result in significant health effects which might be terminal. However, in reality the source had a physical size greater than this, but as it was highly friable it could have physically broken down, as it is considered the source was raw paint some of the sources could have been highly active.

If the radium detected at Dalgety Bay had been mixed to form the paint, 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. This would correspond to 8 MBq per gram which, if applied with a solution of zinc sulphide (ZnS) which had a specific density of 4, would correspond to a volume of around 250mm^3 per gram. This would mean that in its applied form 3 mm^3 would contain around 100 kBq Ra-226. This value is similar to that derived by the Health Protection Agency as the upper maxima activity for ingestion. However, using this value would assume that all of the sources have radium paint as applied, that the maximum ingestible size is 1mm^3, that the radium was mixed according to the standard, and that the volume reduction process of burning has not reduced the volume of the paint. Assuming such a value was valid would mean that a source of a few mm in diameter, having the potential for ingestion due to size, would have an activity of greater than 1 MBq. The Radioactive Substances Advisory Committee of 1958 reported typical radioactive concentration for aircraft luminising paints was between 2.7 and 3.7 MBq/g wet, which is consistent with the above.

Due to its physical size, the 76 MBq source recovered from Dalgety Bay is unlikely to be a painted source and more likely to be raw paint. Thus, caution is needed when assessing potential maxima radium activities per unit volume.

In order to minimise possible ingestion of very high activity sources the area where that source (and several others) were recovered is currently demarcated and the public are advised not to access that area.

3.3. Effective dose levels

Radiological hazards have been defined by the International Commission on Radiological Protection (ICRP) according to the potential to cause harm. Harm is expressed in terms of the Sievert (Sv), where a radiation dose of 1 Sv gives rise to a 5.5% chance of eventually developing cancer (International Bureau of Weights and Measures, 2006). The ICRP has provided dose co-efficients which allow doses from all radionuclides to be expressed in these units (ICRP 72).

For planned exposure situations the limit for a practice (such as operation of a nuclear reactor) is for no member of the public to receive a dose greater than 1 mSv per year (effective dose), which equates to around 1 in 20,000 chance of developing a potentially fatal cancer. If such an exposure were to occur on an annual basis the lifetime dose would be around 75 mSv (assuming a life expectancy of 75 years). However, in planning for such exposures caution is added to derive dose constraints with the constraints of any single existing source being 0.3 mSv per year. Situations where a planned exposure would result in doses greater than 0.3 mSv per year would not be considered optimised. ICRP 76 states that "*at high doses and dose rates, the normal probability coefficient used in normal exposure situations may be* *unsuitable for the calculation of detriment. Publication 60 (ICRP 1991) points out that in the context of potential exposure, the conditional probability of deleterious effects, if in fact a dose is in fact incurred, may be higher than the nominal probability. The Commission uses a dose and dose rate effectiveness factor of 2, which means that at doses exceeding 0.2 Gy or dose rates exceeding about 0.1 Gy per hour, the nominal probability coefficients given in Publication 60 would have to be multiplied by 2 to take account of this factor".*

The long radioactive half-life of radium will mean that those sources found at Dalgety Bay will remain a hazard for thousands of years to come. It is therefore important to determine the magnitude of that hazard and whether the public could encounter these sources either at present or in the future.

Following the principles of ICRP, there are three levels of effective dose used to control radiological hazards.

<1 mSv	Acceptable level of protection in planned exposure situations
1-20 mSv	Individuals receive some direct benefit, however actions needed on pathways
20-100 mSv	Reference level set for the highest planned residual dose from a radiological emergency. (This includes acute exposures) ICRP 103.

The 100 mSv level is that in paragraph A.32 of the Statutory Guidance when considering whether SEPA should regard the possibility of Significant Harm is significant irrespective of the probability of radiation does being received.

3.4. Ingestion

The first assessment of the potential doses from ingestion of Dalgety Bay sources was undertaken by Heaton in 1998 who reported that two samples which had masses of around 1g each and activities of 27 and 37 kBq had Ra-226 solubilities of 12 % and 5.8 % (to 2 s.f.) in hydrochloric acid (similar in pH to that of the stomach). More recent work using a more representative gut solution, developed by the Health Protection Agency for assessment of the consequences in ingestion of a Dounreay fuel fragments (Harrison et al., 2005), has suggested a solubility range of practically zero to almost 36 %. However, it is clear in both studies, the bulk of the solubility is associated with the initial gut solution phase in hydrochloric acid and thus the recent data are consistent with the findings by Heaton which used a HCL solution. In total, 82 sources which were still available from the 2008, 2010 and 2011 programmes were subjected to solubility testing; higher activity sources were avoided to protect staff. Sixty of these have been subjected to solubility testing under both simulated stomach and lower intestine conditions, whilst a further 22 have only been subjected to simulated stomach conditions[14]. Figure 17 shows that in some cases the activity released in the lower intestine phase can be similar to that in the initial stomach conditions.

[14] It is accepted that the data for the 22 samples subjected to stomach leachate only may be an underestimate of the true activity.

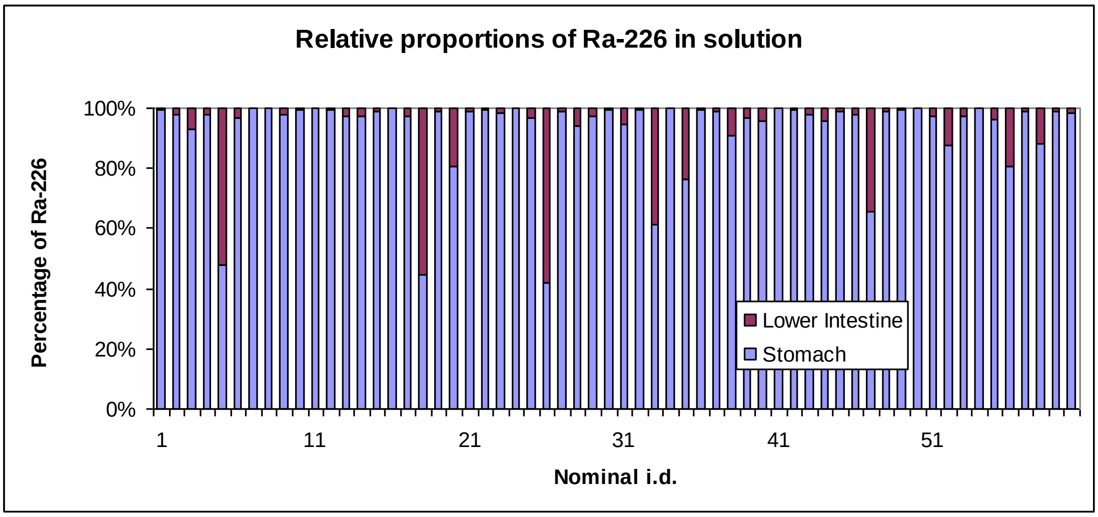


Figure 17: Relative proportions of the Ra-226 solubility in both the stomach and lower intestine.

Figure 18 shows that these sources tended to have an overall lower solubility and for those where solubility was high this was dominated by an initial high solubility in the stomach digestion phase.

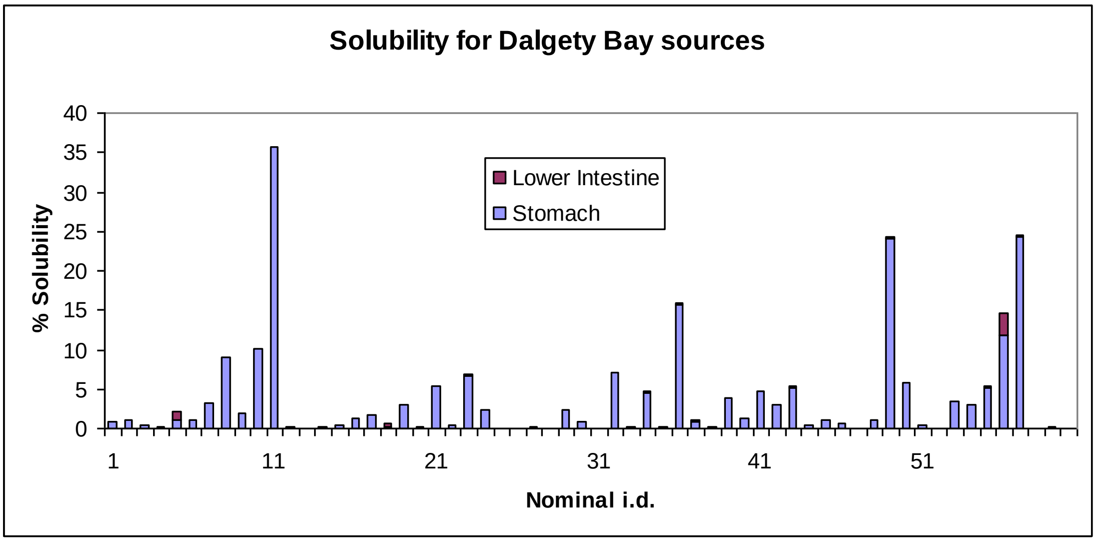


Figure 18: Total Solubility for Dalgety Bay sources subjected to both stomach and lower intestine solubility testing.

The data for the 82 samples shows that data are not normally distributed, and that there is no relationship between activity and solubility (Figure 19).

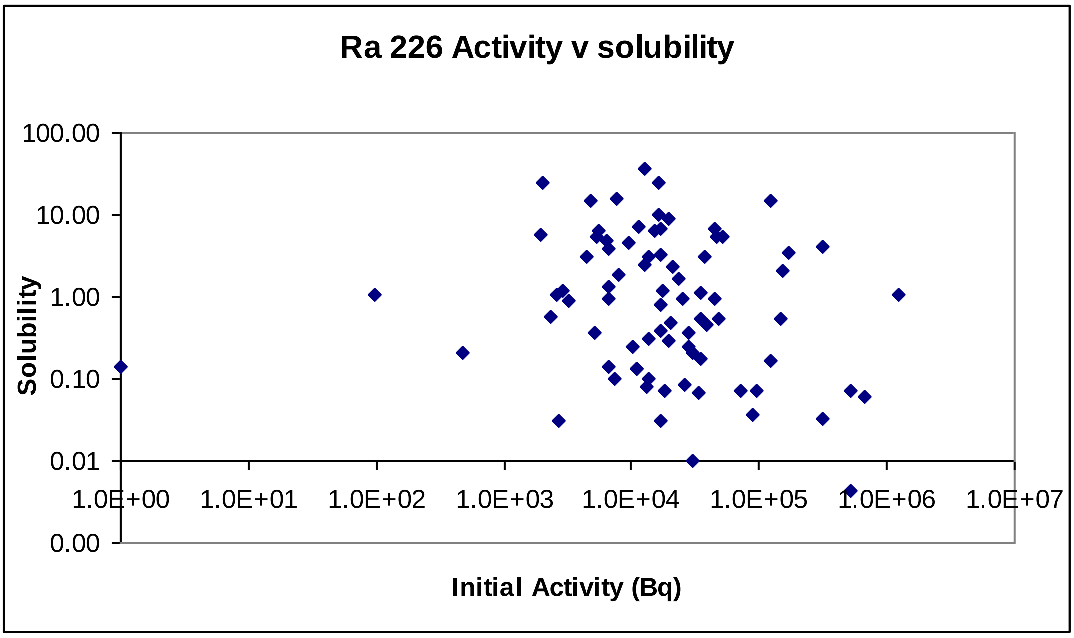


Figure 19: Relationship between initial radium 226 activity and the fraction of radium in the representative gut solution

As a result of the non-normal distribution of the solubilities a log transformation was taken (Figure 20). Following Gilbert (1987) this corrected estimate for mean and standard deviation gives values of 7.59% and 2.54 respectively[15]. This means that ninety five percent of the sources would have a solubility of less than 20.15%. If a cautionary approach were to be adopted then this value should be used in the risk assessment. The implications of using this value has been considered in the uncertainty section (Section 5). It is noted that in using this data for a prospective assessment it assumes that the residual population has a similar solubility range to those already recovered from the beach. In the event that changes in practise of the disposal of radium sources occurred over time e.g. burning with aviation fuel rather than wood, this may result in different chemical forms with differing solubilities.

[15] It is noted that if the Heaton data were included in this assessment, the mean solubility would be greater.

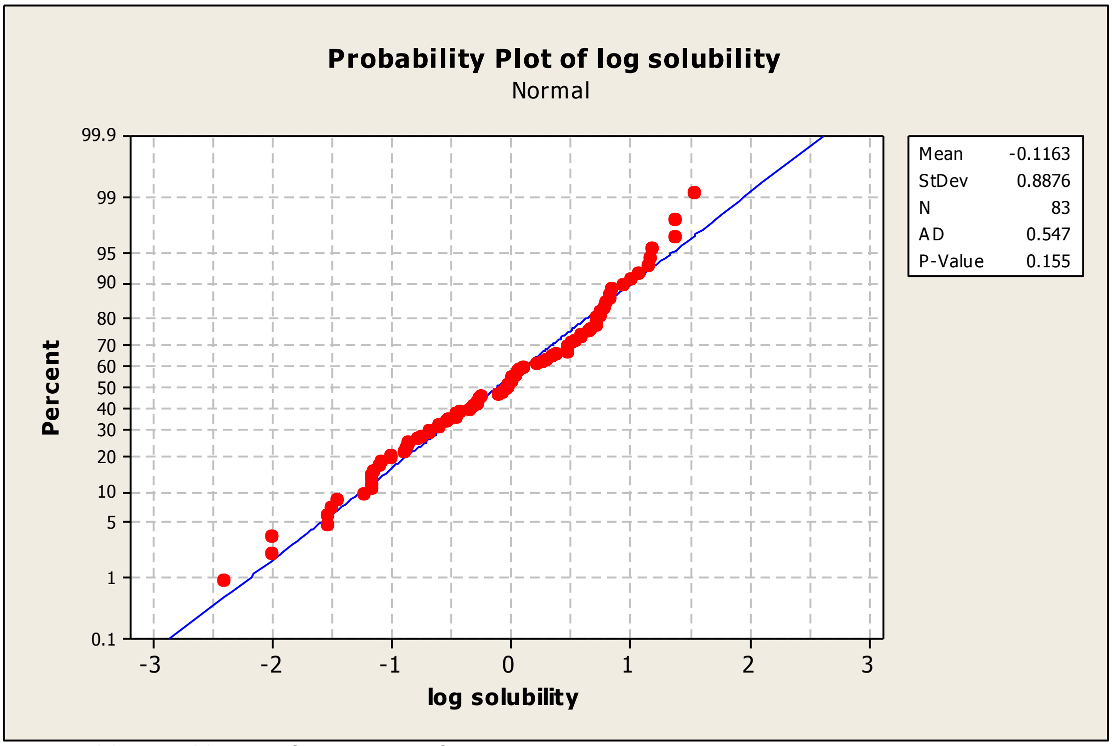


Figure 20: Log10 transformation of the solubility data

The ratio between the radionuclides which deliver the bulk of the dose is not constant in the leachate and can vary from 0.2 to 1.6, ^{226}Ra/^{210}Pb although overall the most recent data shows that the mean is approximately 1:1 (Ra:226/Pb210 0.96). Following a review of the approach to assess doses the HPA

> "*note the assumption made about Po-210 being in equilibrium with Pb-210 in the particles. In terms of the activity of the original particles, this is probably reasonable given the age of the Ra-226. Given the current information available, we agree that it is more realistic to use the in-vitro dissolution data for Pb-210 for calculating doses from Po-210 than the f_1 value for Po-210 given in ICRP72*".

The daughters of radium include a range of gamma, beta and alpha emitters, SEPA has adopted this approach for the calculation of doses, as did the HPA in its 2012 screening assessment which allows these two reports to be consistent. This was the approach recommended by MoD in 2008 which said "economies can be made by a limiting the analysis counting time to the minimum needed to confirm the activity of the radium-226 and at least one decay product" (Brown R, 2008)[16].

Sources which have activities of around 20 kBq of radium-226[17] and the highest solubility observed to date would deliver doses of around 100 mSv to a one year old child (age range 1 to 2 years) which are known to have occupied the beach (CEFAS, 2013). To deliver such a dose to an adult would require an activity of around 125 kBq. Table 3 details the doses from a range of particle activities and age groups for the highest solubility observed to date.

[16] This approach appears to have been endorsed again more recently by the MoD as being "a realistic and suitably cautious assessment of the potential risks" (Ron Brown, Principal Scientist, Defence Science & Technology Laboratory MoD email).
[17] This activity is the current monitoring criteria.

Table 4 shows that particles which have mean solubility would require activities of around 100 kBq of radium-226 to deliver doses in excess of 100 mSv to a one year old child (age range 1 to 2 years) and sources with activities of around 1000 Bq are unlikely to deliver doses greater than 5 mSv to 1-2 year old children. Table 5 shows the doses if the 95th percentile solubility values are used.

