Scoping Health Risk Assessment for Beach Users at Dalgety Bay to Support Advice to Scottish Government Given in February 2012

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ABSTRACT

A scoping public health risk assessment for beach users at Dalgety Bay was carried out at the request of the Scottish Government Health Department. It was recognised that the scoping assessment was being undertaken prior to sufficient data being available for a full public health risk assessment. The aim was to carry out a preliminary assessment of the possible health impact for people currently using the beach area in order to determine if any additional urgent actions were required, in addition to the restrictions on access to an area of the beach and advice to beach users that were put in place in the autumn of 2011.

On the basis of the assessment, HPA updated the advice it had given to SEPA on 28th November 2011 in a letter to the Scottish Government Health Department on 1st February 2012. This report describes the scoping public health risk assessment undertaken by HPA that underpinned the advice.

Since the scoping assessment was carried out in January 2012, work has continued at Dalgety Bay, both in terms of the implementation of a monitoring programme to detect and retrieve contaminated objects from the beach and to further characterise the objects found and the in-situ contamination on the beach and surrounding land. This report contains a short review of this more recent information.

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Approval: October 2012
Publication: October 2012
£15.00
ISBN 978-0-85951-724-9

This work was undertaken under the Environmental Assessment Department's Quality Management System, which has been approved by Lloyd's Register Quality Assurance to the Quality Management Standards ISO 9001:2008 and TickIT Guide Issue 5.5, Certificate No: LRQ 0956546.

Report version 1.0

EXECUTIVE SUMMARY

Radioactive objects have been detected and recovered from Dalgety Bay since 1990. Many surveys have been undertaken on the beach to determine the amount of contamination and possible implications for public health. During surveys in October 2011, a higher number of objects were detected on part of the beach than expected. This prompted a review of the contamination on the beach and whether any urgent actions were required to protect members of the public using the beach area. In November 2011, the Scottish Government Health Department requested that the Health Protection Agency (HPA) carry out a scoping public health risk assessment for beach users at Dalgety Bay. The aim was to carry out a preliminary assessment of the possible health impact for people who are currently using the beach to determine if any additional urgent actions were required, in addition to the restrictions on access to an area of the beach and advice to beach users that had been put in place by the Scottish Environment Protection Agency (SEPA). It was recognised that the scoping assessment was being undertaken prior to sufficient data being available for a full public health risk assessment. A full assessment requires, amongst other things, a detailed knowledge of the sources of the contaminated objects and of all the processes that affect the migration and behaviour of them in the environment over time.

The scoping assessment carried out in January 2012 was based on the monitoring data and supporting information made available to HPA by SEPA up to the end of December 2011. The approach adopted was consistent with that used by HPA for assessing the public health risks for contamination of beaches around the Dounreay and Sellafield nuclear sites by discrete radioactive objects. The assessment addressed two key aspects. Firstly, estimates were made of the likelihood that people using the beach for various activities could come into contact with a radioactive object, taking care that this was not underestimated for current beach users. Secondly, for the unlikely situation that an individual does come into contact with such an object, the resulting radiation doses and associated health risks were assessed. This report describes the assessment undertaken by HPA to support the advice given in February 2012. It also contains a short review of information made available from the monitoring programme and further characterisation of objects retrieved from the area since the scoping assessment was carried out. It is concluded that the results of the scoping study and the advice provided in February 2012 remain valid.

The HPA advice given to Scottish Government and SEPA was:

- there was no public health reason for individuals to stop using the area and that the public health advice provided to SEPA previously remained valid;
- it was important that members of the public should not access the restricted area and should follow the advice given to beach users; that is to wash their hands when leaving and not remove objects from the beach. Parents should also consider stopping their children from digging in the sand;
- frequent monitoring of the beach, particularly areas where a large number of objects have been found, and which have been subject to erosion during storms, should be

carried out to ensure that contaminated objects are detected and removed for the on-going protection of the public. The potential risks of health effects from high activity objects mean that it is very important that objects that contain ^{226}Ra activity at levels that could give rise to localised skin ulceration or to organ/tissue damage from ingestion do not remain on the beach;

- a detailed and comprehensive public health risk assessment needed to be commissioned. This required actions to be taken to obtain the information needed. Specifically, this included:

    - a thorough programme of radiation monitoring and retrieval of contaminated objects from the beach carried out over several seasons;
    - further characterisation of the different types of radioactively contaminated objects found so that better estimations of the potential radiation doses and health risks can be made;
    - a full survey of how people use the beach, and how often.

HPA recognised that the acquisition of detailed information would take time to obtain and steps needed to be taken promptly to initiate the necessary work to enable this information to be obtained. HPA acknowledges that progress has been made on collection of the required information in terms of both the implementation of a monitoring programme to detect and retrieve contaminated objects from the beach and the further characterisation of the objects and in-situ contamination found on the beach and surrounding land. Significant further work is however required before a comprehensive public health risk assessment can be commissioned.

The HPA is of the view that although the risks to public health from radioactive objects on the beach are low, even with the current measures in place to protect beach users momentum needs to be maintained to resolve the problems at Dalgety Bay and that every effort needs to be made to work towards a timely agreement on the long term management strategy for this situation.

CONTENTS

1 INTRODUCTION

A scoping public health risk assessment for beach users at Dalgety Bay was carried out at the request of the Scottish Government Health Department*. It was recognised that the scoping assessment was being undertaken prior to sufficient data being available for a full public health risk assessment. The aim was to carry out a preliminary assessment of the possible health impact for people who are currently using the beach area in order to determine if any additional urgent actions were required, in addition to the restrictions on access to an area of the beach and advice to beach users that were put in place in the autumn of 2011.

The assessment was based on the monitoring data and supporting information made available to HPA by the Scottish Environment Protection Agency (SEPA) up to the end of December 2011. The approach adopted was consistent with that used by HPA for assessing the public health risks for contamination of beaches around the Dounreay and Sellafield nuclear sites by discrete radioactive objects [Brown and Etherington, 2011; DPAG, 2008]. The scoping assessment primarily used information on the radioactive contamination of the coastal area where a large number of objects contaminated with ^{226}Ra were detected and removed between September and December 2011.

On the basis of the assessment, HPA updated the public health advice it had given to SEPA on 28th November 2011 in a letter to the Scottish Government Health Department on 1st February 2012; the advice is replicated in Section 8.

The consideration of the potential health risks to members of the public from contaminated objects that may be ingested via the consumption of seafood caught locally off the coastline was outside the scope of this study and is being addressed separately by the Food Standards Agency.

This report describes the scoping public health risk assessment undertaken by HPA to support the advice given on 1st February 2012. Since the scoping assessment was carried out, work has continued at Dalgety Bay, both in terms of the implementation of a monitoring programme to detect and retrieve contaminated objects from the beach and to further characterise the objects found and the in-situ contamination on the beach and surrounding land. This report contains a short review of this more recent information (Section 9). It is concluded that the results of the scoping study and the advice provided in February 2012 remain valid.

* Request made at a multi-agency meeting in Edinburgh in November 2011 chaired by the Scottish Government

2 KEY INFORMATION RECEIVED ON OBJECTS RETRIEVED FROM DALGETY BAY

SEPA provided HPA with information on the objects that had been detected and retrieved from the beach as a result of monitoring that took place between the beginning of September and December, 2011 [Dale, 2011]. The data were provided in a spreadsheet containing the compiled data on the objects retrieved. Other information on 3 objects with reported high levels of ^{226}Ra, which were not included on the spreadsheet, were obtained from SEPA via emails and phone calls [Dale, 2011]; these objects were included in the assessment. Other data from monitoring surveys carried out by the Ministry of Defence were not available to HPA at the time of the scoping assessment and have not been used.