Table 3: Doses arising from ingestion of a source with maximum solubility (to 2 sf)

Solubility =	35.78 %	Dose mSv					
Original Activity (Bq)	Activity in sol. (Bq)	3 months	1 year	5 years	10 years	15 years	Adult
1,000	357.8	14	4.8	2.	1.9	1.8	0.78
10,000	3,578	140	48	26	19	18	7.8
100,000	35,780	1,400	480	260	190	180	78
1,000,000	357,800	14,000	4800	2600	1900	1800	780

Table 4: Doses arising from ingesting a particle of given activity with mean solubility of 7.59%

Solubility =	7.59 %	Dose mSv					
Original Activity (Bq)	Activity in sol. (Bq)	3 months	1 year	5 years	10 years	15 years	Adult
1,000	75.9	3	1	0.55	0.40	0.38	0.16
10,000	759	30	10	5.5	4.0	3.8	1.6
100,000	7,590	300	100	55	40	38	16
1,000,000	75,900	3000	1000	550	400	380	164

Table 5: Doses arising from a source with solubility at the 95% of the distribution.

Solubility =	20.15 %	Dose mSv					
Original Activity (Bq)	Activity in sol. (Bq)	3 months	1 year	5 years	10 years	15 years	Adult
1000	201	7.9	2.7	1.5	1.1	1.0	0.44
10000	2010	79	27	15	11	10	4.4
100000	20100	790	270	150	110	100	44
1000000	201000	7900	2700	1500	1100	1000	440

If a cautionary approach were to be adopted similar to that which the Dounreay Particles Advisory Group used for Dounreay Particles, the most limiting particles would be used for bounding an assessment. Such a reasonable level of caution would be to use the 95th percentile for the assessment of hazard which would mean that sources of greater than around 12.5 kBq would result in a dose of greater than 100 mSv to a 3 month old child and for an adult this would be around 250 kBq. This is discussed further in Part 5. If a more cautious assessment were to be used this could adopt the maximum solubility observed to date of 35% which would result in sources of less than 10 kBq delivering a dose of greater than 100 mSv to a 3 month old and activities of 20 kBq to a 1 year old child age group. Current monitoring criteria is specified to detect 20 kBq sources to a depth of 10 cm; as a result estimates of the population of sub 20 kBq sources are subject to large uncertainty. This assessment uses the mean solubility data for determining committed effective doses.

3.4.1. Other Dalgety Bay assessments

A number of reports on the potential hazard from ingestion of a Dalgety Bay source have been produced e.g. Heaton 1996 who stated that (based on limited data available at the time):

> *"the estimated doses…cannot be dismissed because in the worst case scenario upon which the calculations were based the doses are significant in respect of current legislation".*

Since that first assessment was performed, the database of available information on the number, physical size, solubility and activity of the sources has grown considerably and has been periodically reported in SEPA 2006, 2008, 2011 and 2012. Some of this information together with further unpublished information was used in a HPA 2012 report on the hazards posed. In that report the HPA assumed that the maximum activity which could be ingested was 100 kBq ^{226}Ra, with a physical size of 1 mm x 1 mm. Using this relationship, larger sources of dimensions of 3 mm would have an activity of around 1 MBq, which would be ingestible[18]. Even this may not be a cautious assessment of the maximum potential hazard. The HPA 2012 report stated that in the event of ingestion of the highest activity source recovered, the possibility of acute organ damage or bone marrow failure cannot be excluded. However, it is clear that the majority of recovered finds have activities much less than this value. The HPA report then concludes that doses from ingestion of a source could be around 330 mSv to a young child for a 100 kBq source, similar to values derived above. For an ingestible 1MBq source this would suggest a dose of a few Sv for a young child. However, as indicated above only a few such sources have been found to date and thus the current possibility of this occurring would, using present beach find data, be remote (Part 4), especially as, at present, the beach is under monthly surveillance. Potentially important is that the HPA assessment did not consider the possibility of children placing an item in the mouth, or higher specific activities which given luminising is likely to have occurred on site could have a significant effect.

In the event of a high activity source, e.g. 10 MBq which has a physical size of 6 by 4 cm, breaking into 4 pieces with equal activity either in the environment or following mouthing, each would have an activity of 2.5 MBq and thus be potentially ingestible and deliver very high doses should ingestion occur if the activity were homogenous. If such a source were not heterogeneous clearly some of the sources would have greater activity than others.

3.4.2. Classification of Harm (Ingestion)

The potential hazard from ingestion of a radioactive particle can be defined according to its radiological properties. As the size of the sources is not routinely assessed and that over time erosion will reduce the physical size, it has been assumed that they are of a size to be ingested (up to 20 mm). From field observations the majority of the sources recovered have physical sizes less than this value. Thus adopting such an assumption in the absence of detailed data is reasonable. If specific physical data on all sources recovered were to become available the report can be updated accordingly. In defining a radioactive source only by its radiological properties other

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[18] Sources have been recovered which have MBq activities and physical sizes up to 20 mm. Litovitz 2010 reported that batteries of up to 20 mm in size have been implicated in many of the complications from button battery ingestions by children less than 4 years of age. Litovitz Toby; Whitaker N, Clark L. (June 2010). "Preventing battery ingestions: an analysis of 8648 cases.". *Pediatrics* **125** (6): 1178–83.

variables such as the range of solubilities observed have been omitted and mean properties assumed. The effect of other variables such as solubility is discussed in the uncertainty section (Section 5).

Table 6. Classification of harm by ingestion

Activity (Bq 226Ra)	Hazard	Guidance
1,000,000 or greater	Doses in excess of 1Sv for 1 year old. Doses from high solubility sources could result in deterministic effects, potential of acute organ damage or bone marrow failure cannot be excluded.	Doses in excess of RCL statutory guidance levels
100,000 to 999,999	Sources pose a high hazard. For mean solubilities doses for one year old range from 100 to 1000 mSv (1 Sv).	Doses in excess of RCL statutory guidance levels at around 100,000 Bq.
10,000 to 99,999	Doses for a one year old range from 10 to 100 mSv	Doses in excess of RCL levels only for very young children (3 months) at around 35 kBq. For older children doses in excess of RCL statutory guidance levels at around 100,000 Bq
1,000 to 9,999	Sources unlikely to deliver doses greater than 10 mSv.	Doses lower than RCL statutory guidance levels
Less than 999	Negligible dose, only of concern if high solubility	Doses lower than RCL statutory guidance levels Only of any potential concern for very young children who are unlikely to use the beach (e.g. 3 month olds). However, consideration should be given to the potential number of encounters as multiple possibilities of encounter would significantly increase the overall dose.

3.5. Inhalation

The potential hazard posed from inhalation of a radium particle at Dalgety Bay was first considered by Heaton in 1998 who reported that:

> *"Only a very low proportion of fines (particles small enough to inhale) were found in each sediment sample, which suggests that there would be a low risk of members of the public inhaling fine material".*

This size fraction was stated as <45 µm of which represented <1% of the sample. In its 2006 and 2008 reports SEPA did not specifically assess the hazard from this pathway. However, in 2012 the Health Protection Agency reported that "for a particle containing 100 Bq of ^{226}Ra and a diameter of 100 µm the committed effective dose would be around 0.1 mSv". This assessment was based on a scaling of a 1mm particle containing 100 kBq of ^{226}Ra (the basis of this assumption). Such a dose would be a low hazard if encountered in isolation (Smith, 2010).

Figure 21 shows the physical size of some of those sources recovered from Dalgety Bay. It is notable that all are physically larger than 100 µm. However they all also contain several thousand becquerels of radium. It is conceivable that, if particle VI were to break into several pieces, many of these could have activities greater than 100 Bq each and be of a size which could be inhaled. The issue of heterogeneity of the radium across each of the samples also needs to be considered in physical breakdown.

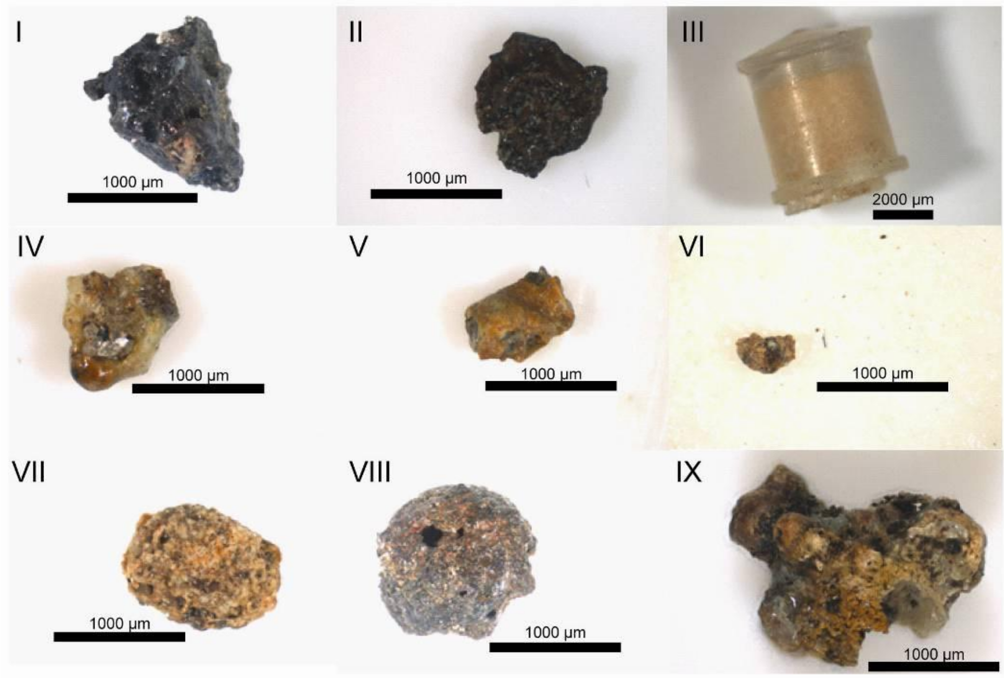


Figure 21: Images of some of the sources and sizes.

The level of ^{226}Ra activity of the sources shown in Figure 21 varies significantly between particles with the highest levels in particle III (150,550 Bq) more than an order of magnitude greater than in the next most active particle, VI (8,303 Bq). The activity order in the particles is III > VI > II > VIII >V >IX > I> IV > VII (907 Bq)

However, none of the monitoring undertaken to date has been capable of detecting if these particles exist due to detector capability and natural background. Thus there was an absence of information on whether such a population exists and if it does its physical characteristics. In order to address this SEPA commissioned a series of samples of surface sediment (over an area of around 0.5 m^2 to a depth of typically 2-3 cm) across the affected area and in control areas to the east and west of the site (as detailed in Section 2.4). This work did not report the presence of any individual sources with activities greater than 100 Bq ^{226}Ra. Thus, although it cannot be concluded that a population of low activity sources does not exist we can conclude at present that, if it does exist its population size is not in the order of hundreds of thousands as by chance alone some of these should have been collected in the sediment samples.

The current monitoring and removal programme means that sources emerging onto the upper areas of beach where physical erosion is likely to occur are unlikely to remain in the environment for longer than around a month which will limit the time for breakdown to occur.

If the current monitoring and recovery programme were to cease and a high activity source were to emerge onto the foreshore and allowed to physically break down this could generate large numbers of sources over time. For example, a 10 MBq source could break into five hundred 20 kBq sources, potentially eventually resulting in the generation of many tens or hundreds of thousands of physically small 100 Bq particles on the beach. The potential implications of such a population are discussed in Part 5.

For single exposures, the HPA assessment suggests sources which have activities of 100 kBq would generate doses of significance (greater than 100 mSv for adults) if they were capable of being inhaled. Assuming a direct relationship between activity and hazard, this would mean that sources of 20 kBq could generate doses of 20 mSv and 1 kBq doses of 1 mSv if they were inhalable (for adults).

It is noted that the area where exposures may occur is typically a wet environment and thus it is unlikely sources could become airborne through normal wind action. However, sources that have been detected at Dalgety Bay, which have had indicative activities greater than 1 kBq, have become airborne during recovery. Importantly there is a need to differentiate between sources which can become airborne and those which are capable of being inhaled, the latter requiring significantly smaller physical sizes than the former. The capability of sources becoming airborne may be a feature of the rapid free draining nature of the upper area of beach. It is also important to consider that sources removed from the area, e.g. on clothing, will dry and may then be more likely to become airborne.

3.5.1. Classification of Harm: Inhalation

Table 7: Hazard via inhalation [19] classification.

Activity (Bq ^{226}Ra)	Hazard	Guidance
1,000,000 or greater	Unlikely pose a significant hazard as all sources recovered to date in this category are too physically large to inhale.	Doses lower than RCL statutory guidance levels due to their current physical size. However, such sources should not be left to physically break

[19] This is for a single exposure, if there is a significant possibility of multiple exposures these values would need to be reconsidered on that basis.

		down to smaller sources where inhalation may be possible.
100,000 to 999,999	Unlikely pose a significant hazard as all sources recovered to date in this category are too physically large to inhale.	Doses lower than RCL statutory guidance levels due to their current physical size. However, such sources should not be left to physically break down to smaller sources where inhalation may be possible.
10,000 to 99,999	If physically small enough sources could pose a significant hazard.	Doses lower than RCL statutory guidance levels due to their current physical size. However, such sources should not be left to physically break down to smaller sources where inhalation may be possible. Doses could potentially be in excess of RCL statutory guidance levels if small enough to inhale – no evidence has found this is the case
1,000 to 9,999	Sources may to pose a significant hazard (1-100 mSv) if small enough to be inhaled	Doses lower than RCL statutory guidance levels due to their current physical size. However, such sources should not be left to physically break down to smaller sources where inhalation may be possible. Doses unlikely to be in excess of RCL statutory guidance levels even if small enough to inhale.
Less than 999	Doses could be around 1 mSv	Doses lower than RCL statutory guidance levels due to their current physical size. However, such sources should not be left to physically break

		down to smaller sources where inhalation may be possible. Consideration should be given to the potential number of encounters as multiple possibilities of encounter would significantly increase the dose deposited.

3.6. Skin contact

The 2008 report by Charles et al stated that typical dose rates for Dalgety Bay sources were around 1 Gray per hour per MBq observed in sources recovered from Dalgety Bay in 2008. It is important to note that in order for deterministic effects to occur to an area of the skin, the radioactive source needs to remain in contact with that area of the skin. Once the source moves the energy deposition at that location ceases. Thus, it is likely that deterministic effects on the skin will only occur where either the dose rate is sufficiently high to result in deterministic effects in short exposure times or the source is trapped close to the skin where it remains for extended periods of time e.g. under the fingernail.

Consideration of the effect from skin contact with a radium source needs to address the thickness of the skin layer between the source and the actively dividing cell layer (the target cells). In young children reference skins are thinner (45 µm) than adults (70 µm) (ICRP Reference Man) Work by Charles and Gow (2010) shows that below skin depths of ~ 70 µm the predicted depth dose curves show a sharp increase due to alpha particle dose. For depths between 10-30 µm the calculated alpha absorbed dose is more than 2 orders of magnitude greater than the beta absorbed dose. Although the HPA risk assessment in 2012 states that ICRP reference values were used, it is unclear whether the assessment was performed for adults only or whether the potential effects for thinner skins were considered. The effects of these thinner skins are discussed in Part 5.

In its 2012 scoping assessment the HPA used a value of 1 Gy/hr/MBq derived by Charles et al, however empirical measurements from the 76 MBq source suggest that the dose rate per MBq from this source may be greater than those previously assessed. This may be attributable to the theory that this source is radium paint in its raw form rather than radium paint as applied. Indeed in 2008 the MoD reported that "if a particle with a radium activity of 1 MBq were to come in contact with the skin … would give rise to an equivalent dose rate of about 2.7 Gy h^{-1}" (Brown R, 2008). Five sources have recently been recovered containing this level of activity has been found even though their dimensions suggest that they should not remain undetected or in contact with the skin for long periods. Work to determine the true dose rate from such high activity sources continues although it has been complicated as the dose rate is so high that few instruments are capable of reliably assessing the true dose rate for skin depths, and specific laboratory protection measures are needed to protect staff undertaking the work. Furthermore, the retirement of Professor Charles from Birmingham University means that direct comparisons between the Dalgety Bay sources recovered in 2008 is no longer possible. However, it is clear that sources with activities greater than 1 MBq can deliver doses which would realistically cause a skin burn in short periods of time and as such should be avoided. It is also clear that using the lower dose rate at least two sources have been recovered which would have delivered dose rates greater than 10 Grays per hour.

In 2005, Harrison et al. assessed the hazards from Dounreay particles which included an assessment of the effects of skin contact. The report stated, "*ICRP recommends dose limits for localised skin exposure to controlled sources and are not intended to apply to existing situations in which the only available protective action takes the form of intervention, as is the case with potential exposure to Dounreay particles. Nevertheless, the limits provide values with which to compare possible doses from these particles. The dose limit for localised skin exposure of workers of 0.5 Sv (1 cm^2,70 µm) can be regarded as conservative when applied to hot particle exposures since the threshold for effects is around 2 Sv (Grays). For the public,* *ICRP reduces the dose limit by a factor of ten to 50 mSv, although this reduction has no scientific basis and its use is questionable*".

Brown R (2008) also used this comparator of Dalgety Bay particle dose rates to the 50 mSv limit. He also stated (based on the information available at the time) that "*It can be seen that there is no likelihood of anyone exceeding the current UK statutory dose limit for the skin of 50 mSv for a member of the public*". Clearly this is now not the case and again reflects the risks of using historical information as a predictor of the future.

If a dose rate of 1 Gray per hour is assumed for Dalgety Bay sources with activities of up to 1 MBq ^{226}Ra then a 1 MBq source held stationary on the skin would deliver doses corresponding to the ICRP worker and public dose limits in less than 30 and 3 minutes, respectively.

However, to result in a deterministic effect sources would need to deliver 2 Grays to the skin. If it were assumed that following normal hygiene practices individuals washed their hands within an hour of leaving the beach, sources would need to have an activity greater than 2 MBq to result in any deterministic effect. If normal hygiene practices were not followed and a source remained under a fingernail for 8 hours, the activity required to reach the threshold where deterministic effects may be produced would be only 125 kBq. For the ED_{50} these exposure times rise by a factor of 5.

Table 8: Dose rate for Dalgety Bay sources

Activity[20]	Dose rate	Time to:			
^{226}Ra Bq	Gy h^{-1}	ICRP limit (public) 50mSv	ICRP limit (workers) 0.5Gy	Threshold 2 Gray	ED_{50} 10 Gray
100,000,000	≥100	≤2 seconds	≤18 seconds	≤ 72 seconds	≤ 6 minutes
10,000,000	≥10	≤18 seconds	≤3 minutes	≤12 minutes	≤1 hour
1,000,000	1	3 minutes	30 minutes	2 hours	10 hours
100,000	0.1	30 minutes	5 hours	20 hours	4 days
10,000	0.01	5 hours	2 days	8 days	6 weeks
1,000	0.001	2 days	3 weeks	2 months	1 year

3.6.1. Assessing skin dose rates

In 1989, the National Council on Radiation Protection and Measurements reported that the interpretation of dose from hot particles on the skin is not straightforward when averaging is used. The report noted that existing methods for assessing exposure to the skin are appropriate when large areas of skin greater than a few tens of square centimetres are irradiated. It noted that existing limits (NCRP 106) of 50 rem for occupational limit (which is consistent with the ICRP limit of 0.5 Sv / Gy for workers) is overly restrictive. In a later document (NCRP 116) advice for the public was a limit of 50 mSv (again consistent with ICRP values). This could mean that the averaging approach used for assessing doses to $1cm^2$ of skin is not appropriate when the peak energy deposition is over a much smaller area, as highly localised dose rates to small areas of skin are negated when this is integrated over $1cm^2$ (Figure 22).

[20] This assumes that all particles have a dose rate of 1 Gray per MBq per hour which for particles with greater activities may be an underestimate.

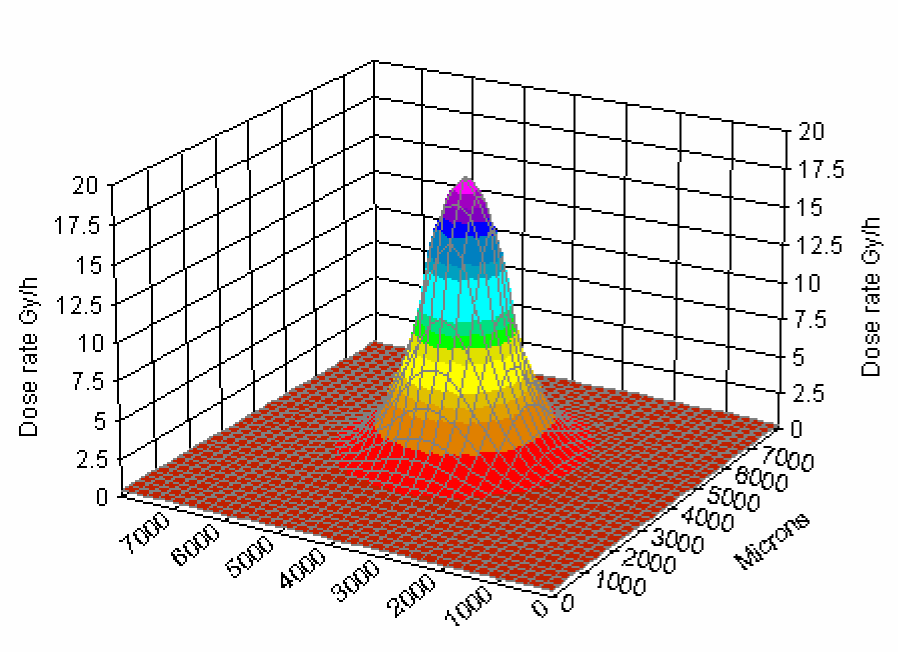


Figure 22: Dose deposition from a point source.

3.6.2. Classification of harm (skin contact)[21]

Table 9: Classification of harm from skin contact for adult skin thickness (70µm)

Activity (Bq ^{226}Ra)	Hazard	Guidance
1,000,000 or greater	Sources of greater than 2MBq are an unacceptable hazard as they could cause deterministic effects with short exposure times. Sources greater than 10MBq are in excess of the ED_{50} value for 1 hour exposures.	Sources greater than 10MBq are in excess of the relevant criteria in the RCL statutory guidance
100,000 to 999,999	Sources pose a high hazard which would if lodged under a finger nail result in deterministic effects over a period of 8 hours	Doses lower than RCL statutory guidance levels.
10,000 to 99,999	Unlikely to deliver doses which could cause deterministic effects on the skin for credible exposure times skin.	Doses lower than RCL statutory guidance levels.
1,000 to 9,999	Protracted exposure times required to cause any deterministic effect even for the most sensitive receptor.	Doses lower than RCL statutory guidance levels.
Less than 999	Negligible doses	Doses lower than RCL statutory guidance levels.

3.7. External gamma dose rates

Historically, (under the Ionising Radiations Regulations (IRR's)) controlled areas were locations where extra vigilance was needed due to the use of a radioactive source and these had a time averaged dose rate of 7.5 µSv per hour. If the 76 MBq activity source were to have been present on the surface of the foreshore this value would have been exceeded at distances of around 1 m from the source.

Assuming a direct relationship between activity and dose rate[22] sources which contain MBq activities could deliver external doses of > 7.5 microSv per hour if a person were within 0.5 m of the source. However, the effects of shielding from burial of the source would reduce this significantly. If the maximum residence time for a person on the beach is around 8 hours (tidal effects) and a person were to remain static for this period of time and within 0.5 m of a 70 MBq source on the surface of

[21] The assessment of hazard from skin contact has been undertaken assuming normal exposures which typically relate to spills over a few cm^2. It is noted that an EU funded work package on penetrating radiation suggested that measured dose rates from 'hot particles' are not comparable to uniform exposures (Work package 4, dose distribution around hot particles Dosimetery of weakly penetrating radiation. Contract FI4P-C96—0037. Phys.-Techn. Bundesanstalt, Department 6.5. Bundesallee. 38116 Braunschweig. Germany.

[22] It is plausible that for physically different sources the effect of self absorption will mean the doses are not linear

the beach they could receive a dose of 1 mSv. [23]However, for lower activity sources the dose reduces proportionately and for sources which are only of a few kBq direct contact is needed for any significant dose to be delivered.

			Dose measured 26/01/12 from Rad-Eye					
Distance (m)	**Gamma Calculated (µSv/hr)**	**uncertainty (2 σ)**	**H*10 µSv/hr (1st)**	**uncertainty (2 σ)**	**H'(0.07) µSv/hr (upright)**	**uncertainty (2 σ)**	**H'(0.07) µSv/hr (belly)**	**uncertainty (2 σ)**
1.00	**15.33**	3.53	17.58	1.72	26.48	2.10		
0.75	**27.20**	6.26	32.58	2.33	52.58	2.95		
0.50	**61.39**	14.12	69.58	3.39	119.58	4.44	160.76	5.15
0.30	**170.05**	39.11	196.58	5.69	339.58	7.48		
0.25	**245.56**	56.48	264.58	6.60	490.58	8.98	699.32	10.73
0.20	**383.67**	88.24	403.58	8.15	751.58	11.12	1,082.12	13.34
0.10	**1,533.00**	352.59	1,459.58	15.49	2,659.58	20.91	4,487.72	27.16
0.05	**6,139.00**	1,411.97	4,199.58	26.28	9,899.58	40.34	17,550.00	66.62
0.04	**9,583.00**	2,204.09	Not measured					
0.001	**1.53E+07**	3.53E+06	Not measured					
0.0001[24]	**1.53E+09**	3.53E+08	Not measured					

Table 10: Dose rate from sources with increasing distance

Thus, external irradiation to people in close proximity to a multi mega Becquerel source on or near the surface of the beach could be significant and should be avoided.

In order to provide some conformation that people walking across the beach did not currently receive an external dose from being in proximity to large numbers of sources, 263 gamma dose rates were taken across the affected area[25]. The maximum dose rate was 73 nGy/hr (mean 27 and standard deviation 9.7 nGy/hr). If a person remained at that location for an entire year they would receive a dose of 0.6 mGy. In comparison, the UK average background dose rate of 2.7 mSv with the natural contribution to this being around 2.2 mSv. However, it is noted that this work was undertaken when there is a monthly monitoring an recovery programme ongoing and may change following any further erosion of the beach environment or mobilisation of sources.

[23] It is noted that an individual (rough sleeper) has been observed motionless on the beach for some time. The individual is apparently a regular visitor during the summer months when he does gardening work in return for food/money. He is known to the Council workers, but would not have been picked up by the habits survey.
[24] Derived from the inverse square law and may overestimate the dose to 1cm^2. However the maximum dose rate will be the same.
[25] It is notable that this is during a sustained campaign of monthly monitoring and removal.

3.8. Precedent in Scotland and the UK

3.8.1. Dounreay, Caithness

The occurrence of high activity point sources on publicly accessible beaches in Scotland is not unique to Dalgety Bay. Around the beaches of Dounreay, Caithness fragments of irradiated nuclear fuel have been detected and removed since 1984, and a routine monitoring programme has been in place since 1999. In 2006 a group of independent experts – the Dounreay Particles Advisory Group (DPAG), assessed the hazard posed by these particles and devised a classification scheme based on the hazard posed and the potential exposures to the public. This scheme divided the sources into three categories: *Significant, Relevant* and *Minor (*Table 13*)*. The DPAG classification of the particles according to hazard (dose) is provided below

	All Ages	Adult male	One year old child
	Skin Contact Grays hr^{-1}	Ingestion (mSv)	Ingestion
Significant	> 3	>8	>30mSv
Relevant	0.3 – 3	0.1-8	0.5-30 mSv
Minor	<0.3	<0.1	<3 (<0.5mSv)

Table 13: Classification of dose per exposure pathways and age

DPAG considered that the *Significant* particles represented a realistic hazard to human health and recommended that a clean up exercise was undertaken to remove these from the marine environment even though at the time the probability of such an encounter was one in many millions and a *Significant* source had not been recovered on a publicly accessible beach. This has been undertaken over a number of years and has been reported by the Dounreay Particles Advisory Group and its successor Particles Recovery Advisory Group (Dounreay). Management arrangements for developing an appropriate strategy for these offshore particles were subjected to public consultation to ensure social factors could be addressed.

From earlier data in this report it is clear that many of the sources recovered from Dalgety Bay would be considered as *Significant* under the DPAG classification scheme. For the high activity sources these would be many times greater than the value considered as *Significant*.

3.8.2. Sellafield, Cumbria

At the nuclear licensed site at Sellafield, Cumbria, monitoring of beaches has been part of the routine marine environmental monitoring programme since 1983. In 2003, as part of the routine monitoring programme a radioactive particle was found and prompted a review of beach monitoring and a programme of large area monitoring on beaches was commissioned from St Bees to Drigg Point. As a logical progression to the requirement for large area beach monitoring, attention is now also being given to the offshore environment and understanding the potential for radioactive particles to be present on the seabed.

In 2011 the HPA produced a report which assessed the hazard and risks from radioactive particles and objects on beaches around Sellafield. The report concluded that if sources were found which could deliver skin doses greater than 300 mSv per hour there should be an urgent review of the health risks. The report stated that doses from some of the alpha sources (up to a few tens of milli sieverts) could give rise to potential significant health risks (Table 14). However the probability of that occurring was very small.

	Alpha Rich		Beta rich	
	Adult	One year old	Adult	One year old
Ingestion	20 mSv	55 mSv	6.5 mSv	15 mSv
Inhalation	Few mSv	Few mSv	6 mSv	6 mSv
Skin contact	0.008Gy hr^{-1}	0.008Gy hr^{-1}	0.1 [26]Gy hr^{-1}	0.1 Gy hr^{-1}

Table 14: Maximum potential doses from Sellafield particles

In comparing Table 4 to Tables 13 and 14, it is clear that for ingestion, using the mean solubility for Dalgety Bay particles, the mean ingestion doses are over an order of magnitude greater than for Sellafield particles which the HPA regard as significant. For skin contact the dose rates for the highest activity sources from Sellafield is at least 700 times less than for the equivalent Dalgety Bay source.

[26] Estimated dose rate from highest recovered beta particle (up to August 2009)

3.9. Overall Classification of the Harm posed by Dalgety Bay sources

Previous sections assessed the hazard posed by the radioactive sources present at Dalgety Bay. Clearly some of those sources have unacceptable potential health effects and all efforts should be made to ensure that the possibility of members of the public encountering such sources are minimised. However, for the bulk of the sources their potential effects are lesser and thus the actions required may be dependent upon the potential for the public to encounter such sources thus the sources require to be classified according to their ability to cause harm. Table 15 represents that classification and is based on the limiting exposure pathway.

Category	**Activity range (Ra-226) (Bq)**	**Potential Effects**
Unacceptable Hazards	>1,000,000 or greater	Doses in excess of RCL criteria **Ingestion**: doses of a few hundred mSv for mean solubility particles for all age groups. Ingestion doses higher than ICRP acute exposure target. Doses could give rise to organ damage or bone marrow failure. Doses in excess of HPA's definition of a significant hazard for Sellafield particle. Doses in excess of DPAG's definition of a significant hazard for Dounreay particle. **Skin**: plausible deterministic effects in very short exposure times **Inhalation**: significant doses if inhaled, no evidence to date to suggest such sources occur. **External**: High external dose rates from proximity to source
High Hazard	100,000 to 999,999	Doses in excess of RCL criteria **Ingestion**: doses of a hundred mSv for mean solubility particles especially to young children. Ingestion doses higher than ICRP acute exposure target. Doses in excess of HPA's definition of a significant hazard for Sellafield particle. Doses in excess of DPAG's definition of a significant hazard for Dounreay particle **Skin**: plausible deterministic effects if lodged on skin for a few hours. **Inhalation**: significant doses if inhaled, no evidence to date to suggest such sources occur. **External**: low external dose rates from proximity to source
Moderate Hazard	10,000 to 99,999	Doses likely in excess of RCL criteria for some pathways **Ingestion**: doses of a few hundred mSv for more soluble particles especially to young children. Doses to other children are only likely to be in excess of 100

		mSv if the activity is toward the higher end of the class or the solubility is greater than the mean value. Ingestion doses higher than ICRP acute exposure target. Doses in excess of HPA's definition of a significant hazard for Sellafield particle. Doses in excess of DPAG's definition of a significant hazard for Dounreay particle. **Skin**: unlikely to result in deterministic effects unless lodged on skin for prolonged exposure times **Inhalation**: significant doses if inhaled, no evidence to date to suggest such sources occur. **External**: low external dose rates from proximity to source
Low Hazard	1,000 to 9,999	Doses unlikely to be in excess of RCL criteria. **Ingestion**: unlikely to give rise to doses of more than a few tens of mSv even from the more soluble particles. Ingestion doses likely to be within ICRP acute exposure target. **Skin**: improbable to result in deterministic effects unless lodged on skin for prolonged exposure times (days) **Inhalation**: significant doses if inhaled, no evidence to date to suggest such sources occur. **Externa**l: negligible external dose rates from proximity to source.
Negligible Hazard	less than 999	Doses implausible to be in excess of RCL criteria **Ingestion**: unlikely to give rise to doses of more than a few mSv even from the more soluble particles. Ingestion doses likely to be well within ICRP acute exposure target. **Skin**: improbable to result in deterministic effects unless lodged on skin for prolonged exposure times (weeks) **Inhalation**: significant doses if inhaled, no evidence to date to suggest such sources occur. However, LoD of monitoring equipment means that if such a population we to exist it would be unlikely to have been identified. **External**: Trivial external dose rates from proximity to source.