SEPA commissioned some limited work to provide information on the likely solubility, following ingestion, of the objects found on the beach during autumn 2011. The detailed results of this work were not available at the time of this study. However HPA had received information from SEPA [Dale, 2012] that the initial results were broadly consistent with previous dissolution work on objects from Dalgety Bay [SEPA, 2011] where solubility up to 25% was observed.

2.1 Radioactivity content of detected and retrieved objects

Within the monitoring data supplied by SEPA there were limited data on the radionuclide content of the objects detected and retrieved from the beach. The best method to utilise the gamma-spectrometry measurements made on only a few objects and the estimated ^{226}Ra activity based on in-field count per second data was agreed in discussion with Andrew Tyler from Stirling University [Tyler, 2012]. In summary, it was agreed that the gamma spectrometry data on radionuclide content of the objects should be used for the objects where this was available, as it is more accurate than the estimated activity based on the in-field count per second data. From the gamma spectrometry data, ^{214}Bi is likely to be the most accurately measured radionuclide and it was noted that SEPA had used the ^{214}Bi measurements to provide a correlation between the ^{214}Bi activity and the in-field count per second data to estimate the ^{226}Ra activity content of all the detected and retrieved objects.

The following approach was used to estimate the activities of the radionuclides in the ^{226}Ra decay chain (lead-214 (^{214}Pb), bismuth-214 (^{214}Bi), lead-210 (^{210}Pb) and polonium-210 (^{210}Po):

a all daughters were assumed to be in equilibrium with ^{226}Ra, including ^{210}Po (for which no measurements were available).

b if a ^{214}Bi activity was given, it was assumed that all of the daughters considered were present with this activity (ie secular equilibrium was assumed with all radionuclides having the measured ^{214}Bi activity). This is consistent with the gamma spectrometry measurements available.

c for objects that had not been subject to a gamma spectrometry measurement, an estimate of the ^{214}Bi activity was required. For those objects where both an activity was estimated based on in-field counts per second data and a gamma spectrometry measurement of ^{214}Bi activity was available, the average ratio between the in-field estimated activity and the gamma spectrometry measured activity was 3.5. For those objects where just an in-field estimated activity was available, this ratio was used to estimate the ^{214}Bi activity. The activity for all other daughter radionuclides considered was assumed to be equal to the activity of ^{214}Bi.

d for the most active objects found (that were not reported in the spreadsheet from SEPA), the activities of each of the daughter radionuclides was assumed to be the same as the activity reported, consistent with the available information on other retrieved objects.

For presentation purposes, the ^{226}Ra activity content has been used throughout this report. Consistent with the methodology adopted by HPA for assessing health risks from contaminated objects on the beaches around the Sellafield site [Brown and Etherington, 2011], objects were grouped into 'activity bands' for the purposes of assessing the potential health risks. The 'activity bands' are: ≤10 kBq; 10 – 100 kBq, 100 – 1000 kBq; ≥1000 kBq. The ^{226}Ra activity was used to assign objects to these activity bands. The numbers of objects found in each activity band are given in Table 1. Most of the objects detected (over 80% of the total) are within the lower activity band; only about 1% of the recovered objects fall within the highest activity band.

Table 1 Summary of objects found at Dalgety Bay by SEPA from September – December 2011[a]

Activity band (kBq)[b]	Maximum activity within activity band (kBq)	Number of objects[c]
≤ 10	10	379
10 to 100	91	70
100 to 1000	360	7
≥ 1000	76,000	4

a) Data sent to HPA by SEPA on 23rd December 2011 detailing finds made between September 2011 and December 2011. Three additional objects found in November 2011, reported by SEPA to contain 76 MBq, 4.5 MBq and 3.6 MBq, are also included.

b) Refers to the activity of radium-226 which is assumed to be in secular equilibrium with all its radioactive progeny

c) Number relates to objects recovered of any size

3 APPROACH FOR EVALUATING RISKS TO HEALTH

A robust approach was taken to scope the potential health risks to a beach user* at Dalgety Bay. The methodology was based on that used for the contaminated beach situations at Dounreay [DPAG, 2008] and Sellafield [Brown and Etherington, 2011].

* Beach user is used to cover members of the public using the area for walking, recreation and bait digging and includes the use of the area by the sailing club

Cautious assumptions were made where the currently available data on the object characteristics are limited and take into account the uncertainty in the population of objects on the beach. The cautious assumptions that were made mean that it is more likely that the health risks to beach users have been overestimated than underestimated. The population of objects over the whole beach and surrounding area and how this varies with time will only become clearer now a comprehensive monitoring strategy is being implemented. Details of the assumptions made in the scoping assessment are given in this report.

There are two main considerations when evaluating the risks to health from radioactive objects on the beach. The first is an evaluation of the likelihood that people using the beach for various activities will come into contact with radioactive objects on the beach. The second is an evaluation of the health risks that may arise if an individual does come into contact with such an object. These heath risks can be evaluated by assessing the radiation doses. These two strands together can be used to evaluate the overall risks to health for a beach user from the discrete radioactive objects that are being found on the beach.

In order to evaluate the likelihood that an individual using the beach could come into contact with a radioactive object, a number of aspects need to be considered. Firstly, an estimate of the number of objects on the beach must be made using information from the monitoring programme and data on the sensitivity of the detection system used for beach monitoring. This is termed the “population of objects”, which is the best estimate of the number of objects present on a beach and is taken to be representative of the number present at any time that the beach is used. Secondly, information is needed on the activities people engage in on the beach and the time they spend there. Lastly, the mechanisms by which an individual can become exposed to objects on the beach need to be considered, taking into account the range of activities undertaken.

In order to assess the risks to health if an individual comes into contact with an object on a beach, radiation doses were assessed using the information available on the objects that were retrieved as a result of beach monitoring and object retrieval between September and December 2011 as well as information on the characteristics of objects previously detected and removed from Dalgety Bay. These radiation doses depend on the physical and chemical characteristics of the objects, their radionuclide content and the nature and duration of exposure.

Different age groups were considered because both the probability that an individual using the beach could encounter an object and the risks to health, if an individual comes into contact with an object on a beach, depends on the age of the beach user. Three age groups were considered: young children (aged 0–5 years); children (aged 6-15 years) and adults (over 16 years). For the assessment of health risks, these ages were represented by a 1 year old for young children and a 20 year old for individuals over 16. The choice of a 1 year old child for the 0–5 years age group ensured that the highest health risks for young children who are active and mobile on the beach were assessed. Health risks were not explicitly evaluated for the 6–15 year old age group but will lie between the values for a 1 year old child and a 20 year old adult.

In order to assess the health risks associated with people using the beach, it is important to have sufficient data on the activities undertaken on the beach. A detailed habit survey for the beach and surrounding area is not currently available. Data on beach occupancy and beach activities have been compiled for West Cumbrian beaches from habit surveys undertaken in 2007 and 2009 by Cefas on behalf of the Environment Agency [Cefas 2008; 2010]. These data were used to scope the beach occupancy at Dalgety Bay and further details of the assumptions made are given in Section 4.2.

4 PROBABILITY OF ENCOUNTERING AN OBJECT ON THE BEACH

4.1 Estimating the population of objects on the beach

The estimated population of objects on the beach should be representative of the number of objects on the beach at any time that the beach is used. As stated above, the scoping assessment was based on the monitoring that was undertaken by SEPA between September and December 2011 in the coastal stretch where a large number of objects were detected and removed. A full assessment of the estimated population of objects requires detailed information on the beach monitoring including frequency of monitoring, beach areas covered and the detection efficiency of the monitoring systems used. This information will only become available with time following a considered beach monitoring programme with clear criteria which is currently being put in place. For the purposes of the scoping assessment, the following assumptions were made:

a the population of objects was estimated for the area of beach where the large number of objects were found in autumn 2011 (about 400 – 500 m stretch of beach). Figure 1 is a illustrative map of where the objects were found;

b the population of objects is remaining constant with time in this area of the beach. This is consistent with correspondence with SEPA in early 2012 [Dale, 2012] where it was reported that a similar number of objects had been detected by SEPA and the Ministry of Defence contractors in early 2012;

c the population of objects across the whole of Dalgety Bay beach is the same as that in the area of beach where the large number of objects were found in autumn 2011;

d all objects to a depth of 10 cm have been found (assuming reasonably reliable detection of objects with a few 10's of kBq of ^{226}Ra to a depth of 10 cm) [Dale, 2011]. All the objects (including those found below 10 cm) were assumed to be in the top 10 cm of sand for estimating the number of objects per gram of sand on the beach. This density of objects was then assumed to be constant to a depth of 30 cm, which is the nominal depth people were assumed to access when using the beach. These assumptions may have underestimated the total number of objects with lower activity content that will not have been detected if they are at depth. However, it is noted that objects with activities as low as 122 Bq have been detected. It is also noted that a few high activity objects (for example the 76 MBq object) have been detected at much lower depths. The potential health risks from these high activity objects were addressed separately, where appropriate, in the assessment.

The robustness of these assumptions is discussed in Section 7. The estimated population of objects expressed in both per hectare of beach and per gram of sand that were used in the scoping assessment are given in Table 2.

Table 2: Estimated population of objects on the beach[a]

Activity band (kBq)[b]	Number of objects per hectare of beach[c]	Number of objects per gram of sand[d]
≤ 10	550	$3\ 10^{-7}$
10 to 100	100	$5\ 10^{-8}$
100 to 1000	10	$5\ 10^{-9}$
≥ 1000	5	$3\ 10^{-9}$

a) Data sent to HPA by SEPA on 23rd December 2011 detailing finds made between 15th September 2011 and 6th December 2011. Three additional objects found in November 2011, reported by SEPA to contain 76 MBq, 4.5 MBq and 3.6 MBq, are also included.

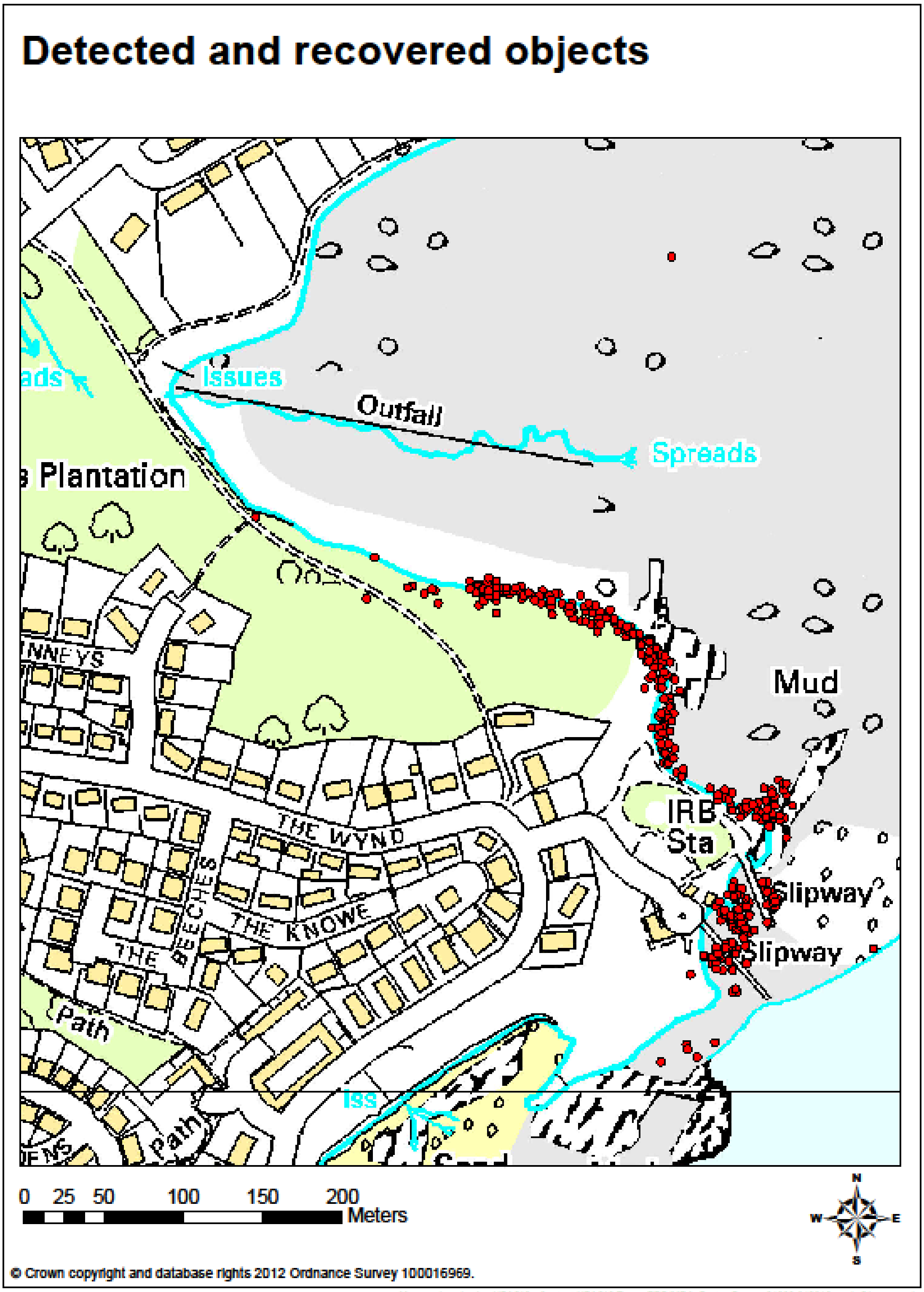
b) Refers to the activity of ^{226}Ra which is assumed to be in secular equilibrium with all its radioactive progeny

c) Number relates to objects recovered of any size

d) Calculated assuming that all detected objects were in a sand depth of 10 cm. This density of objects was then assumed to be constant to a depth of 30 cm.

4.2 Beach usage and exposure pathways

Beach usage was based on that for West Cumbrian coastline in the absence of specific habit survey data for Dalgety Bay. The habit surveys compiled for West Cumbrian beaches identified a wide range of beach activities which can be grouped because the mechanisms by which individuals come into contact with sand while carrying out these activities are similar. The grouping of beach activities provided a robust classification which could be used for other beach activities which were not identified during the habit surveys but which could be undertaken. Three groups of activities were identified; leisure activities, walking and fishing, including bait digging [Brown and Etherington, 2011]. The Leisure group included playing in sand, paddling, rock pooling and general activities on sandy beaches where sand is likely to come into contact with a large fraction of the body. People fishing and bait digging were assumed to have a large amount of sand on their hands and be engaged in energetic digging but would generally be fully clothed. The Walking group included dog walkers, general walking and those activities where the individual is likely to pick up objects occasionally from the beach but not actively dig into the sand.



Map produced using HPAGIS. Contact HPAGIS Team, ERD/MRA, Porton Down. 01980-612618 or gis@hpa.org.uk

Figure 1: Illustrative map showing objects found and recovered by SEPA between September and December 2011 [Dale, 2011]

In the absence of specific habit data for Dalgety Bay, the values for beach occupancy that were assumed were taken from the study of health risks from radioactive objects on beaches in the vicinity of the Sellafield site [Brown and Etherington, 2011]. Occupancy values for typical beach users were used. However, in order to provide an upper bound of the likelihood of beach users encountering a radioactive object, the highest occupancy identified for each group of beach users across the West Cumbrian beaches considered was also used in the assessment. It should be noted that the occupancy values for beach users with high occupancy in West Cumbria are significantly higher than those observed at beaches around Dounreay, including Sandside Bay in North West Scotland [Smith and Bedwell, 2005]. The annual occupancy observed at beaches around the Dounreay site for typical beach users are broadly similar to those observed in West Cumbria. The annual beach occupancies assumed in the scoping assessment are given in Table 3.