Table 15: Classification of harm for Dalgety Bay sources

In 2008 Brown R stated a particle with a radium activity of 1 MBq would pose *"a realistic potential hazard to members of the public*" if it came in contact with the skin, and "*particles with activities above 100 kBq would be classified as "relevant under the DPAG classification…. DSTL agree with their (*DPAG*) view that such particles should be "monitored and removed*". This was prior to increased numbers of finds, but it does show that in 2008 the MoD had accepted that some of the particles bring found at Dalgety Bay should be removed presumably on the basis of the hazard such sources pose to human health.

Part 4. Risk Assessment

SEPA's approach to assessing the potential risks at Dalgety Bay will follow the approach developed and adopted for considering actions from the irradiated nuclear fuel fragments on public beaches around the Dounreay Nuclear Licensed Site, Caithness. This approach has developed through iteration and consultation with a DPAG, PRAG(D), public agencies and the public. However, although the mechanism for assessing the risks from the sources is consistent the actions resulting from that assessment may differ according to the impact of potential actions on the contamination and the local community.

Part 3 assessed the hazard posed by these sources that related to both the radioactive properties of the sources, (i.e. how much radioactivity they contain), and the exposure mechanism, (i.e. how a person will come into contact with them). In order to assess the potential risks to the public using the beach it is necessary to consider both the hazard and the possibility of that hazard being encountered. This is typically undertaken through a multiplication of the hazard posed and the potential rate of encounter. In ICRP 60, the commission stated that for both individual and collective exposures if the doses, should they occur, would not be in excess of the dose limits, it is adequate to use the product of the expected dose and its probability of occurrence.

ICRP 64 states that "*it is not appropriate to depend on the use of the product of the probability of an event and the number of attributable deaths should an event occur, i.e. the expectation value of the number of deaths, because this conceals the fact that the outcome will be either no consequence if the event does not occur or the full consequences if it does"*. Publication 64 continues that "*many individuals will in fact place a greater emphasis on the scale and character of the consequence than on the probability of the occurrence. At low probabilities of the potential event, an overall individual risk limit might imply doses when the event occurs that would be large enough to call for intervention"*.

Thus, for high hazard sources where there is a low probability of occurrence to an individual it is not appropriate only to multiple the hazard by the probability. (Dale et al 2008). Whilst for lower hazard consequences such an assessment may be appropriate, for this reason it is necessary to assess the potential risks for different populations of sources which are classified by hazard to allow such assessment to be performed.

In ICRP publication 103, the Commission recommended that the conceptual framework outlined in publication 64 remains valid. This framework is further expanded in ICRP publication 76 which states "*for potential exposures it is important to take account of both deterministic and stochastic effects*" Publication 76 notes that for high doses or dose rates the normal probability coefficient used in normal exposure situations may be unsuitable for calculation of detriment. Publication 60 (ICRP 1991) notes that in the context of potential exposure, the conditional probability of deleterious effects, if a dose is in fact incurred, may be higher than the normal probability. The Commission uses a dose and dose rate effectiveness factor of 2, which means that for doses exceeding about 0.2 Gy or dose rates exceeding about 0.1 Gy per hour the normal probability co-efficient given in Publication 60 would have to be multiplied by 2 to take account of this factor.

4.1. Introduction

The potential current and future risks from the radioactive sources present are difficult to quantify meaningfully as the numbers and activities can only be known following their removal, when they no longer remain a risk to the public. However, recent work suggests that the population levels seen in 2011 are being maintained and thus it is appropriate to assess the risks to the public according to current levels.

As the foreshore area is frequently used by the public for a variety of uses, SEPA commissioned a study into the current use of the site and the potential future usage of the site if current restrictions were not in place. The findings of this study are reported in Part 2. However it is clear that the bulk of the intertidal area is used for a diverse range of purposes and thus there is a need to assess the potential for exposures to occur across the entire foreshore area (Figure 15).

The terms used to assess what is a "likely" occurrence, is a subjective one and differs from individual to individual, together with individual acceptance of those outcomes. However, for the purposes of this report we have adopted the definitions of likelihood categorisation according to the Intergovernmental Panel on Climate Change (Table 16) and following discussions with the Dalgety Bay Particle Advisory Group.

Table 16: Likelihood scale (IPCC)

Terminology	**Likelihood of occurrence /outcome**
Virtually certain	>99% probability
Very Likely	>90 % probability
Likely	>66% probability
About as likely as not	33 to 66% probability
Unlikely	<33% probability
Very unlikely	<10% probability
Exceptionally unlikely	<1% probability

4.2. Relationship between Hazards and Risks

Assessments of the risk posed by radioactive sources needs to consider two principal factors: the probability of encounter and the hazard posed by a source in the event of such an encounter. Both factors can be assessed separately and then combined appropriately to provide an overall assessment of risk.

ICRP guidance applicable to situations where potential exposures could occur, such as radioactive particles, is specifically addressed in Publication 82. Although the advice is restricted to situations where areas are 'sparsely distributed' with radioactive particles, ICRP Publication 64 provides a conceptual framework for protection from potential exposure. Publication 64 details individual risk limitation and recommends:

> *"In order to establish requirements to constrain exposure to individuals from a particular source, the Commission recommends the use of constraints such that the sum of the risks from all relevant sources does not exceed the individual limit. For the treatment of potential exposure, the Commission recommends that limits of risk be the same order of magnitude as the health risk implied by the dose limits for normal exposures. However, the dose limits themselves are not applicable to potential exposure situations".*

Specific advice in Publication 82 relating to acceptable doses states that in exposure situations where the annual effective dose approaches 100 mSv, intervention will almost always be justified, which is consistent with the values used in the IAEA Basic Safety Standards. However, this value may not be appropriate in a potential exposure situation where the potential for encounter is probabilistic, this advice being consistent with the approach outlined in Publication 64. However, particles that could deliver a dose of around 100 mSv give a valuable indication of the need to consider a specific assessment for potential exposure situations.

On a national level, the UK Government and Devolved Administrations asked specific advice from the Health Protection Agency - Radiation Protection Division (HPA-RPD) in support of the Radioactive Contaminated Land Regulations. The response, including specific advice in relation to the assessment of potential exposures, stated that:

> *"if the dose that would be received from 'Hot Particles' or other heterogeneous contamination is less than or equal to 50 mSv, and the equivalent doses to the skin and lens of the eye are below 50mSv/y and 15mSv/y respectively, then it is appropriate to compare the product of the annual dose that could be received (Effective Dose) and the annual probability of the dose being received (Probability) with the dose criterion of 3 mSv/y. These dose levels are selected to essentially avoid the possibility of any deterministic effects.*
>
> *If 'Hot Particles' or heterogeneous contamination could result in doses above 50 mSv, or equivalent doses to the lens of the eye or to skin above 15mSv/y and 50mSv/y, respectively, then consideration needs to be given to the possibility of deterministic health effects in addition to the probability of the dose being received. At doses above around 100 mSv, consideration also needs to be given to the potential non-linearity of the dose-response relationship".*

The advice from HPA-RPD and ICRP suggests that at doses greater than 50 or 100 mSv specific assessments are needed. For such a dose level, ICRP suggest that an annual probability of encounter of 10^{-5} may be applicable. If this were to be combined with the hazard as 100 mSv represents around 1 in 200 chance of developing cancer and a 10^{-5} probability would give an overall 'risk' of 1 in 2 million of encountering and then developing a cancer.

For doses that could result in death, a probability of encounter of 1 in a million is the upper value for safety. This value is consistent with the Health and Safety Executive (HSE) advice of 'no danger' being equivalent to an annual fatal risk of less than 1 in a million (Health and Safety Executive, 2005, 1988), and broadly consistent with that from ICRP.

Determination of the potential risk posed by radioactive sources requires specific information on the hazard and probability of encounter. The environment agencies are required to make assessments of doses to 'reference groups' as realistic as possible (Article 45 of the Euratom Basic Safety Standards Directive). Such a requirement will need specific information on the hazard posed by the entire population of sources and the potential exposure pathways to realistically assess the potential risks posed by the radioactive sources.

Information on the potential hazard posed by sources can be combined into a single value through multiplication of hazard assessment and probability of encounter.

Combining these two values allows a hierarchy to be developed of probabilistic hazards. However, for hazards that pose a realistic chance of causing a stochastic or deterministic effect (i.e. around 100 mSv effective dose / 0.5 Gy hr^{-1} external dose) this product is not appropriate. Work by Lindell (2000) reports that a high-hazard multiplied by a low-probability event is not the same as the product of a low-hazard high-probability event, even if the numbers are numerically the same. This is reflected in the advice from HPA-RPD that at "*doses above 50 mSv, or equivalent doses to the lens of the eye or to skin above 15 mSv/y and 50 mSv/y, respectively, then consideration needs to be given to the possibility of deterministic health effects in addition to the probability of the dose being received".* This is also reflected in Paragraph A.32 of the Statutory Guidance to RCL which states:

"Where:

(a) in a single exposure event, the potential EFFECTIVE DOSE would be greater than 100 millisieverts; or
(b) contact with contamination would result in a potential absorbed dose to the skin greater than 10 Grays in an hour;

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

Thus, for values where the hazard becomes high, these two values should be kept separate and not combined. In such situations the resultant assessment of risk must consider site-specific issues, the relative benefits of interventions and the associated costs. In the context of public concern regarding any issue associated with exposure to radioactivity, some form of public information is generally warranted and in light of recent social trends toward litigation for any chance of personal risk, provision of information to individuals who may be exposed to such hazards may be needed.

Thus, for these reasons where the doses are of potential significance the potential for encounter and the resultant hazard are kept separate in this report.

4.3. Significant Pollutant Linkages

The beach monitoring finds can be divided according to the areas of the beach where they were found and this allows a specific assessment to be made for users of that area (receptors) and establish Significant Pollutant Linkages. Appendix 9.4 details all of the finds made in 2012 by both MoD's contractor and SEPA from January to September. However, as indicated earlier it is important to realise that the recent find rates are no indication of future finds and that a retrospective assessment of the risks cannot in this case provide a reasonable estimate of future risks.

From Part 3, the radioactive sources which are the most prevalent and therefore likely to pose a significant hazard from ingestion to the public are sources with activities in the range of 10 - 100 kBq (Table 6). The precise value of this number will be dependent upon the associated error of the field assessment as compared to the real activity together with the age of the receptor. The poor relationship between the monthly monitoring contractor's field data and laboratory data makes the derivation of any correction to give confidence in the data difficult. However, it is recognised that 10 kBq represents the lower value of those sources of consequence for human health. This means that sources with activities less than this value are unlikely to pose a significant risk (unless multiple exposures occur or sources become able to be inhaled). Importantly, the sources which are most likely to have been 'missed' by any of these surveys which are close to the surface will have been lower activity sources as they are the sources which are least detectable in the upper beach surface. However, it is noted that higher activity sources buried at depth will also have been ‘missed’.

Adopting this approach for the 2012 MoD contractor’s data only, the number of sources which need to be considered for a risk assessment falls to around 5-6 hundred per year rather than potentially a few thousand. Using those data from MoD in 2012, this would result in a population of sources of:

Area	>100kBq	Annualised	10 – 100kBq	Annualised
B[27] Ross Plantation	Nil	Nil	35	46.6
C Demarcated area	2	2.6	34	45.3
D Boat Park	Nil	Nil	19	25.3
E Slipways	6	8	93	124
F Headland	Nil	Nil	11	14.6
∑	9	11.6	192	256

Table 17: Numbers of higher activity sources in each area (using MoD data only)

For the SEPA data in 2012, 360 finds were made of which 118 had activities greater than 10 kBq (including a single 2 MBq source). Assuming these would all have been detected by the MoD contractor this makes annualised totals of:

	>100 kBq			10 -100 kBq		
Area	SEPA	MoD finds Annualised	Total	SEPA	MoD Finds Annualised	Total
B[28] Ross Plantation		Nil	Nil	13	46.6	59.6
C Demarcated area	3	2.6	5.6	10	45.3	55.3
D Boat Park	2	Nil	2	40	25.3	65.3
E Slipways	4	8	12	26	124	150
F Headland	1	Nil	1		14.6	14.6
G New Harbour				4		4
∑		11.6			256	

Table 18: Numbers of higher activity sources in each area (using MoD and SEPA data, data has been rounded).

These data then require to be normalised for the physical area to enable direct comparisons between the find rates of different areas to be made which is shown in Table 19 below:

[27] Areas not currently routinely monitored have not been included
[28] Areas not currently routinely monitored have not been included

Area	ha	Annualised >100kBq	Density sources per ha	Annualised 10 -100 kBq	Density sources per ha
B[29] Ross Plantation	0.3992			59.6	149
C Demarcated Area	0.2336	5.6	24	55.3	236
D Boat Park	0.1228	2	16	65.3	531
E Slipways	0.2017	12	59	150	743
F Headland	0.2743	1	4	14.6	53
G New Harbour	0.1717			4	23
∑	1.4033	20.6		348.8	

Table 19: Numbers of higher activity sources in each area per unit area (using MoD and SEPA data).

Table 19 shows that areas C (Demarcated Area), D (Boat Park) and E (Slipways) are the areas where the source density of potentially realistically hazardous (for human exposures) sources is greatest. This finding is consistent with physical investigations and observations made already.

The reason that these areas may be those of greatest density could be, as the intrusive work has confirmed, the presence of a layer of made ground material containing high activity sources at depth at the Demarcated Area (C). For the Boat Park area (D), as confirmed by the intrusive investigation, this is in front of an area where there is mass fill of ash and clinker. For the Slipway area (E), sources in front of the Headland could be transported to the Slipway area where the slipways are acting as groynes resulting in the deposition of material. This process is clearly evident for inert material on the western slipway where the beach height to the west is much greater than to the east (Figure 23).

Figure 23: Western slipway showing different accumulation of sediment to the west.

[29] Areas not currently routinely monitored have not been included

It is evident from the processes outlined in the Coastal Processes Report and the results of the intrusive investigation that for the Ross Plantation area (Area B), the lower find rates here are consistent with a plume of sources being moved by coastal processes into the bay and physically breaking down during that process to activities less than 10 kBq.

Based on mean solubility a 3-month old child would receive 100 mSv from ingestion of a 35 kBq source. Figure 21 shows an ingestible sized source which contained 150 kBq which had been recovered from the beach. Further such sources are reported in the SEPA find data on our website. For a 1-year old child this same dose is attributable to a source with an activity of 100 kBq, and for an adult this would be a source in the order of 700 kBq.

Equivalent sources have been found at Dalgety Bay, which are in greatest in number per area in Areas C (Demarcated Area), Area D (Boat Park) and E (Slipways). When sources are removed from these areas they are repopulated with similar activity sources most likely as a result of coastal processes.

For skin doses, based on Charles 2008, sources of 10 MBq would deliver 10 Gy/h to adult skin. Two such sources have been recovered recently on the beach in the currently Demarcated Area (Area C) with potentially further such sources recovered in the early 1990's. Therefore, it is reasonable to assume that further caches of such sources exist. This is further confirmed by the results of the physical intrusive work which revealed high activity sources present within the made ground which, if allowed to erode, would pose a significant hazard to the public.

SEPA considers that significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring on Area C, D and E at Dalgety Bay in line with the criteria set out in paragraph A.32 of the Statutory Guidance.

For Areas C, D and E current management arrangements including signage demarcation and monitoring and removal is reducing the risks to the public. However, the practicability, effectiveness and durability of these current measures are still to be assessed.

SEPA does not consider that it has sufficient information to determine whether a significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring at Areas B and F due to the uncertainties discussed at Part 5 of this Risk Assessment. SEPA will keep these areas under review and consider whether further inspections are required.

4.4. Probability of encounter

The potential for a member of the public to encounter a radioactive source has been undertaken using a tool developed by the Health Protection Agency for SEPA. This tool uses site specific occupancy data from the habits survey together with information on source populations[30] to assess potential rates of encounter[31]. Assessments have been made for the area as a whole and for the areas of the beach as defined in Figure 15. The probability of encounter for a single individual using the

[30] HPA 2005

[31] The HPA tool assumes that the sources and the substrate are sand sized and thus the true probability may be under or over estimated dependent on the nature of the substrate. Although limited the tool does allow comparisons to be drawn.

beach has been assessed, as has the possibility that anybody using the beach would encounter a source. Importantly this assessment does not consider preferential selection, which as discussed earlier may be the most likely pathway.

Consistent with the HPA approach used to assess the probability of encounter at Dounreay beaches, the assessment has assumed that all of the sources recovered remained on the beach. However, whilst the ongoing monitoring programme remains in place this will as a result be a cautious assessment as these sources are removed on a monthly basis. However, if the monitoring were to cease without remediation, these risks could be realised.

Appendix 9.4 reports the assessment of the probability of encounter for users of the foreshore. As would be expected, the most likely encounter with a source which could realistically cause harm is via skin contact. The model uses an assumption regarding skin areas exposed and breathing rates and thus the two factors which are variable is the time of occupancy and the number of sources per unit area. The model derives a probability that a source will be encountered on any individual one-hour visit and uses this factor to determine the total probability per year based on the number of hours occupancy. The model can be adapted, for example for changes in exposed skin area and breathing rates but without direct measurements of all of the people using the area such modifications would add only further uncertainty to the assessment. The model does provide an informative tool for assessing the potential probabilities of exposure from particles and also allows direct comparison between differing areas of the beach and with Dounreay where remedial action has been taken.

In the event that remedial action is undertaken at Dalgety Bay, a sensitivity analysis of the probability of encounter may be performed. However, it is largely intuitive that if the skin area were to double or halve the relative probability of contact would change by a similar factor.

The most likely area that a source, which was a realistic hazard to human health, would be encountered is the slipway area (Area E). This has been estimated at around 1 in around 2000 per year for an adult using the area for around 2 hours per month with the greatest chance of exposure being via skin contact. Importantly, this is an area that is extensively used by children and also an area where a dial and an instrument panel have been recovered, thus there is a potential that the true probability of encounter with a source is in all likelihood much greater than currently estimated. If these data are corrected for sources that were "missed" by the monitoring this would increase the probability of encounter proportionally: for example if 50% of the sources were missed, the probability of encounter would double. This assessment has used the observed habits which are skewed due to the management arrangements currently in place, it is accepted that it may be an underestimate.

As this area of the beach is used by many people the collective risks to users of the beach would be much greater (should the sources remain on the beach). Thus there is a need to assess the chance that any person using the beach would encounter a source of significant hazard. This approach is consistent with an approach adopted for a review of the Dounreay authorisation and more recently at Hinkley Point C (NDAWG). Using the current habits for Dalgety Bay this would give a total occupancy of 124 hours per year and result in a chance of around 1 in 600 that any of the adults using that area of foreshore would encounter a source of significant hazard which would most likely be by skin contact. For the entire population of people recorded in the habits survey (adults, children and infants) this rises to around 1 in 500.

For the foreshore at Ross Plantation, although the number of sources of high activity recovered is much lower, the greater usage of this area means that the probability of encounter for any adult user of this area is similar to that around the slipways.

If the entire foreshore area, and all users of that area, currently being used by the public is considered, the probability that any of those users in each age division will encounter a source presented in Table 20. Full details of the assessment are presented in Appendix 9.4 and in HPA 2005.

	Inadvertent Ingestion	Skin contact (wet and dry)	Overall – all pathways
Adults	3 million	494	334
Children	7 million	2280	1640
Infants	1.1 million	4185	2317

Table 20: Chance of contact with a higher activity source (1 in.…)

Overall the total chance of any users (of any age division) encountering a source which is of a significant hazard (> 10 kBq) is around 1 in 700,000 for inadvertent ingestion and 1 in 300 for direct skin contact and a total probability of around 1 in 200 per year across all users (Appendix 9.4). Importantly this assessment may not be a true representation of the probability of encounter as sources will have been missed which would increase the possibility, sources recovered from deeper depths reducing the possibility as habits may not be representative. Equally, some of the sources will be too physically large to be a realistic hazard for all pathways. However the assessment represents the most likely probabilities based on the information currently available. These issues are discussed further in the uncertainty section.

Thus, SEPA consider that for areas C, D and E there is an identified pathway which is credible and capable of exposing a receptor to radioactive contamination. For Areas C and D, the pathway is at present not being realised due to current management arrangements. However, the practicability, effectiveness and durability of these current measures are still to be assessed.

4.5. Risk

Risk is a relative term and the acceptability or otherwise of a risk is an individual decision. The risk is often expressed as a product of hazard and probability of that hazard being realised. The threshold for acceptability of Risk (TOR) for Nuclear Power Stations[32] has suggested that a value of 1 in a million in tolerating risk of death is broadly acceptable, although it must be stressed that this is the upper level and should be significantly reduced where practicable, below this value. The TOR document specifically states that "*Tolerability' does not mean 'acceptability'. It refers to a willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce still further if and as we can*". The 1 in a million value also only refers to death, other effects such as skin burns and stochastic effects are not specifically considered.

Thus Dalgety Bay sources present on the beach which could result in deterministic effects on the skin and known effects on health should be avoided. Therefore for users of the Dalgety Bay beach the individual risk of encountering a source that could

[32] The Tolerability of Risk from Nuclear Power Stations, Health and Safety Executive, 1992.

give rise to doses of greater than 100 mSv committed effective dose should be significantly lower than 1 in a million.

Current estimates are that the probability for such an encounter is below that value on an individual level but above that for all users of the beach.

Normal practice in radiation protection systems is to determine individual risk which for authorised releases is where the possibly of exposure is assumed to occur. The annual committed effective dose limit for authorised releases is 1 mSv, which represents an approximate 1 in 20,000 chance of death from that exposure.

Collective dose represents a manner of assessing the population effect of a release and can be informative in making management decisions on a range of possible options. Collective dose is a function of a large number of exposures to a population and results in a total collective dose measured in ManSv. This assessment does not correspond to a specific number of deaths from the exposure as the doses to individuals are low, but it can be informative where a range of options are available.

Risks from radioactive sources are not best assessed by either of these techniques as the individual exposures can be high whilst the probability of encounter can be relatively low. The Tolerability Of Risk for Nuclear Power Stations report distinguishes between these two types of risk: individual and societal risk, and suggests that "*it could be represented, for example, by the chance of a large accident causing a defined number of deaths or injuries. More broadly, societal risk can be represented as a 'detriment', viz the product of the total amount of damage caused by a major accident and the probability of this happening during some defined period of time".* In 2011 the House of Commons Select Committee for Science and Technology[33] suggested that the TOR does not quantify societal total 'detriment' of multiple deaths, disaster management, public shame and outrage, land rendered unproductive and so on. The issues of risk acceptance are further complicated by voluntary as opposed to imposed risks.

4.6. Individual Risks v Societal risks

Therefore, the actions need to be based both on the magnitude of the hazard and the potential for that to be realised by any user of the beach to address both individual and societal risks.

For individual risks the probability of any individual encountering a source which could deliver a dose of greater than 10 Gray per hour or 100 mSv committed effective dose (CED) is at around 1 in 20 million for high rate adult users of the slipway area.

For societal risk if this is defined as the probability that anybody using the beach would have the potential to encounter an unacceptable hazard it becomes a function of the hazard posed and the total occupancy of the beach per unit time. In approach this is similar to a collective dose approach but in this situation the detriment rather than being a small potential detriment over a large population all of the detriment is associated with a single individual. This type of approach is consistent with the recommendations from the House of Commons Select Committee for Science and Technology 12th December 2011, which considered risk perception.

[33] House of Commons Select Committee for Science and Technology 12th December 2011

For Dalgety Bay beach, site specific habits survey data estimates have been made of the total probability of anybody visiting the beach encountering a source of significance. These societal risk estimates are reported in Appendix 3 and the annual total probability of anybody ingesting a particle, which would have an unacceptable hazard is less than 1 in a million (1 in 750 thousand). For skin contact, a comparator of 1 in a million is not appropriate as deterministic effects on the skin are the relevant criteria, although it is worth noting that the actual chance is around 1 in a few hundred.

4.7. Risks to Future Users

The radioactive contamination present at Dalgety Bay is heterogeneous in nature and extent, which makes any prospective assessment of risks to future users of the beach area problematic. However, given a number of multi-MBq sources have been found recently within the beach and in all likelihood at least two further sources were found in 1990, it is reasonable to assume that further caches of such sources exist. This is further confirmed by the results of the physical intrusive work which revealed high activity sources present within the made ground which if allowed to erode would pose a significant hazard to the public. As the radionuclide is long lived, any contamination present will represent a hazard for many years to come and if physical breakdown of the sources occurs, the relative risks from such hazards may increase.

4.8. Further sources

Authors Note:

Some sections of this report and its implications cannot be completed until the MoD supplies its interpretation of the findings from the physical investigation.

The physical investigation work undertaken by MoD suggested that there are a number of areas in the current coastline at Dalgety Bay where radioactive sources are currently buried at depth. It is reasonable to assume that given these findings radioactive sources will continue to be present in the near surface environment of the beach at Dalgety Bay for the foreseeable future. A specific consideration of the likely number and activity of such occurrences can only be considered once the MoD report is available and will form an addendum to this report.

4.9. Change in land use

This assessment has assumed that the current land use, as defined by Paragraph A.27 of the RCL Statutory Guidance, is maintained, any change in the land use would be controlled under the Planning Regime, through which actions to minimise risks would be controlled. However, it also assumes that any contamination present below the slipways remains in-situ from routine maintenance. Equally, it assumes that current coastal defences are maintained.

Part 5. Uncertainty

Most assessments of the doses received by members of the public as a result of authorised discharges of radioactivity into the environment are carried out deterministically and the result presented as a single 'point' value (RIFE). No attempt is made to calculate the range of doses that could be received by members of the public in such assessments. In the guidance on principles for the assessment of prospective public doses issued by the environment agencies, the FSA and the then NRPB state that "Where the assessed dose to the critical group[34] exceeds 0.02 mSv/y the uncertainty and variability in the key assumptions for the dose assessment should be reviewed".

Uncertainty is a measure of the lack of knowledge of the system that is under investigation. Uncertainty in the assessment of Dalgety Bay sources can be grouped into two broad categories summarised below:

- Measurement uncertainty; the uncertainty in the field or laboratory measurements.
- Parameter value uncertainty; numbers of sources; occupancy of the area; future changes to site.

All assessments are subject to uncertainty; this assessment has been undertaken using typical (mean) values as taking maximum values for each of the parameters would result in a highly improbable event. However, there is a need to determine where uncertainties may lie and what the potential effect of those uncertainties on the robustness of the assessment may be.

5.1. Activity Measurement uncertainty

The activity of the radioactive sources can be determined in the field or in laboratory conditions. In-field estimates of activity can vary according to the location of the source to the measurement instrument. However, overall it would be normal to expect that some measurements would underestimate the activity whilst some would over estimate, which is what has been assumed in this report. However, Figures 11, 12, 13 and 14 show that the typical in field estimates are unreliable as a robust indicator of activity. As the majority of the most comprehensive monitoring undertaken is via the MoD's contactor, the total number of sources assigned to the low and high category may be an over and an underestimate respectively. This would mean that the potential encounter of such higher hazard sources is greater than that estimated.

Source activity may also be underreported due to the effects of self absorption. Typically, this would only be for the physically larger sources for the gamma emissions but will affect all sources for the beta and alpha component of the dose rate. Self absorption reduces the amount of radiation which leaves the source itself and thus will reduce the estimate of activity.

The effects of heterogeneous distribution will also affect estimates of source activity. For example, Table 10 reported that one source had a dose rate difference of around a factor 2 two between two orientations (upright and belly). Thus if the activity were estimated from one side only this could significantly under or over estimate the true activity.

[34] The term 'critical group' is to all practical purposes equivalent to the current ICRP nomenclature of representative individual

Laboratory estimates of activity are reported with an associated uncertainty of the measurement which is typically less than 5%. However, the activity determination can be affected by the physical properties of the source, i.e. if the radium were located on the source close to or far away from the detector. For estimates of activities in leachate solution this affect does not occur as the source is homogenous.

5.2. Numbers of sources

The assessed population of sources on the beach in 2012 was used using the MoD data on a pro rata basis and the SEPA data as a single value. However, there is no evidence to suggest that the current rate of finds is stable over a period of years and the findings from the physical investigation suggest that it will be influenced by erosive events and as such will be unpredictable. It is also necessary to account for potential missed sources and although the MoD contractor is currently operating to a detection criterion of 95 % for sources within the top 10 cm of beach (for activities greater than 20 kBq), there are areas of the beach where this is currently impossible to achieve due to the high background dose rates. Importantly, one of these areas is near the slipways, which has a high occupancy rate. Thus, there is a need to consider the impact of the population being significantly greater than the current estimates for this area.

5.3. Current Programme

Currently a monthly monitoring programme of the affected area of the beach is undertaken to a criterion specified by the DBPAG. This programme removes sources from the beach such that those sources can no longer pose a risk to the public. However, the current assessment assumes that these sources are present on the beach for a year which although consistent with other assessments is not the case. Equally, the effect of a reduction in the frequency of monitoring should be considered, for example if the monitoring were to cease would this result in the build up on sources in the near surface environment or would the sources become more physically dispersed and affect different populations?

The demarcation of part of the beach at Dalgety Bay also means that sources on this area should not be available to the public. However, recent visits to the beach by SEPA officers have indicated that people have begun to reuse this area.

5.4. Ongoing contamination

The physical investigation has revealed that further sources remain in made ground at Dalgety Bay, which over time may erode onto the beach area. The numbers and activities associated with these sources are difficult to quantify in any meaningful manner as the deposited material is so heterogeneous. However, as sources have continued to be removed from the area over the last 20 years it is reasonable to assume that this will continue for some time to come without intervention. As multi-mega Bq sources has been recovered in 1990 and further sources in 2011 and 2012 it should be assumed that further sources of this type could be found on the beach.

The numbers of sources are difficult to quantify in any meaningful manner. Although current find rates may offer an indication of future rates this does not necessarily hold as a single erosion event could release many hundreds of sources onto the beach. Alternatively, further caches of sources may not be released for a number of years. Furthermore the nature of any ongoing contamination cannot be predicted, for example, particles may all be small and indistinguishable from the beach matrix, which would mean that potential inadvertent exposures are of primary concern. Alternatively, a cache of radioactive artefacts may be released in which case the primary pathway of concern may be preferential selection.

The current monitoring and recovery programme does mean that the sources continue to be removed from the beach on a monthly basis. Thus any changes in the nature of the contamination can be detected, reported and acted upon as appropriate. Whilst this monitoring remains in place it also means that the potential for secondary caches to develop is reduced as is the potential for the affected area to increase.

5.5. Source breakdown

Weathering and erosion are a natural part of the cyclical process of rock formation and breakdown, which reduces large rocks and boulders to progressively smaller sizes until they finally undergo either lithification, metamorphosis or return to an igneous rock state. This means that the larger radioactive sources at Dalgety Bay will like rocks break down over time to physically smaller sources: due to the longevity of radium 226, these smaller sources will remain radioactive and pose a hazard to the public. Breakdown of physically larger objects will either result in physically smaller radioactive particles with the same radioactive component or multiple radioactive sources. In the case of the former this may mean that the sources are more hazardous as they could be inhaled or more easily lodged or ingested. Whilst for the latter this could increase both the probability of encounter and the potential hazards from ingestion and inhalation.

5.6. Hazard

5.6.1. Ingestion

As the size of the sources is not routinely assessed and that over time, erosion will reduce the physical size it has been assumed that they are of a size to be ingested (up to 20 mm). From field observations the majority of the sources recovered have physical sizes less than this value. Clearly some of the sources recovered are too physically large for this to occur. However over time these will breakdown at a much faster rate than radioactive decay and generate ingestible particle sizes. However, the physical breakdown of such source may mean that the overall number of sources increases and as a consequence so will the probability of encounter.

There is no information to assess whether future levels of hazard will remain consistent with current levels.

5.6.2. Solubility

The assessment of solubility of the sources has used a mean solubility for the sources recovered and subjected to the representative GI solution. In the event that this is not representative this could clearly result in higher or lower doses per unit intake. Furthermore, if a more protective level of solubility were chosen e.g. the 95th percentile this would result in a significantly greater number of sources being identified as a realistic hazard and result in a significant increase in the probability of ingestion of a particle which was a realistic hazard. It would also mean that the hazard posed by the particles already identified as a realistic hazard would increase. It is suggested that for any actions to address the long-term contamination this value should be adopted.

5.6.3. Skin

The assessment of hazard on skin has been based on the skin thickness of an adult. As children have thinner skins (ICRP Reference man) the typical doses for children from any given exposure will be greater than for an adult. However, even for an adult some areas of the skin are thinner than others and the assessment has been based on average values of skin thickness for an adult.