Table 3: Annual beach occupancy assumed[a]

	Bait digging and fishing		Walking/leisure[b]	
	Typical[c], h y^{-1}	High[d], h y^{-1}	Typical[c], h y^{-1}	High[d], h y^{-1}
Adult	90	900	120	1100
Child	60	280	40	200
Young child	0	0	70	280

a) Occupancy values were taken from Oatway *et al* (2011).

b) Values for walkers have been used to represent the annual beach occupancy for both the walkers and leisure groups (see Section 4.2 for description of beach activities considered).

c) Values for typical beach occupancy were the median values (50th percentile) of the distribution of beach occupancies across all beaches in West Cumbria for which habit surveys were undertaken.

d) Values for high beach occupancy were the highest values observed within each Group of beach users.

No specific occupancy information had been obtained at the time of this study for activities associated with the Sailing Club at Dalgety Bay. It is reasonable to assume that sailing club activities fit within the range of activities covered by the walking and leisure groups identified above and specific occupancy values were not considered for sailing club activities.

The potential for people to be exposed to objects occurs as a result of exposure to sand containing an object while using the beach. The main mechanisms by which individuals can come into contact with sand while using the beach and therefore be exposed to an object were considered in this scoping assessment. The mechanisms involve either an object entering the body or direct contact with it on the skin. Internal exposure to an object can occur from inhalation of air in which sand is resuspended and from inadvertent ingestion of sand. External exposure can occur from sand being in stationary contact with a small area of skin and the skin becoming externally irradiated. External exposure can occur from an object directly on the skin (including in the eye or ear); an object located under fingernails or toenails; an object located within clothes and an object located within shoes. The term ‘probability of encounter’ is used in the remainder of the report to refer to the likelihood of a person being exposed to an object from these exposure mechanisms.

The external gamma exposure to a person who is a short distance away from an object was estimated to be small but was included for completeness. The proximity of a person to objects on the beach was considered, in broad terms, in the estimation of radiation doses from this pathway (see Section 5.5). This exposure pathway was not included in the estimation of the probability of encountering an object via the main mechanisms identified above.

It is also possible that an individual could be exposed as a result of an object entering a wound, either if an individual is injured while on the beach or has an open wound when visiting the beach. This potential exposure pathway was considered for the study on the health risks from radioactive objects on beaches in the vicinity of the Sellafield site [Oatway *et al*, 2011]. Adopting the same scoping approach used, the probability of a beach user at Dalgety Bay coming into contact with an object via a wound was considered in the scoping assessment.

Values for the parameters used to describe how individuals can be exposed to objects on the beach were taken from Brown and Etherington (2011). Some simplifying assumptions were made for the scoping assessment due to the lack of detailed knowledge available on the beach activities undertaken. A summary of the methodology, parameter values used and the assumptions made is given in Appendix A. For estimating exposure from objects entering the body, parameters describing inadvertent ingestion rates and inhalation rates of sand from activities undertaken on the beach were used. For estimating exposure to objects in direct contact with the skin, a number of parameters were used including the areas of skin exposed to sand, the range of activities that people undertake on the beach and the amount of sand that can be trapped under nails, in clothes and in shoes during a beach visit. Best estimate values were adopted for the exposure pathway parameters used in the determination of the probability of encountering an object.

The size of the objects affects whether or not individuals are likely to be exposed to them. Objects with a size greater than about 1-2 mm are unlikely to remain in stationary contact with a small area of skin or to be inadvertently ingested and it is not possible for objects of this size to be deposited in the lungs if inhaled. It was therefore assumed that for general beach users, only objects less than a few mm diameter are likely to give rise to exposures resulting in radiation doses via these exposure pathways.

It is recognised that there may be beach users with the rare medical condition known as pica, one aspect of which can be the deliberate ingestion of large non-nutritional objects. There is also the possibility that children may put objects in their mouths and accidentally swallow them; this is most common in children between the ages of 2 and 3 [Cheng and Tam, 1999]. The deliberate or accidental ingestion of large objects is very unlikely but it is recognised that there have been a few objects with sizes of the order of a few tens of mm found that contain high levels of ^{226}Ra.

The probability of skin contact with objects of dimensions larger than a few mm containing high levels of activity, for example from sitting on one on the beach or carrying one around in a pocket, is discussed in Section 5.4.

It is reasonable to assume that people handling boats in and out of the water will be exposed to sand and beach material via the same pathways as other beach users. HPA is aware that people carry out boat maintenance over the winter months and may lie or crouch on the ground and therefore be close to objects on the beach and the boat-storage areas around the Sailing Club. Exposure via skin contact is unlikely to be higher than for other beach users and is likely to be lower during winter as heavier clothing will be worn. External gamma doses from close proximity to objects were considered (see Section 5.5).

4.3 Annual probability of encountering radioactive objects

The estimated probabilities of encounter were very similar for the three groups of beach users (walkers, leisure activities and bait diggers /anglers) and so these were considered together as a general group of beach users for the scoping assessment. It was assumed for the purposes of estimating the probability of encounter that all objects on the beach were of a size that could be 'encountered' via the different exposure pathways considered, ie, they could be inadvertently ingested, inhaled or become trapped against the skin. The estimated probabilities of encounter are conservative because they assumed that the whole beach area is contaminated with radioactive objects at the density observed on the area of the beach where a high number of objects were detected and removed during the autumn of 2011. Although there is uncertainty in the numbers of objects on the rest of the beach, there was no evidence at the time of the study that higher densities of objects had been found in the past or as part of the current monitoring programme. A comprehensive monitoring programme has been set up to continue to characterise the contamination on the beach and remove contaminated objects at Dalgety Bay.

The estimated annual probability of encounter is dependent on the estimated number of objects that could be on the beach, the activities undertaken on the beach and the time members of the public spend on the beach. An overview of the methodology used is given in Appendix A. The estimated probabilities of encounter are given for typical beach users in Table 4. The estimated probability of a typical beach user encountering an object, summed over the different exposure pathways considered, ranged from $1\ 10^{-4}$ (chance of 1 in 10 thousand per year) to $1\ 10^{-3}$ (chance of 1 in one thousand per year). Based on the information available, the probability of encounter was highest for adult beach users, with values for children typically being about a factor of 2–3 lower. The majority of the objects recovered from the beach have an activity of <10 kBq and the total annual probability was dominated by the probability of encountering such objects, as can be seen in Table 4. The probability of encountering objects with activities greater than 1 MBq (the highest activity range considered) was less than 1 in 100 thousand per year. It should be noted that only 4 objects with activities in this range were detected in the period considered and the highest activity objects were not close to the surface and were of sizes greater than a few mm in diameter.

The estimated annual probability of encountering an object, summed over the different exposure pathways considered, for individual beach users with high annual beach occupancy ranged from $1\ 10^{-3}$ (chance of 1 in one thousand per year) to about $5\ 10^{-3}$ (chance of 1 in two hundred per year), as shown in Table 5. It should be noted that the annual occupancy used for these beach users equated to adults spending 3 hours per day on the beach and children spending a few hours per week on the beach.

From the results in Tables 4 and 5, some general observations can be made on which routes of exposure are more likely to lead to an individual being exposed to an object. The most likely way this can occur is from the object adhering to the skin or becoming trapped in clothing or shoes so that it is in stationary contact with a small area of skin for an extended period of time. The results showed that the probability of inadvertently ingesting an object was very small (much lower than 1%); the probability of inhaling an object was even smaller.

Adopting the same scoping approach used in the study on the health risks from radioactive objects on beaches in the vicinity of the Sellafield site [Oatway *et al*, 2011], the probability of a beach user at Dalgety Bay coming into contact with an object via a wound was estimated to be extremely low and at least two orders of magnitude lower than that from inadvertent ingestion. Using the results in Table 4, the annual probability of encounter from this exposure pathway was therefore estimated to be no higher than 1 in 1000 million for a typical adult beach user and 1 in 100 million for a young child. Due to this extremely low probability of encounter, this exposure pathway was not considered further in the scoping assessment.