The effect of a source on the skin tends to assume that the source has a physical size less than that of the area being assessed ($1cm^2$). This means that sources that have high beta and alpha dose rates and are physically small tend to report low dose rates when the area is integrated despite high dose rates to the skin directly under the source itself. SEPA has requested guidance from the HPA on the interpretation of this as some of the sources recovered from Dalgety Bay could deliver doses in excess of 10 Gray per hour to small areas less than 1 cm^2, but when this is integrated over 1 cm^2 the doses rates are much smaller. However, it is clear that some of the sources do give dose rates in excess of 10 Grays per hour over 1 cm^2. Many of the sources recovered from Dalgety Bay are physically larger than 1 cm^2 and thus caution is needed when calculating dose rates from direct measurements such as TLD's as these tend to have an area less than 1 cm^2 and it is assumed that the doses outwith the TLD area would be less, whereas in fact the dose rates are equally likely to be either the same or greater.

5.7. Habits

The habits survey was conducted in October 2012 and was limited to a week of surveys. Current habits have been skewed by the protection measures in place and media coverage, thus the habits observed currently may not be only those observed in 20 years time.

During the time of the habits survey the Sailing Club was not hosting Sailing regattas where reportedly large numbers of people travel significant distances to attend. These people would not have been captured in the assessment of current habits and importantly this is when the greatest occupancy of the slipway areas is likely to occur. SEPA understand that these regattas have recently recommenced.

Given the potential effects of these significant uncertainties on the resultant assessment of hazard and risk, it would be appropriate to add a significant level of caution to any final recommendations.

5.8. Exposure pathways

It is not possible to determine the potential for exposures from pica, preferential selection or a child deliberately placing an item in the mouth and subsequently parts of, or all of, that item being ingested. It is known that people have removed dials and artefacts from the beach and that some visitors have removed stones etc.

5.9. Depth of source finds

The capability of any monitoring instrument in detecting any source is dependent upon the activity of the source, and the proximity of that source to the detector. For example if a source was 10 cm away from a detector, it would produce a count rate to that detector of 4 times less than if it were 5 cm away (known as the inverse square law). Thus as the source becomes further away from the detector the possibility of detection diminishes. This effect is further compounded by shielding from the beach sediments and orientation of the source together with other factors such as background radiation levels, distance above ground, water etc. The overall effect of this is that the probability of detection for any source decreases with distance, with the lower activity sources being effectively undetectable at shallower depths than higher sources. This means that for high activity sources buried at depth these may not be detected and removed under the current monitoring arrangements. This effect is of little consequence for the bulk of the beach users, but for a child digging to depths of greater than a few tens of centimetres there is a possibility that an encounter could occur.

5.10. Overall effect

The compounded effect of underestimation of the activity of the sources recovered, which would result in greater numbers of sources classified as a realistic hazard, coupled with the uncertainty in solubility and future numbers and activity of sources together with a significant uncertainty in current and future hazards, however what is clear even using mean values is that some of the sources recovered from Dalgety Bay could potentially deliver life threatening doses if encountered.

Part 6. Conclusions

Summary of Significant Pollutant Linkages

<table>
<tr><th colspan="2">EVIDENCE FOR POLLUTANT LINKAGES</th></tr>
<tr><th>Linkage</th><th>Discussion</th></tr>
<tr><td>Linkage:

Radium sources within beach environment which are close to surface and can be encountered by the public via direct contact.</td><td>Source

Shallow and deep sediments impacted by radium 226 contamination.

Samples of radium indicate doses to humans would pose a hazard in excess of the relevant criteria in the RCL statutory guidance. Sources continue to be detected across the entire area, which are in excess of these criteria. Sources in excess of 10 MBq Ra-226 would give doses to the skin in excess of 10 Gray per hour. Sources of greater than 100,000 Bq Ra-226 would give ingestion doses in excess of 100 mSv for children. For lower activity sources the effects of skin thickness and greater solubility may mean that these sources could also deliver doses in excess of the relevant statutory criteria.

Pathway
Skin Contact and Ingestion
Radioactive sources are present in the area, which continue to be mobilised and come to the surface. The public use the site as a whole. Skin contact and inadvertent ingestion pathways are present. Digging in sediment would provide a further pathway.

Receptor
Public

The public have access to all of the area minus the current Demarcated Area.</td></tr>
<tr><td colspan="2">SUMMARY OF LINKAGE:

Based on mean solubility a 3-month old child would receive 100 mSv from ingestion of a 35 kBq source. For a 1-year old child this same dose is attributable to a source with an activity of 100 kBq, a number of such sources reported in the SEPA find data on our website have activities greater than this value and are of ingestible size[35]. For an adult this would be a source in the order of 700 kBq the number of sources found to date with activities greater than this value is relatively low. Higher numbers of sources in excess of 35 kBq have been found in Areas C, D and E with fewer found outwith these areas.

Equivalent sources continue to be found at Dalgety Bay which are in greatest in number per area in Areas C, D and E (the currently Demarcated Area, Boat Park area and the Slipways area). When sources are removed from these areas they are repopulated with similar activity sources most likely as a result of coastal</td></tr>
</table>

[35] Assuming maximum size for ingestion of 20mm. From Litovitz Toby; Whitaker N, Clark L. (June 2010). "Preventing battery ingestions: an analysis of 8648 cases.". Pediatrics 125 (6): 1178–83.

EVIDENCE FOR POLLUTANT LINKAGES	
Linkage	**Discussion**
	processes. For skin doses, based on Charles 2008, sources of 10 MBq would deliver 10 Gy/h to the adult skin. Two such sources were found in 2011 which would deliver such a dose rate, although in all likelihood at least one further source was also found in this area in 1990, it is therefore reasonable to assume that further caches of such sources exist. ***SEPA considers that significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring on Area C, D and E at Dalgety Bay in line with the criteria set out in paragraph A.32 of the Statutory Guidance.*** ***For Areas C, D and E current management arrangements including signage demarcation and monitoring and removal is reducing the risks to the public. However, the practicability, effectiveness and durability of these current measures are still to be assessed.*** As the conditions set out in paragraph A.32 have been met the probability of a radiation dose in line with paragraph A.33 has not been assessed. SEPA does not consider that it has sufficient information to determine whether a significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring at Areas B and F due to the uncertainties discussed at Part 5 of this Risk Assessment. SEPA will keep these areas under review and consider whether further inspections are required.

Radioactive sources of radium which continue to be present at Dalgety Bay are capable of giving doses which would be above the relevant thresholds as defined by Paragraph A.32 of Chapter A, Part 3 in the RCL Statutory Guidance. The Habits Survey has identified that pathways currently exist whereby a significant dose could be received by a member of the public using the area indicating significant pollutant linkages. Currently the most likely location for this to occur is around the Slipways (Area E), however if people were to use the Demarcated Area (Area C) and Boat Park area (Area D), there would also be a significant pollutant linkage in this area.

SEPA does not consider that it has sufficient information to determine whether a significant possibility of significant harm from the identified Significant Pollutant Linkage is occurring at Areas B and F due to the uncertainties discussed at Part 5 of this Risk Assessment. SEPA will keep these areas under review and consider whether further inspections are required.

Although the chance for any individual encountering a source of which poses a realistic hazard is currently low, as so many people use the beach, collectively the potential for an encounter is relatively high. As the contamination has a long half-life, without current interventions such as the current demarcation and signage, coupled with a removal programme of the sources, the potential for the situation to deteriorate to a level where unacceptable exposures are likely to occur would increase, to levels where an encounter is almost certain to occur.

The results of the physical investigation are suggestive that the lens of material which contains the high activity sources remains in the coastal environment and is susceptible to erosion, as are the various radioactive sources contained within ash and clinker beds. This means that potential significant hazards will remain at Dalgety Bay for many years to come. No assessment can be made of the possibility that a child will sight and remove an artefact such as a dial from the beach and as a consequence become exposed either directly, via lodging on the skin, under a fingernail or ingestion.

Due to its long half-life, radium sources at Dalgety Bay will take 1600 years for the hazard to reduce by 50%. This means that sources currently present either within the beach or made ground will pose a risk to future generations without suitable interventions. SEPA will review the current management arrangements for the site in a separate document.

Due to the uncertainty of potential future magnitude of the contamination in terms of source activity, number, solubility and dose rate, coupled with uncertainty of exposure pathways and users of the foreshore, there is a need for caution to be adopted in addressing the contamination to provide a high level of confidence that the public will be afforded a suitable level of protection in the future. However, it is clear there are at least three areas (Areas C, D and E) of the foreshore where radioactive sources continue to be found which are in excess of the RCL dose criteria. However, if a more cautious assessment were made using higher solubility areas B, F and G may also be considered for designation.

Part 7. References

AMEC 2013. Dalgety Bay Coastal Processes Review. Rr415i2 March 2013.

Brown, 2008. Risk Assessments For Radium Contamination at Dalgety Bay. Radium Dalgety Bay Review DSTL 2008.

Brown R. (2013). Email Brown Ronald [RJBROWN@mail.dstl.gov.uk]. Fri 26/10/2012 10:11. RE: DBPAG - HPA Press Release.

Camplin, B. 1990. Letter to Mr G Stott, HMIPI Edinburgh, from W Camplin, MAFF, Fisheries Laboratory, 31 October 1990. File Ref: FLR 5445

Charles MW. (2008). Skin dose from Ra-226 contamination: Dose estimation & comments. M W Charles. http://www.sepa.org.uk/radioactive_substances/publications/dalgety_bay_reports.aspx

Charles M. W. and C. Gow (2010). Skin dose from Dalgety Bay Ra-226 contamination: Dose rate measurements for ten selected samples 21st October 2010. http://www.sepa.org.uk/radioactive_substances/publications/dalgety_bay_reports.aspx.

Dale P, Robertson I and Toner M, 2008. Journal of Environmental Radioactivity **99** pp1589–1595

Defence Estates (2010). Dalgety Bay Radiological Support. Completion Report DE Project No.: 12920 www.mod.uk/NR/rdonlyres/024C8FBA-6D68-40E8-A7E5-9146DBE046A8/0/dalgety_text.pdf

DPAG (2008). The Dounreay Particles Advisory Group 4th Report, November, 2008. http://www.sepa.org.uk/radioactive_substances/publications/dounreay_reports.aspx

ENVIROS 2007, Dalgety Bay. Land Quality Assessment Phase Two: Intrusive Investigation Land Quality Assessment Report – Final. Defence Estates. Project 12920. August 2007.

Gilbert 1987. Statistical methods Environmental Pollution Management Chapter 13.

Harrison, J. D., Fell, T. P., Phipps, A. W., Smith T. J., Ellender, M., Ham, G. J., Hodgson A, Wilkins, B. T. 2005. Health Implications of Dounreay Fuel Fragments: Estimates of Doses and Risks, Health Protection Agency Radiation Protection Division/University of Birmingham. www.sepa.org.uk/radioactive_substances/publications/dounreay_reports.aspx

Heaton, B. et al, 1996. Assessment of the Implications of Radium Contamination of Dalgety Bay Beach and Foreshore, University of Aberdeen and Auris Environmental Ltd.

HSE 2001. Reducing risks, protecting people HSE’s decision-making process ISBN 0 7176 2151 0

HSE 2005. HSE Criterion for delicensing nuclear sites. HSE Policy Statement.

HSE, 1988. Tolerability of risk from nuclear power stations.

HPA 2005. K Smith and P Bedwell Public Health Implications of Fragments of Irradiated Fuel Module 3: The likelihood of encountering a fuel fragment on Sandside beach.

HPA 2012. J Brown and W Oatway. Scoping Health Risk Assessment for Beach Users at Dalgety Bay to Support Advice to Scottish Government Given in February. HPA-CRCE-040. Health Protection Agency. http://www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE040/

HPA 2011. J Brown and G Etherington. Health Risks from Radioactive Objects on Beaches in the Vincinity of Sellafield site. http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1296685585268

IAEA Safety Principles. International Atomic Energy Agency. Safety Standards. IAEA Fundamental Safety Principles No. SF-01.

IAEA BSS (2011). International Atomic Energy Agency. IAEA Safety Standards Radiation Protection and Safety of Radiation International Basic Safety Standards. General Safety Requirements.

International Commission on Radiological Protection. ICRP Publication 72, Age-Dependent Doses from Intake of Radionuclides: Part 5 Compilation of ingestion and inhalation dose coefficients. (Pergamon Press, Oxford, 1996)

International Commission on Radiological Protection. ICRP Publication 89, Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values. (Pergamon Press, Oxford, 2002).

ICRP 103. (2007) The 2007 Recommendations of the International Commission on Radiological Protection ICRP Publication 103 Ann. ICRP 37 (2-4), 2007.

ICRP 109 (2009). Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations ICRP Publication 109. Ann. ICRP 39 (1), 2009.

ICRP 111 (2009) Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas After a Nuclear Accident or a Radiation Emergency. ICRP Publication 111. Ann. ICRP 39 (3), 2009

International Bureau of Weights and Measures, 2006.

Lindell, B., 2000. How Safe Can We Be? International Radiation Protection Association, Hiroshima.

Litovitz Toby; Whitaker N, Clark L. (June 2010). "Preventing battery ingestions: an analysis of 8648 cases.". Pediatrics 125 (6): 1178–83.

Lochard J., Bogdevitch I., Gallego E., Hedemann-Jensen P., McEwan A., Nisbet A., Oudiz A., Schneider T., Strand P., Carr Z., Janssens A., Lazo T. (1993) ICRP 64 Protection from Potential Exposure - A Conceptual Framework ICRP Publication 64. Ann. ICRP 23 (1), 1993.

NCRP 106. Limit for Exposure to Hot Particles on the skin. (1989) NCRP Report 106

NCRP 116. Limitation of Exposure to Ionizing Radiation (1993) (Supersedes NCRP Report No. 91)

Work package 4, dose distribution around hot particles Dosimetery of weakly penetrating radiation. Contract FI4P-C96—0037. Phys.-Techn. Bundesanstalt, Department 6.5. Bundesallee. 38116 Braunschweig. Germany.

Seil, H. A., Voil, C.H., Gordon, M.A. (1915). The elimination of soluble radium salts taken intravenously and per Os. NY Med. J. 101, 8969-898.

SEPA 2006. Radium Contamination at Dalgety Bay, Fife Probabilistic and Hazard Assessment: A Screening Assessment www.sepa.org.uk/radioactive_substances/publications/dalgety_bay_reports.aspx

SEPA 2009. Dalgety Bay Radium Contamination. Preliminary assessment produced by Scottish Environment Protection Agency (SEPA) Environmental and Organisational Strategy Directorate.

Smith G M. (2010) What is a low dose? Letters to the editor. J. Radiol. Prot. 30 (2010) 93–101.

Wilson C. A., Adderley W P. Tyler A. N and Dale P. Characterising the morphological properties and surface composition of radium contaminated particles: a means of interpreting origin and deposition. Submitted.

Part 8. Appendices

8.1. All Sources recovered from the beach

Table 21 is the number of sources recovered each month or year where data is available. Where information is provided sources removed from the made ground have not been included. The areas monitored are inconsistent as is the technique used and determination of the number of sources present.

Year	Month	Number of sources
1990	September	14
1990	December	176
1991	August	506
1991	December	28
1992	June	No information
1992	October	76
1993	July	48
1993	November	30
1994	September	45
1997		102
1998		11
2000		80
2002		93
2005		97
2006		37
2008		38
2009	May	27
2009	May	33
2009	May	1
2009	June	9
2009	July	15
2009	August	0
2009	October	1
2009	December	17
2010	March	1
2010	April	20
2010	May	3
2011	September	30
2011	September	16
2011	October	330
2011	November	93
2011	December	9
2012	January	74
2012	January	202
2012	February	67
2012	March	42
2012	March	5
2012	April	65
2012	April	41
2012	May	6
2012	May	97
2012	June	115
2012	June	12
2012	July	76
2012	August	168
2012	September	141
2012	October	40

8.2. Solubility of all sources subjected to representative gut digestion.

Source ID	Ra 226 solubility percent	Source ID	Ra 226 solubility percent	Source ID	Ra 226 solubility percent
DBP 03 03	0.95	DBP 12-15	0.79	S105	0.18
DBP 03 18	1.11	DBP 11-18	0.08	S106	0.07
DBP 05 05	0.49	DBP 14-30	7.06	DB/08/001	0.17
DBP 05 09	0.29	DBP 13-16	0.25	DB/08/003	0.07
DBP 12 06 a&b	2.06	DBP 04-03	4.63	DB/08/004	6.27
DBP 25 02	1.05	DBP 10-23	0.13	DB/08/005	0.03
DBP 13 23	3.23	DBP 13-09	15.82	DB/08/007	4
DBP 19 14	8.96	DBP 12-21	0.97	DB/08/009	0.04
DBP 19 38	1.88	DBP 07-04	0.14	DB/08/012	0.55
DBP 20 02	10.19	DBP 14-03	3.92	DB/08/031	1.03
DBP 22 05	35.78	DBP 16-45	1.31	DB/08/032	0
DBP 23 36	0.21	DBP 14-07	4.82	DB/08/033	0.01
DBP 23 45	0.08	DBP 03-05	3.09	DB/08/034	0.25
DBP 24 05	0.14	DBP 15-01	5.34	DB/08/035	0.1
DBP 03 09	0.38	DBP 11-03	0.36	DB/08/036	0.87
DBP 26 02	1.21	DBP 13-31	1.17	DB/08/037	0.21
Amec 133	1.68	DBP 11-09	0.57	DB/08/038	0.97
Amec 141	0.54	DBP 09-32	0.03	DB/08/039	6.33
Amec 170	3	DBP 11-25	1.04	1	0.06
Amec 178	0.14	DBP 04-16	24.28	5	0.45
DBP 12-33	5.38	DBP 11-13	5.72	17	0.07
DBP 15-12	0.53	S027	0.36	25	14.79
DBP 11-12	6.81	S046	0.07	26	0
DBP 12-18	2.27	S079 face down	3.51	30	6.88
DBP 14-34	0.07	S081	3.09		
DBP 09-02	0.03	S084	5.28		
DBP 06-19	0.31	S086 T&G (1)	14.66		
DBP 04-21	0.1	S087	24.61		
DBP 07-12	2.46	S100	0.01		

8.3. Schematic showing how source breakdown could occur

Figure 24: A source physically breaks into 2 equally sized particles both of which contain equal amounts of radioactivity. The hazard from skin contact is reduced, although as particles become physically smaller the possibility of ingestion and inhalation increases. As the number of sources has increased the possibility of contact has also increased

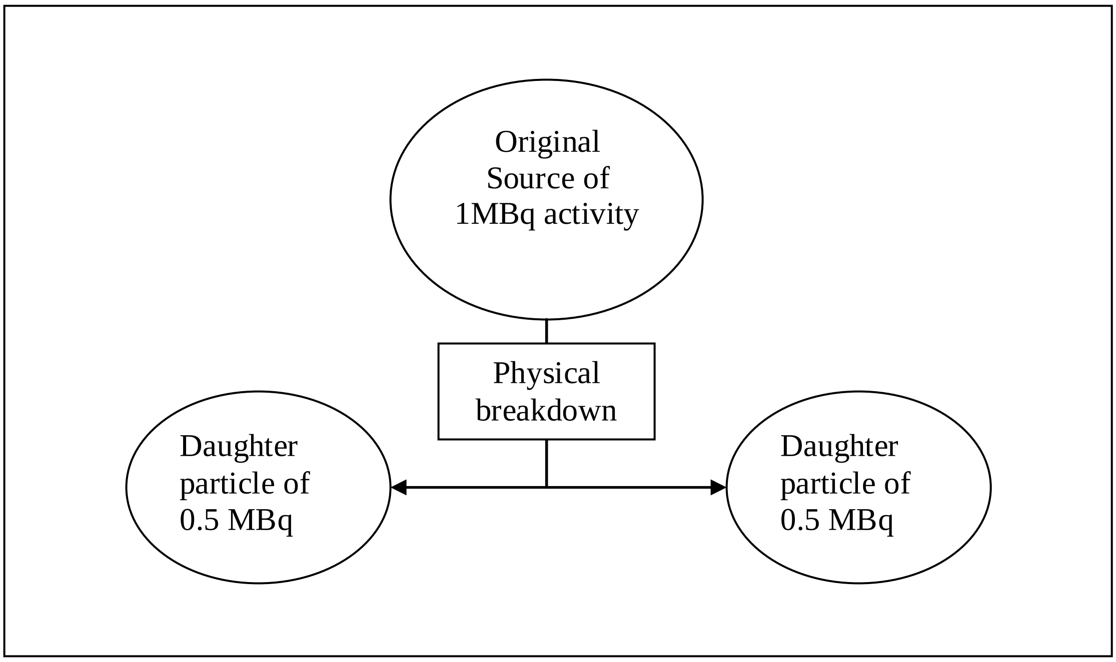


Figure 25: A source physically breaks into 2 equally sized particles one of which contains all the radioactivity. The hazard from skin contact remains the same, as the particle has become physically smaller the possibility of ingestion and inhalation increases. The possibility of contact remains the same.

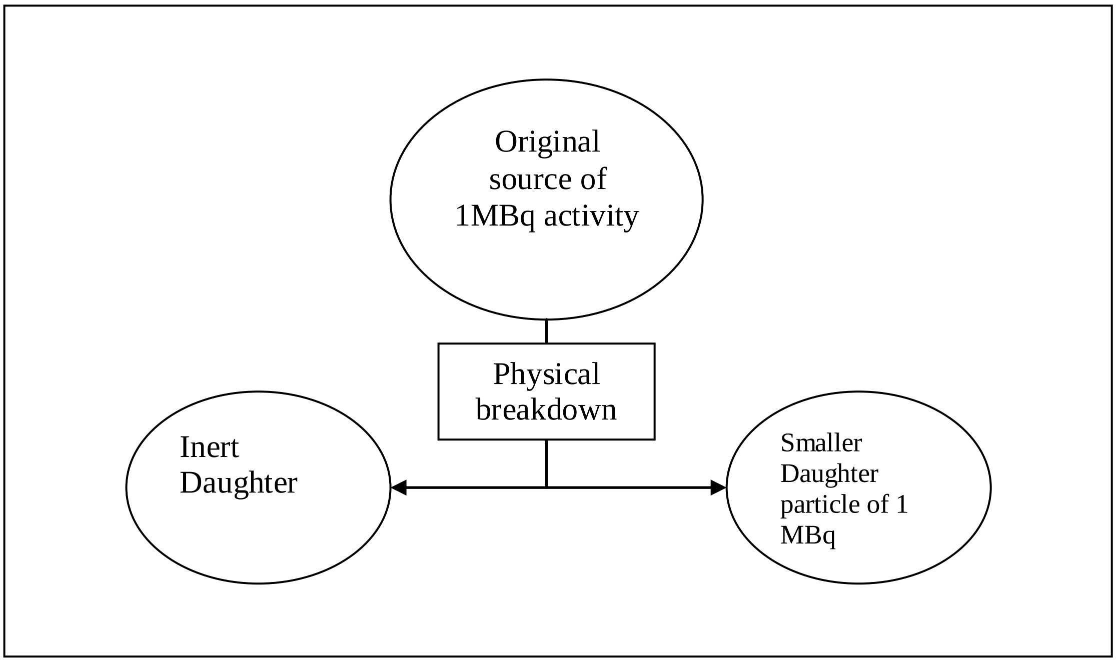
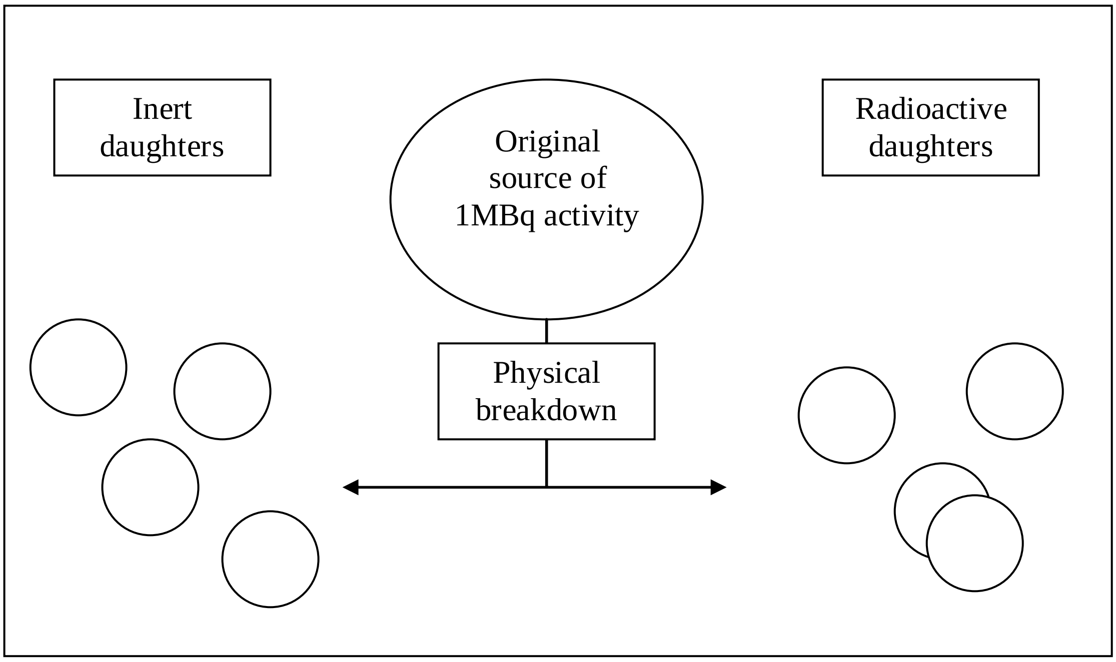
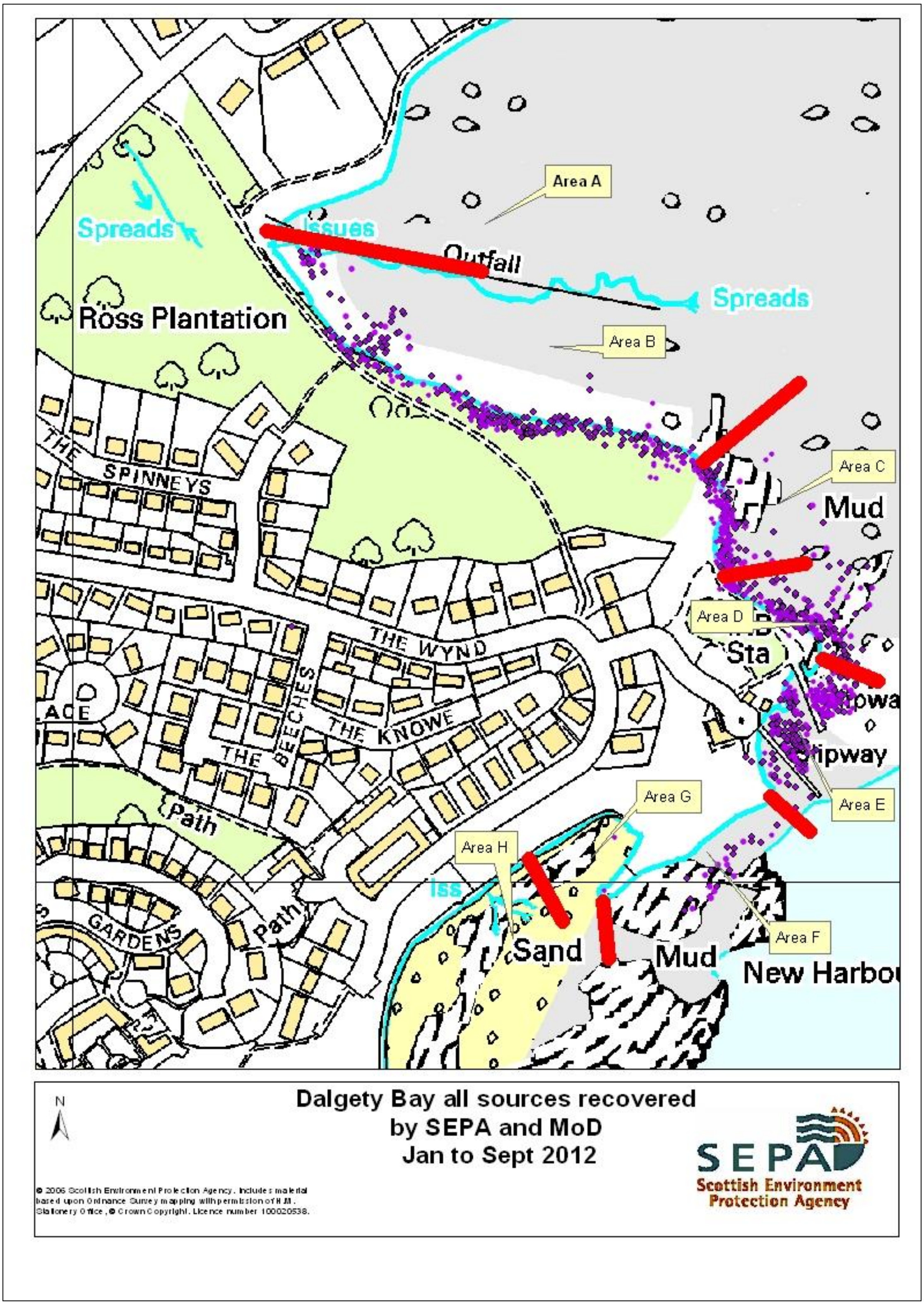
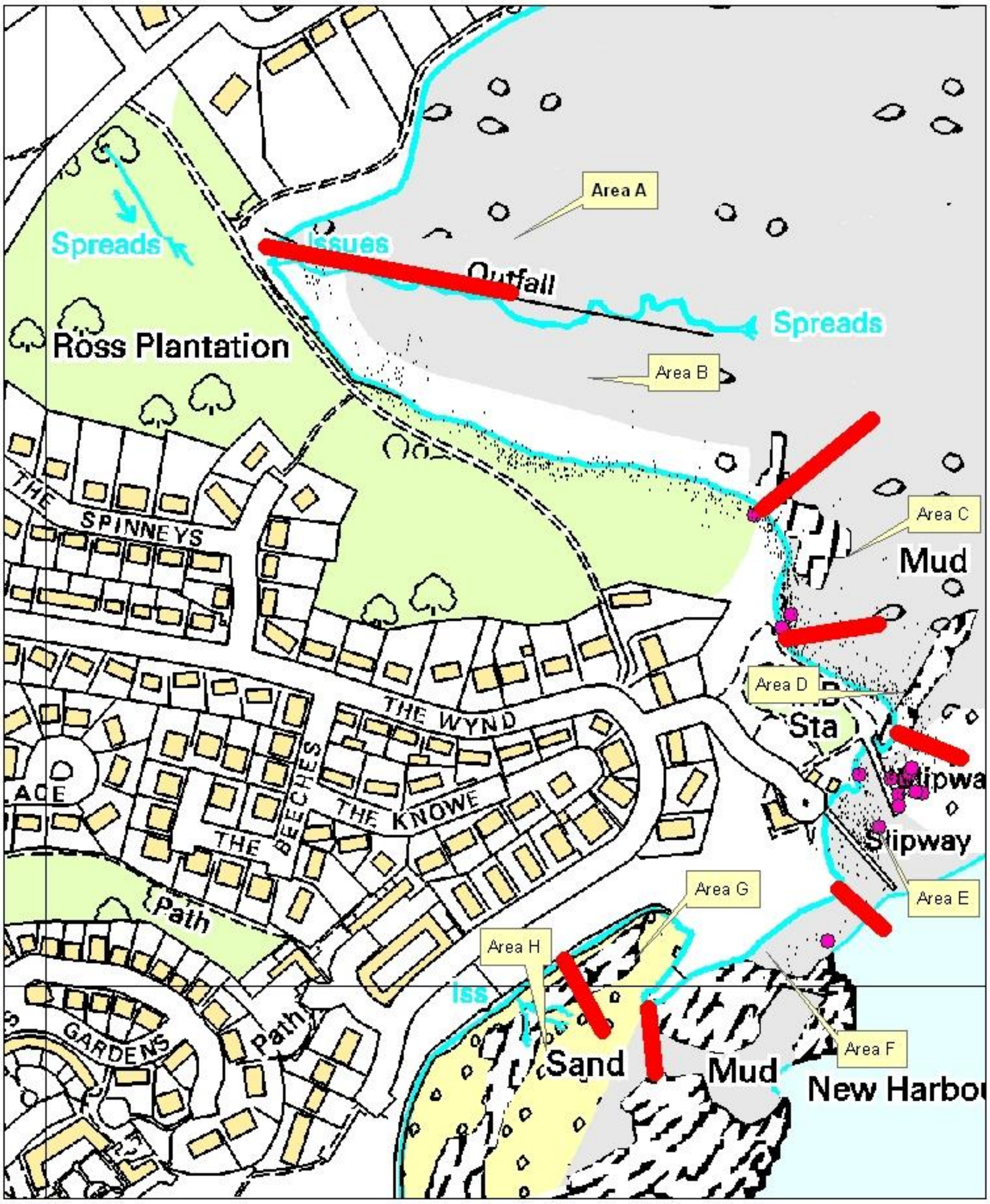


Figure 26: A source physically breaks into many smaller particles some of which contain radioactivity. The hazard from skin contact is reduced, although as particles become physically smaller the possibility of ingestion and inhalation increases. As the number of sources has increased the possibility of contact has also increased.