As noted in Section 4.2, there may be beach users with the rare medical condition known as pica, one aspect of which can be the deliberate ingestion of large non-nutritional objects. There is also the possibility that young children may put objects in their mouths and accidentally swallow them. There has been a lot of focus on an object that was retrieved from the beach containing an estimated 76 MBq of ^{226}Ra. This object had an estimated size of 60 x 50 x 35 mm [Dale, 2011]. These dimensions are at the upper end of sizes that can physically be ingested by an adult (about 70 mm) [ICRP, 2006; Oatway *et al*, 2011]. It is larger than the maximum size that can be ingested by children; values of about 20 mm for a 1 year-old and 40 mm for a 10 year-old, based on the size of coins that can be swallowed by children of different ages, can be found from reviewing the open literature [Oatway *et al*, 2011]. Very few objects with very high activity have been found on the beach: only 3 objects with ^{226}Ra activities of a few MBq and one object with a ^{226}Ra activity significantly higher than this (the 76 MBq object) were found between September and December 2011. When considering the 76 MBq object, it is also very important to note that it was found at a depth of about 75cm and was, therefore, not readily accessible to beach users, although it is possible that, due to the dynamic nature of the beach environment, it may have been more accessible to beach users at some point in time. These factors taken together mean that the likelihood that a person with pica both uses the beach and finds and deliberately ingests a large object with such a high activity is extremely low. It is acknowledged that, if an object with this activity was ingested, it could give rise to a high radiation dose and this has been considered in Section 5.2 as part of the scoping assessment. From the limited information available on the approximate sizes of the 3 objects with ^{226}Ra activities of a few MBq, it cannot be ruled out that they may be small enough to be accidentally swallowed by children. However, as only a very small number of such objects have been found on the beach, it is extremely unlikely that a child would find and ingest one.

Table 4: Annual probability of encountering radioactive object for a typical beach user as a function of age[a]

Activity band (kBq)[b]	Inhalation	Ingestion	Skin contact[c]	Total
Adult (aged 20 years)				
≤ 10	$2\ 10^{-8}$	$1\ 10^{-7}$	$5\ 10^{-4}$	$5\ 10^{-4}$
10 to 100	$4\ 10^{-9}$	$3\ 10^{-8}$	$1\ 10^{-4}$	$1\ 10^{-4}$
100 to 1000	$4\ 10^{-10}$	$3\ 10^{-9}$	$1\ 10^{-5}$	$1\ 10^{-5}$
≥ 1000	$2\ 10^{-10}$	$2\ 10^{-9}$	$6\ 10^{-6}$	$6\ 10^{-6}$
Total	$2\ 10^{-8}$	$2\ 10^{-7}$	$7\ 10^{-4}$	$7\ 10^{-4}$
Child (aged 10 years)				
≤ 10	$8\ 10^{-10}$	$9\ 10^{-8}$	$1\ 10^{-4}$	$1\ 10^{-4}$
10 to 100	$2\ 10^{-10}$	$2\ 10^{-8}$	$2\ 10^{-5}$	$2\ 10^{-5}$
100 to 1000	$2\ 10^{-11}$	$2\ 10^{-9}$	$2\ 10^{-6}$	$2\ 10^{-6}$
≥ 1000	$9\ 10^{-12}$	$9\ 10^{-10}$	$1\ 10^{-6}$	$1\ 10^{-6}$
Total	$1\ 10^{-9}$	$1\ 10^{-7}$	$2\ 10^{-4}$	$2\ 10^{-4}$
Young child (aged 1 year)				
≤ 10	$9\ 10^{-10}$	$8\ 10^{-7}$	$2\ 10^{-4}$	$2\ 10^{-4}$
10 to 100	$2\ 10^{-10}$	$1\ 10^{-7}$	$4\ 10^{-5}$	$4\ 10^{-5}$
100 to 1000	$2\ 10^{-11}$	$1\ 10^{-8}$	$4\ 10^{-6}$	$4\ 10^{-6}$
≥ 1000	$9\ 10^{-12}$	$9\ 10^{-9}$	$2\ 10^{-6}$	$2\ 10^{-6}$
Total	$1\ 10^{-9}$	$1\ 10^{-6}$	$3\ 10^{-4}$	$3\ 10^{-4}$

a) Probability of encounter is very similar for all beach users, regardless of activity undertaken. Values for walkers are presented.

b) Refers to the activity of ^{226}Ra which is assumed to be in secular equilibrium with all its radioactive progeny

c) Includes a contribution from objects on the skin (50%), in shoes (43%), in clothing (7%) and under fingernails (<1%)

Table 5: Annual probability of encountering any object for a high occupancy beach user as a function of age[a]

Activity band (Bq)[b]	Inhalation	Ingestion	Skin contact[c]	Total
Adult (aged 20 years)				
≤ 10	$2\ 10^{-7}$	$1\ 10^{-6}$	$5\ 10^{-3}$	$5\ 10^{-3}$
10 to 100	$3\ 10^{-8}$	$2\ 10^{-7}$	$9\ 10^{-4}$	$9\ 10^{-4}$
100 to 1000	$3\ 10^{-9}$	$2\ 10^{-8}$	$9\ 10^{-5}$	$9\ 10^{-5}$
≥ 1000	$2\ 10^{-9}$	$1\ 10^{-8}$	$5\ 10^{-5}$	$5\ 10^{-5}$
Total	$2\ 10^{-7}$	$2\ 10^{-6}$	$6\ 10^{-3}$	$6\ 10^{-3}$
Child (aged 10 years)				
≤ 10	$5\ 10^{-9}$	$5\ 10^{-7}$	$8\ 10^{-4}$	$8\ 10^{-4}$
10 to 100	$9\ 10^{-10}$	$9\ 10^{-8}$	$1\ 10^{-4}$	$1\ 10^{-4}$
100 to 1000	$9\ 10^{-11}$	$9\ 10^{-9}$	$1\ 10^{-5}$	$1\ 10^{-5}$
≥ 1000	$5\ 10^{-11}$	510^{-9}	$8\ 10^{-6}$	$8\ 10^{-6}$
Total	$6\ 10^{-9}$	$6\ 10^{-7}$	$9\ 10^{-4}$	$9\ 10^{-4}$
Young child (aged 1 year)				
≤ 10	$4\ 10^{-9}$	$3\ 10^{-6}$	$9\ 10^{-4}$	$9\ 10^{-4}$
10 to 100	$7\ 10^{-10}$	$6\ 10^{-7}$	$2\ 10^{-4}$	$2\ 10^{-4}$
100 to 1000	$7\ 10^{-11}$	$6\ 10^{-8}$	$2\ 10^{-5}$	$2\ 10^{-5}$
≥ 1000	$4\ 10^{-11}$	$4\ 10^{-8}$	$1\ 10^{-5}$	$1\ 10^{-5}$
Total	$5\ 10^{-9}$	$4\ 10^{-6}$	$1\ 10^{-3}$	$1\ 10^{-3}$

a) Probability of encounter is very similar for all beach users, regardless of activity undertaken. Values for walkers are presented.

b) Refers to the activity of ^{226}Ra which is assumed to be in secular equilibrium with all its radioactive progeny

c) Includes a contribution from objects on the skin (50%), in shoes (43%), in clothing (7%) and under fingernails (<1%)

5 RADIATION DOSES AND HEALTH EFFECTS FROM ENCOUNTERING AN OBJECT ON THE BEACH

Health effects can generally be categorised as:

- *stochastic effects*, principally cancer. The probability of occurrence of the effect increases with increasing radiation dose without a threshold, but the severity of the effect is independent of dose [ICRP, 2007]. Stochastic effects may take many years to develop;
- *deterministic effects*, which occur only for high radiation doses above a certain *threshold*. The threshold is usually set at the level of dose corresponding to a risk of 1% that the effect would occur. At the threshold, the severity of the effect would be relatively low. Once the threshold is exceeded, the severity of the effect increases with increasing dose. Deterministic effects often occur within hours or days of the radiation exposure. Examples include skin ulceration, or depletion of red bone marrow cells.