8.4. Sources recovered January to September 2012

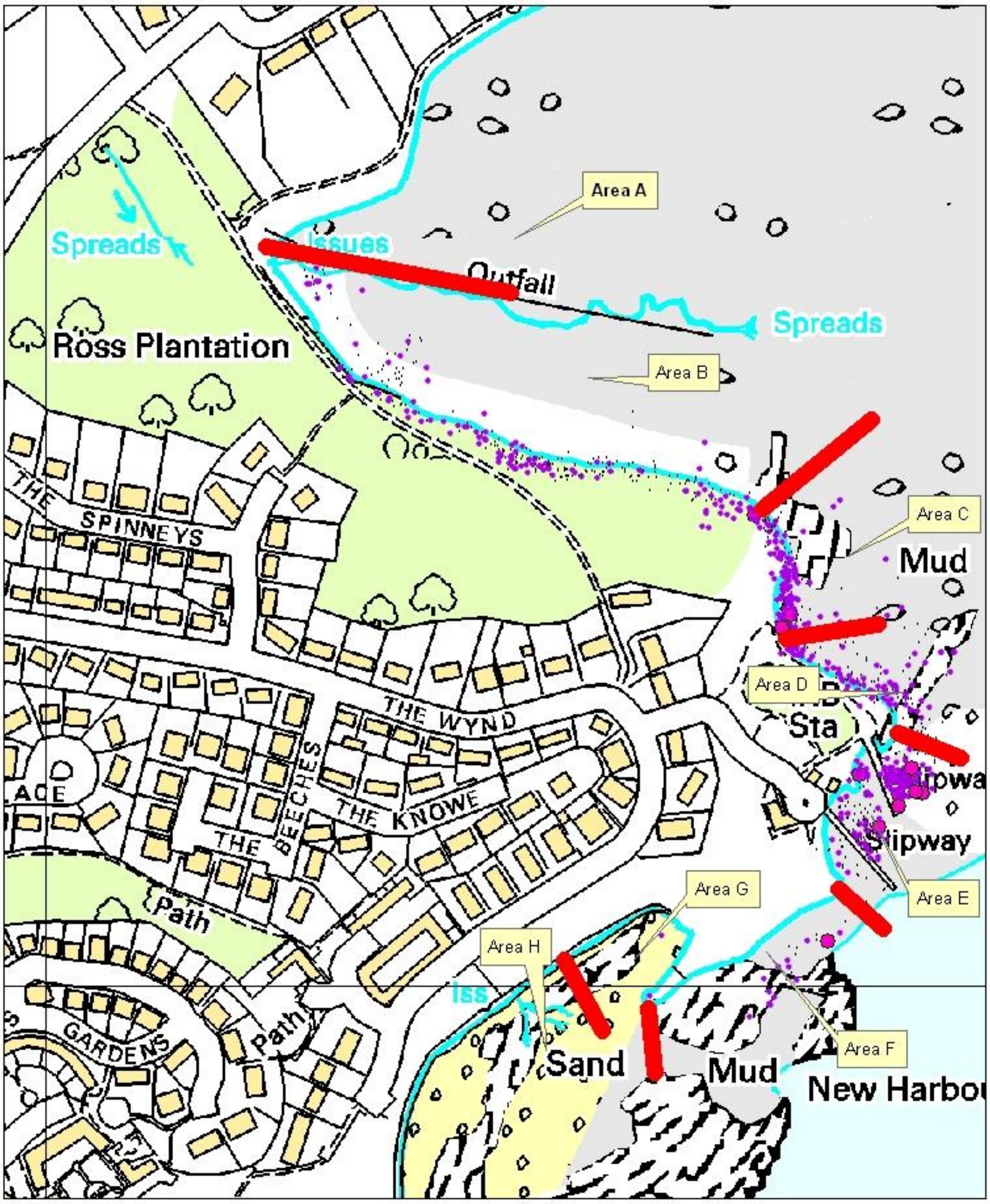




N

Dalgety Bay Sources recovered by SEPA and MoD Activity > 100kBq

SEPA Scottish Environment Protection Agency



N

Dalgety Bay Sources recovered by SEPA and MoD
Activity > 100kBq pink
Activity 10 - 100kBq purple

SEPA Scottish Environment Protection Agency

8.5. Probability of Encounter for selected areas

Probability of encounter for all users of all of the beach at Dalgety Bay for high hazard sources
Results of Calculations

Exposure Pathway		Adult	Child	Infant
Inhalation of an item	per visit	6.68E-11	9.30E-12	3.20E-12
	per year	4.58E-08	8.83E-10	3.80E-10
Inadvertent Ingestion	per visit	7.27E-10	1.45E-09	7.27E-09
	per year	4.98E-07	1.38E-07	8.65E-07
Direct Skin Contact				
dry sand	per visit	8.43E-08	9.05E-08	3.94E-08
	per year	5.77E-05	8.60E-06	4.69E-06
wet sand	per visit	4.21E-06	4.53E-06	1.97E-06
	per year	2.88E-03	4.30E-04	2.34E-04
dry and wet sand	per visit	4.30E-06	4.62E-06	2.01E-06
	per year	2.94E-03	4.39E-04	2.39E-04
Fragment under fingernails	per visit	6.24E-08	2.24E-08	4.94E-09
	per year	4.28E-05	2.13E-06	5.88E-07
Fragment on clothes	per visit	5.52E-07	3.25E-07	1.54E-07
	per year	3.78E-04	3.09E-05	1.83E-05
Fragment in a shoe	per visit	1.45E-06	1.45E-06	1.45E-06
	per year	9.95E-04	1.38E-04	1.73E-04
Total probability	per visit	6.37E-06	6.42E-06	3.63E-06
	per year	4.36E-03	6.10E-04	4.32E-04

In terms of Chance

Exposure Pathway		Adult	Child	Infant
Inhalation of a fragment	per visit	14,960,732,579	107,530,265,411	312,815,317,559
	per year	21,840,487	1,131,901,816	2,628,698,689
Inadvertent Ingestion	per visit	1,376,387,397	688,193,699	137,638,740
	per year	2,009,325	7,244,144	1,156,629
Direct Skin Contact				
dry sand	per visit	11,865,409	11,046,448	25,394,601
	per year	17,322	116,279	213,401
wet sand	per visit	237,308	220,929	507,892
	per year	347	2,326	4,268
dry and wet sand	per visit	232,655	216,597	497,933
	per year	340	2,280	4,185
Fragment under fingernails	per visit	16,019,406	44,705,320	202,350,397
	per year	23,386	470,583	1,700,424
Fragment on clothes	per visit	1,811,036	3,072,293	6,492,393
	per year	2,644	32,340	54,558
Fragment in a shoe	per visit	688,194	688,194	688,194
	per year	1,005	7,245	5,784
Total probability	per visit	157,068	155,781	275,663
	per year	230	1,640	2,317

Probability of encounter for all users of all of the beach at Dalgety Bay and all sources
Results of Calculations

Exposure Pathway		Adult	Child	Infant
Inhalation of an item	per visit	2.68E-10	3.74E-11	1.28E-11
	per year	1.26E-07	3.55E-09	1.53E-09
Inadvertent Ingestion	per visit	2.92E-09	5.84E-09	2.92E-08
	per year	1.37E-06	5.54E-07	3.47E-06
Direct Skin Contact				
dry sand	per visit	3.38E-07	3.64E-07	1.58E-07
	per year	1.59E-04	3.45E-05	1.88E-05
wet sand	per visit	1.69E-05	1.82E-05	7.91E-06
	per year	7.94E-03	1.73E-03	9.41E-04
dry and wet sand	per visit	1.73E-05	1.85E-05	8.07E-06
	per year	8.10E-03	1.76E-03	9.59E-04
Fragment under fingernails	per visit	2.51E-07	8.98E-08	1.98E-08
	per year	1.18E-04	8.54E-06	2.36E-06
Fragment on clothes	per visit	2.22E-06	1.31E-06	6.19E-07
	per year	1.04E-03	1.24E-04	7.36E-05
Fragment in a shoe	per visit	5.84E-06	5.84E-06	5.84E-06
	per year	2.75E-03	5.54E-04	6.94E-04
Total probability	per visit	2.56E-05	2.58E-05	1.46E-05
	per year	1.20E-02	2.45E-03	1.73E-03

In terms of Chance

Exposure Pathway		Adult	Child	Infant
Inhalation of a fragment	per visit	3,724,875,437	26,772,542,207	77,883,759,147
	per year	7,908,441	281,816,415	654,486,853
Inadvertent Ingestion	per visit	342,688,540	171,344,270	34,268,854
	per year	727,577	1,803,624	287,974
Direct Skin Contact				
dry sand	per visit	2,954,212	2,750,309	6,322,667
	per year	6,273	28,951	53,132
wet sand	per visit	59,084	55,006	126,453
	per year	126	580	1,063
dry and wet sand	per visit	57,926	53,928	123,974
	per year	123	568	1,042
Fragment under fingernails	per visit	3,988,461	11,130,588	50,380,556
	per year	8,469	117,165	423,367
Fragment on clothes	per visit	450,906	764,930	1,616,455
	per year	958	8,052	13,584
Fragment in a shoe	per visit	171,344	171,344	171,344
	per year	364	1,804	1,440
Total probability	per visit	39,106	38,786	68,634
	per year	83	409	577

Probability of encounter for high rate user of the slipways beach at for high hazard sources Dalgety Bay

Results of Calculations

Exposure Pathway		Adult	Child	Infant
Inhalation of an item	per visit	2.06E-10	2.87E-11	9.87E-12
	per year	4.75E-09	3.45E-10	1.18E-10
Inadvertent Ingestion	per visit	2.24E-09	4.49E-09	2.24E-08
	per year	5.16E-08	5.38E-08	2.69E-07
Direct Skin Contact				
dry sand	per visit	2.60E-07	2.80E-07	1.22E-07
	per year	5.99E-06	3.35E-06	1.46E-06
wet sand	per visit	1.30E-05	1.40E-05	6.08E-06
	per year	2.99E-04	1.68E-04	7.30E-05
dry and wet sand	per visit	1.33E-05	1.43E-05	6.20E-06
	per year	3.05E-04	1.71E-04	7.44E-05
Fragment under fingernails	per visit	1.93E-07	6.91E-08	1.53E-08
	per year	4.43E-06	8.29E-07	1.83E-07
Fragment on clothes	per visit	1.71E-06	1.01E-06	4.76E-07
	per year	3.92E-05	1.21E-05	5.71E-06
Fragment in a shoe	per visit	4.49E-06	4.49E-06	4.49E-06
	per year	1.03E-04	5.38E-05	5.38E-05
Total probability	per visit	1.97E-05	1.98E-05	1.12E-05
	per year	4.52E-04	2.38E-04	1.34E-04

In terms of Chance

Exposure Pathway		Adult	Child	Infant
Inhalation of a fragment	per visit	4,844,914,117	34,822,820,216	101,302,749,719
	per year	210,648,441	2,901,901,112	8,441,864,475
Inadvertent Ingestion	per visit	445,732,099	222,866,049	44,573,210
	per year	19,379,657	18,572,171	3,714,435
Direct Skin Contact				
dry sand	per visit	3,842,518	3,577,304	8,223,839
	per year	167,066	298,109	685,320
wet sand	per visit	76,850	71,546	164,477
	per year	3,342	5,963	13,707
dry and wet sand	per visit	75,343	70,143	161,252
	per year	3,276	5,846	13,438
Fragment under fingernails	per visit	5,187,757	14,477,462	65,529,565
	per year	225,555	1,206,456	5,460,797
Fragment on clothes	per visit	586,490	994,938	2,102,510
	per year	25,500	82,912	175,210
Fragment in a shoe	per visit	222,866	222,866	222,866
	per year	9,690	18,573	18,573
Total probability	per visit	50,865	50,448	89,271
	per year	2,212	4,204	7,439

Probability of encounter for all users of the slipways beach at Dalgety Bay for high hazard sources
Results of Calculations

Exposure Pathway		Adult	Child	Infant
Inhalation of an item	per visit	2.06E-10	2.87E-11	9.87E-12
	per year	1.65E-08	5.17E-10	2.37E-10
Inadvertent Ingestion	per visit	2.24E-09	4.49E-09	2.24E-08
	per year	1.79E-07	8.08E-08	5.38E-07
Direct Skin Contact				
dry sand	per visit	2.60E-07	2.80E-07	1.22E-07
	per year	2.08E-05	5.03E-06	2.92E-06
wet sand	per visit	1.30E-05	1.40E-05	6.08E-06
	per year	1.04E-03	2.52E-04	1.46E-04
dry and wet sand	per visit	1.33E-05	1.43E-05	6.20E-06
	per year	1.06E-03	2.57E-04	1.49E-04
Fragment under fingernails	per visit	1.93E-07	6.91E-08	1.53E-08
	per year	1.54E-05	1.24E-06	3.66E-07
Fragment on clothes	per visit	1.71E-06	1.01E-06	4.76E-07
	per year	1.36E-04	1.81E-05	1.14E-05
Fragment in a shoe	per visit	4.49E-06	4.49E-06	4.49E-06
	per year	3.59E-04	8.08E-05	1.08E-04
Total probability	per visit	1.97E-05	1.98E-05	1.12E-05
	per year	1.57E-03	3.57E-04	2.69E-04

In terms of Chance

Exposure Pathway		Adult	Child	Infant
Inhalation of a fragment	per visit	4,844,914,117	34,822,820,216	101,302,749,719
	per year	60,561,427	1,934,600,742	4,220,932,237
Inadvertent Ingestion	per visit	445,732,099	222,866,049	44,573,210
	per year	5,571,652	12,381,448	1,857,218
Direct Skin Contact				
dry sand	per visit	3,842,518	3,577,304	8,223,839
	per year	48,032	198,740	342,660
wet sand	per visit	76,850	71,546	164,477
	per year	961	3,975	6,854
dry and wet sand	per visit	75,343	70,143	161,252
	per year	942	3,897	6,719
Fragment under fingernails	per visit	5,187,757	14,477,462	65,529,565
	per year	64,847	804,304	2,730,399
Fragment on clothes	per visit	586,490	994,938	2,102,510
	per year	7,332	55,275	87,605
Fragment in a shoe	per visit	222,866	222,866	222,866
	per year	2,786	12,382	9,287
Total probability	per visit	50,865	50,448	89,271
	per year	636	2,803	3,720
Summation	per year		455	

Probability of encounter for all users of all of the beach at Dalgety Bay
Results of Calculations

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of an item	per visit	6.68E-11	9.30E-12	3.20E-12
		per year	4.58E-08	8.83E-10	3.80E-10
2	Inadvertent Ingestion	per visit	7.27E-10	1.45E-09	7.27E-09
		per year	4.98E-07	1.38E-07	8.65E-07
3	Direct Skin Contact				
	dry sand	per visit	8.43E-08	9.05E-08	3.94E-08
		per year	5.77E-05	8.60E-06	4.69E-06
	wet sand	per visit	4.21E-06	4.53E-06	1.97E-06
		per year	2.88E-03	4.30E-04	2.34E-04
	dry and wet sand	per visit	4.30E-06	4.62E-06	2.01E-06
		per year	2.94E-03	4.39E-04	2.39E-04
4	Fragment under fingernails	per visit	6.24E-08	2.24E-08	4.94E-09
		per year	4.28E-05	2.13E-06	5.88E-07
5	Fragment on clothes	per visit	5.52E-07	3.25E-07	1.54E-07
		per year	3.78E-04	3.09E-05	1.83E-05
6	Fragment in a shoe	per visit	1.45E-06	1.45E-06	1.45E-06
		per year	9.95E-04	1.38E-04	1.73E-04
	Total probability	per visit	6.37E-06	6.42E-06	3.63E-06
		per year	4.36E-03	6.10E-04	4.32E-04

In terms of Chance

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of a fragment	per visit	14,960,732,579	107,530,265,411	312,815,317,559
		per year	21,840,487	1,131,901,816	2,628,698,689
2	Inadvertent Ingestion	per visit	1,376,387,397	688,193,699	137,638,740
		per year	2,009,325	7,244,144	1,156,629
	Summation (Inadvertent Ingestion)	total		666,531	
4	Direct Skin Contact				
	dry sand	per visit	11,865,409	11,046,448	25,394,601
		per year	17,322	116,279	213,401
	wet sand	per visit	237,308	220,929	507,892
		per year	347	2,326	4,268
	dry and wet sand	per visit	232,655	216,597	497,933
		per year	340	2,280	4,185
5	Fragment under fingernails	per visit	16,019,406	44,705,320	202,350,397
		per year	23,386	470,583	1,700,424
6	Fragment on clothes	per visit	1,811,036	3,072,293	6,492,393
		per year	2,644	32,340	54,558
7	Fragment in a shoe	per visit	688,194	688,194	688,194
		per year	1,005	7,245	5,784
	Total probability	per visit	157,068	155,781	275,663
		per year	230	1,640	2,317
	Summation			185	