Where the aim is to assess the likelihood and severity of deterministic effects, the absorbed dose to organs (for example the skin) is the dosimetric quantity that should be used. The unit of absorbed dose is the gray, abbreviated to Gy. To ensure an adequate level of radiological protection, the probability of stochastic effects also needs to be considered and equivalent doses to organs and effective dose are the dosimetric quantities that can be used. The unit of both equivalent dose and effective dose is the sievert, abbreviated to Sv. The equivalent dose to an organ is determined from the absorbed dose by multiplying by a radiation weighting factor which broadly reflects the differences in the effectiveness of each radiation type in causing stochastic effects. Effective dose provides a single quantity that broadly reflects the risk of stochastic effects across a population, summed over all organs and tissues. In this study, the term committed effective dose is used to describe the effective dose received from intake of activity associated with an object integrated over the lifetime of the individual to age 70, ie 50 years for an adult and 69 years for a 1-year-old child.

Risks of stochastic effects were evaluated for intakes by ingestion for a 1 year old child and a 20 year old adult. Risks for a 10 year old child lie between the values for these two ages. The lifetime risks of radiation-induced fatal cancer were estimated using the committed effective doses that would result from an object being inhaled or ingested and a risk factor of 16% per Sv and 9% per Sv for a 1 year old child and a 20 year old adult, respectively [Haylock, 2010]. The risks are for all cancers, calculated using the ICRP Publication 103 excess relative and additive risk models for all solid cancers [ICRP, 2007] and UNSCEAR relative and additive risk models for leukaemia [UNSCEAR, 2006]. The calculations of the lifetime risk of radiation-induced fatal cancer took into account the fact that the dose is received over many years following the intake, as well as the increase in age of the individual over the period that the dose is received. It may be noted that the adult value differs from ICRP's nominal risk coefficient for lethally-adjusted cancer risk for adult workers of 4.1% Sv^{-1} [ICRP, 2007] mainly because ICRP's value is averaged over ages between 18 and 64 and risks decrease with age because of decreasing life expectancy.

5.1 Classification of objects

For the purposes of evaluating doses and risks to health, it was assumed, based on information on recent and past objects retrieved, that all objects contain ^{226}Ra and the daughter radionuclides ^{214}Pb, ^{214}Bi, ^{210}Pb and ^{210}Po are in equilibrium, ie for this decay chain, equal activities of each of the radionuclides in each object.

As discussed in Section 4.2, objects with a size greater than about 1 -2 mm are unlikely to remain in stationary contact with a small area of skin or to be inadvertently ingested and it is not possible for objects of this size to be deposited in the lungs if inhaled. Using the information available for objects where the size has been estimated [Dale, 2011], the maximum activity has been estimated for objects with sizes up to 1 mm. It has been assumed that the radionuclides are distributed homogeneously throughout each object and that the activity content is proportional with size. Using these assumptions, the ^{226}Ra content for a 1 mm object was estimated to be in the range of 7 Bq to 100 kBq using the size information available. For this scoping assessment, a cautious value of 100 kBq was used to estimate the doses and health risks if an object is encountered via the exposure mechanisms considered, ie. the assumption has been made that all objects have a ^{226}Ra activity of 100 kBq. The lower ^{226}Ra activities in the majority of the objects that have been found (see Table 1) were not taken into account in the evaluation of doses and risks to health. There is some information that some of the objects that were retrieved from the beach during the autumn of 2011 were friable and broke up in-situ into small fragments. This may lead to it being more likely that beach users could come into contact with ^{226}Ra activity via the exposure mechanisms considered. In the scoping assessment, the conservative assumption was made when estimating the health risks that all objects contain 100 kBq of ^{226}Ra and that all objects, regardless of size, could be encountered, as described above. The situation that smaller fragments resulting from objects breaking up on the beach may contain the majority of the activity that was in the original object was therefore taken into account in the scoping of health risks.

5.2 Doses and health effects from ingestion of radioactive objects on the beach

It is very unlikely that an object will be inadvertently ingested (see Section 4.3). Assuming a cautious solubility of the object in the gut of 25% [SEPA, 2011; Dale, 2012], the committed effective doses were calculated for an adult and a 1 year old child ingesting an object with a ^{226}Ra activity of 100 kBq. The corresponding lifetime risk of death from all radiation-induced cancers arising from these doses was also estimated. The doses and risks arising from these doses are given in Table 6. Both doses and health risks may be assumed to scale with the activity of the object, although care is needed in the interpretation of health risks when doses become high enough for deterministic effects to occur.

Table 6: Committed effective doses and health effects from inadvertent ingestion of an object with a ^{226}Ra activity of 100 kBq

Age	Committed effective dose[a], mSv	Lifetime risk of radiation-induced fatal cancer,%
Adult	55	0.5
Young child	330	5

a) Solubility of object in the gut of 25% assumed

Deterministic effects arising from localised doses to the gut and red bone marrow following ingestion of an object were also considered. The most appropriate way to assess the likelihood that deterministic effects could occur is to determine whether the threshold for the effect could be exceeded. Scoping calculations indicated that the absorbed doses to the gut and red bone marrow following ingestion of an object with a ^{226}Ra activity of 100 kBq would be much lower than the threshold absorbed doses for acute exposure of 6 Gy and 1 Gy, for the gut and red bone marrow, respectively [ICRP, 2012]. The absorbed doses to both the gut and red bone marrow were estimated to be of the order of 0.001 Gy.

In Section 4.3, it was noted that, although extremely unlikely, if a person with pica had found and deliberately ingested the large object retrieved from the beach containing 76 MBq of ^{226}Ra (estimated size of 60 x 50 x 35 mm), it could have given rise to a high radiation dose. The calculation of doses for ingestion of an object of this type is complex and depends on its detailed characteristics (including solubility, how the contamination is distributed within the object, its friability etc) which are not yet known. It was therefore, in any case, not possible to accurately calculate doses from ingestion of this object. However, based on very cautious assumptions for estimating doses, the possibility of acute organ damage or bone marrow failure cannot be excluded following ingestion of such an object [Harrison *et al*, 2007].

5.3 Doses and health effects from inhalation of radioactive objects on the beach

There is some observational evidence [Dale, 2011] that some of the objects retrieved from the beach have been very friable and resemble fine dust. Individual particles of this size will not have been detected and retrieved from the beach. A conservative scoping assessment has therefore been made of potential inhalation doses on the basis that objects on the beach may break down into small particles in-situ.

Whether an object can be inhaled (that is, whether it can enter the nose or mouth) depends on particle size, breathing conditions, and ambient air velocity and direction. After an object is inhaled, the location of deposition within the respiratory tract depends mainly on aerodynamic diameter and inhaled particles with aerodynamic diameters in excess of a few tens of µm would only be deposited in the extra-thoracic airways rather than the lungs. It is only for particles smaller than about 10 µm that there is a significant probability of a particle reaching the alveolar-interstitial region of the lungs [Jarvis et al, 1996].

The inhalation of a single particle was considered. The activities of particles of different sizes were estimated by scaling the activity with the size of the particle assuming homogeneity within the object. For example, based on an object of 1 mm diameter containing 100 kBq of ^{226}Ra, a 100 µm particle would contain 100 Bq, a 10 µm particle would contain 0.1 Bq and a 1 µm particle would contain 0.0001 Bq. Table 7 gives the estimated committed effective doses for an adult for particles of 100µm, 10µm and 1 µm. These doses and the associated lifetime risks of radiation-induced fatal cancer are extremely small. Even if a few of these objects were inhaled at the same time during a beach visit, the doses would remain very small.

Table 7: Committed effective doses and health effects from inhalation of a single particle of different sizes

Particle diameter, µm	Assumed ^{226}Ra content[a], Bq	Committed effective dose[a,b], µSv	Lifetime risk of radiation-induced fatal cancer[b],%
100	100	100	$9\ 10^{-4}$
10	0.1	0.2	$2\ 10^{-6}$
1	0.0001	0.001	$9\ 10^{-9}$

a) Based on a 1 mm diameter particle containing 100,000 Bq (100 kBq) of ^{226}Ra.

b) Values for adults.

A theoretical calculation of the upper limit on the committed effective doses from inhalation of particles of different sizes was made. The very conservative assumption was made that an object breaks down simultaneously into small inhalable sizes and is breathed in by a beach user such that the intake is 100 kBq of ^{226}Ra. Committed effective doses were estimated for the object breaking down into different particle sizes and the deposition probabilities in different areas of the lung for each particle size were taken into account. The estimated doses from an intake of 100 kBq of ^{226}Ra (including the daughters in secular equilibrium) to an adult are given in Table 8.

This is a theoretical calculation because there are a number of factors that, in practice, would significantly reduce the doses given in Table 8 from the potential break down of an object containing 100 kBq of ^{226}Ra. The main factors are: the size distribution of the particles if an object breaks down into smaller fragments; the likely dispersal of any such particles and fragments over an area of the beach; how much of this particulate material could be resuspended into the air; and how much of this resuspended material would be inhaled. In practice, HPA judges that the committed effective doses would be at least 2 to 3 orders of magnitude lower than those given in Table 8.

Table 8: Committed effective doses from the theoretical inhalation of particles of different sizes with a total intake of 100 kBq of ^{226}Ra

Particle size, µm	Committed effective dose[a,b], mSv
100	100
10	200
1	1000

a) These doses are calculated assuming, very conservatively, that an intake of 100 kBq of ^{226}Ra (with equal activities of the daughter radionuclides) occurs, with this entire intake being at the given particle sizes. In practice, any intake could only be a very small fraction of the amount of activity available for intake.

b) Values for adults.

The likelihood of an individual inhaling an object is also very low and was estimated to be $2\ 10^{-8}$ (1 in 50 million per year) for a typical beach user (see Section 4.3). It should be noted that this was estimated assuming that the sand and any associated contaminated particles on the beach were dry enough to become airborne.

The detailed models to calculate the deposition probabilities in different areas of the lung for each particle size for children are not available and so it is not possible to undertake an equivalent theoretical calculation for children. Using default ICRP parameters (in particular an aerodynamic diameter of 1 µm, which is associated with the highest dose per unit intake values), committed effective doses for a 1 year old child could be expected to be up to a few times higher than those for adults.

Deterministic effects arising from localised doses to the lung following inhalation were also considered. Particles with an aerodynamic diameter of 1 µm give rise to the highest absorbed doses to the lung. Scoping calculations indicated that absorbed doses to the lung following inhalation of a single intake of 1 µm particles containing a total ^{226}Ra activity of 100 kBq would be much lower than the threshold absorbed dose for acute exposure of 6.5 Gy [ICRP, 2012]; the absorbed dose was estimated to be less than 0.5 Gy.

5.4 Doses and health effects from radioactive objects on the skin

The irradiation of the skin resulting from stationary contact of the objects with the skin is the exposure route with the greatest potential for deterministic effects on health. The most appropriate way to assess the likelihood that deterministic effects could occur is to determine whether the threshold for the effect could be exceeded. The available animal data on the effects of hot particle irradiation of skin, mainly from studies using pigs but supported by human data, allow the estimation of an ED_{50} value (1 cm^2, 70 µm)* for acute ulceration of about 10 Gy and a threshold of about 2 Gy. It is clear from these data, together with data for larger skin area exposures, that toleration of radiation will be increased when a particle moves during skin contact, by even a few mm, and when dose rates are low [Harrison *et al*, 2005].

The work undertaken by Monty Charles at Birmingham University on behalf of SEPA in 2008 and 2010 [Charles, 2008; Charles and Gow, 2010] has been used to scope the likely doses to the skin from contact with an object. The 2008 theoretical study estimated an absorbed skin dose of about 5.5 Gy h^{-1} for a nominal 1 MBq ^{226}Ra object using ICRP recommendations on skin thickness and exposed area. In the 2010 study, radiochromic dye film measurements were made on 10 objects. Two medium sized objects (with linear dimensions of about 3mm) gave the highest skin dose rates which can be normalised to 1 MBq of ^{226}Ra giving about 1 Gy h^{-1}.

It was reported by SEPA [Dale, 2011] that the objects found in autumn 2011 had a different appearance to the earlier objects retrieved from the beach, which were typically metallic clinker. The gamma spectrometry measurements showed that the ^{226}Ra daughters were approximately in equilibrium with the ^{226}Ra parent as was the case with the earlier objects. Some provisional empirical measurements made by Stirling University were available on the timescale required for the scoping assessment and HPA was also undertaking theoretical calculations of skin contact doses. However, due to the preliminary nature of this work, it was decided to use the results from Charles and Gow (2010) as the basis for estimating the external doses to the skin from skin contact with objects. A scaling factor of 1 MBq of ^{226}Ra giving 1 Gy h^{-1} was used.

* ED_{50} is the value at which the effect is seen in 50% of the population. Doses are calculated for a skin area of 1 cm^2 at a depth of 70 µm, abbreviated as (1 cm^2, 70 µm).

It was assumed that an object of size about 1mm diameter (grain of sand) is the largest size that would get trapped under a nail or remain in stationary contact on the skin in shoes or clothes [Oatway *et al*, 2011]. An object of this size containing 100 kBq of ^{26}Ra (see Section 5.1) would give a dose to the skin of 0.1 Gy h^{-1}. The threshold for localised skin ulceration (2 Gy) would not be reached for 20 hours. As indicated above, this threshold dose only applies for objects in stationary contact, and if the object is moved by a distance equivalent to its own size, then the threshold value would be significantly higher. It is therefore unlikely that objects could remain in stationary contact with the skin for this length of time.

The attractiveness of larger contaminated artefacts on the beach that may lead to them being preferentially picked up by members of the public has been identified as a potential exposure pathway. As identified above, there has been a lot of focus on a single object that was retrieved from the beach containing an estimated 76 MBq of ^{226}Ra. This object had an estimated size of 60 x 50 x 35 mm [Dale, 2011]. The threshold dose for localised skin ulceration as a result of contact with a large object, at 10-20 Gy, is higher than that for a smaller particle because a large object is a distributed source rather than a point source [Brown and Etherington, 2011]. Using this information, this object would give the dose required to cause localised skin ulceration in about 20 minutes if it was picked up from the beach, put in a pocket and remained in stationary contact close to the skin.

When considering these potential exposures from picking up and carrying around objects or artefacts that may contain a high content of ^{226}Ra, it should be remembered that the severity of the effect would be relatively low and the skin would heal. Also, the toleration to the exposure will be increased when a particle moves across the surface of the skin during contact, even by only a few mm.

Only objects containing a ^{226}Ra activity of greater than 1 MBq could give rise to the doses required to cause skin reddening or localised ulceration of the skin if picked up and kept in a pocket or directly sat on for a few hours. Only a few objects have been found with ^{226}Ra activities at this level. Advice has been given to local beach users not to pick up objects from the beach. It is very important that objects that contain ^{226}Ra activity at levels that could give rise to localised skin ulceration do not remain on the beach. HPA continues to recommend that monitoring and recovery of contaminated objects is undertaken as part of a comprehensive monitoring strategy to ensure the on-going protection of the public.

There is some evidence that contamination may not be homogeneously distributed either within the larger objects found or over their surface. If it is conservatively assumed that the threshold for localised skin ulceration for larger objects is 2 Gy (the same as for small objects), a large object containing 76 MBq of ^{226}Ra within a small volume or on a small area of its surface would give rise to the doses required to cause localised skin ulceration within about 10 minutes if it remained in stationary contact close to the skin. As stated above, it is therefore very important that objects that contain ^{226}Ra activity at such high levels do not remain on the beach.

5.5 Effective dose from external irradiation

The effective doses from external irradiation to a person standing a short distance away from an object or lying on the ground close to an object was considered. The calculation of effective doses from discrete objects arising from beta and gamma irradiation is complex. Scoping calculations indicated that gamma irradiation is the major contributor to the effective dose from external irradiation and the doses are presented below. External gamma doses* for three situations were calculated:

a lying face-down on the ground directly over an object;
b lying face-up on the ground directly over an object;
c standing 0.5 m away from an object on the ground.

The exposures were modelled using Monte Carlo analyses for ICRP reference male and female phantoms [ICRP, 2009]. For the purposes of the scoping assessment, the calculations were carried out for the object that was retrieved from the beach containing an estimated 76 MBq of ^{226}Ra; this object had an estimated size of 60 x 50 x 35 mm [Dale, 2011]. It was assumed that the contamination was homogeneously distributed throughout the volume of the object and the reference point for calculating the external gamma doses was on the front of the body at the bottom of the sternum. For the cases where a person is lying on an object on the ground, it was assumed that the largest face of the object just touches the outer surface of the skin. The estimated external gamma dose-rates for these three situations are given in Table 9 for both the object containing an estimated 76 MBq of ^{226}Ra (estimated size of 60 x 50 x 35 mm) and for an object containing 100 kBq ^{226}Ra (consistent with the approach adopted for other exposure pathways, as described in Section 5.1).

Table 9: Effective dose rates from external gamma irradiation from being in close proximity to an object on the ground

Scenario	Effective dose rate from external gamma irradiation, µSv h^{-1}	
	Object with activity of 100 kBq ^{226}Ra^{a}	Object with activity of 76 MBq ^{226}Ra^{a}
Lying face-down over an object on the ground surface	0.4	330
Lying face-up over an object on the ground surface	0.3	220
Standing on the beach	0.007	5

a) Refers to the activity of radium-226 which is assumed to be in secular equilibrium with all its radioactive progeny

5.5.1 External gamma doses from lying on the beach

Using the external gamma dose rates in Table 9, external gamma doses were estimated for individuals sun-bathing on the beach or lying on the beach, for example undertaking boat maintenance. An individual lying directly over an object containing

* The effective dose from external gamma irradiation is referred to as 'external gamma dose' in the rest of this Section.

100 kBq of ^{226}Ra for 120 hours a year (see Table 3) would receive an external gamma dose of about 30 – 50 µSv, the higher dose being for a person lying face down on the beach.

It is highly unlikely that an individual would lie directly on a large object for any significant period of time as it would be uncomfortable. However, if it is assumed very conservatively that an individual did lie on an object on the ground surface for 8 hours with a similar activity to the large 76 MBq ^{226}Ra object retrieved from the beach during the autumn of 2011, the external gamma dose would be about 3 mSv. External doses to the skin arising from objects being in contact with the skin are addressed separately in Section 5.4.

5.5.2 External gamma doses from walking on the beach

Using the external gamma dose rates in Table 9, external gamma doses were also estimated for individuals walking on the beach. It was assumed that a typical beach user walking on the beach for 120 hours per year (see Table 3) will always be close to a few objects on or near the surface of the beach and that there are always 2 objects, each containing 100 kBq of ^{226}Ra, within 0.5 m of them. It was estimated that this would lead to an external gamma dose of about 1 µSv. An individual standing within 0.5 m of a 76 MBq ^{226}Ra object on the beach surface for an hour would receive a dose of about 5 µSv. Being close to a large number of low activity objects will also give rise to very small external gamma doses.

6 OVERALL RISKS TO A BEACH USER

The annual probability of coming into contact with an object while spending time on a beach was estimated (Section 4.3). When evaluating the overall risks to the health of a beach user in the unlikely event that contact with an object does occur, effects on health arising from both deterministic effects and stochastic effects must be considered.

Deterministic effects. If absorbed doses are well below thresholds, then deterministic effects will not occur whatever the probability of encounter.

Stochastic effects. The overall risk to the beach user may be determined by multiplying the annual probability of encountering an object by the risk that that a person would contract a fatal cancer during his or her lifetime if exposure to the object did occur. It is justified to multiply the two probabilities together to determine the overall risk since they are independent of each other [ICRP, 2007]. The result of this calculation is the probability that the person would contract a fatal cancer at some point during his or her lifetime as a result of using a beach over a period of 1 year.

The overall risks discussed were derived using cautious assumptions about the probability of encountering an object and the activity content of these objects; all objects were assumed to contain 100 kBq of ^{226}Ra with all the daughters in secular equilibrium.

The greatest potential for stochastic effects on health was from the ingestion of objects. Table 10 shows the highest estimated lifetime risk of radiation-induced fatal cancer for an adult resulting from one year's potential exposure by ingestion. Table 11 shows the same information for young children (1 year old). The highest estimated overall risks for a typical beach user were estimated to be very small, with the chance of dying from cancer as a result of one year's potential exposure being $5\ 10^{-8}$ (chance of 1 in 20 million per year) for ingestion of an object by a 1 year old child. The highest overall risks were from the lower activity particles because the probability of encountering these is at least a hundred times higher than for the highest activity particles, as shown in Tables 4 and 5.

Table 10: Estimated overall risks of fatal cancer for an adult beach user associated with possible ingestion of particles as a result of using Dalgety Bay beach for a period of 1 year[a]

	Typical occupancy	High occupancy
Activity, Bq[b]	10^5	10^5
Effective dose, mSv	55	55
Lifetime risk of cancer if particle ingested, %	$5\ 10^{-1}$	$5\ 10^{-1}$
Annual probability of ingesting a particle	$2\ 10^{-7}$	$2\ 10^{-6}$
Overall risk of fatal cancer	**$9\ 10^{-10}$**	**$8\ 10^{-9}$**

a) Where contamination from discrete objects could result in effective doses above 50 mSv y^{-1}, then consideration needs to be given to the possibility of deterministic health effects in addition to the probability of the dose being received [HPA, 2006]. The possibility of deterministic effects was addressed in the scoping assessment.

b) Refers to the activity of ^{226}Ra which is assumed to be in secular equilibrium with all its radioactive progeny

Table 11: Estimated overall risks of fatal cancer for a young child beach user associated with possible ingestion of particles as a result of using Dalgety Bay beach for a period of 1 year[a]

	Typical occupancy	High occupancy
Activity, Bq[b]	10^5	10^5
Effective dose, mSv	330	330
Lifetime risk of cancer if particle ingested, %	5	5
Annual probability of ingesting a particle	$1\ 10^{-6}$	$4\ 10^{-6}$
Overall risk of fatal cancer	**$5\ 10^{-8}$**	**$2\ 10^{-7}$**

a) Where contamination from discrete objects could result in effective doses above 50 mSv y^{-1}, then consideration needs to be given to the possibility of deterministic health effects in addition to the probability of the dose being received [HPA, 2006]. The possibility of deterministic effects was addressed in the scoping assessment.

b) Refers to the activity of radium-226 which is assumed to be in secular equilibrium with all its radioactive progeny

The exposure route with the greatest potential for deterministic effects on health is irradiation of the skin resulting from stationary contact of objects with the skin. For an object to deliver a radiation dose to the skin which could give rise to localised ulceration of the skin, it has to remain in stationary contact with the same small area of skin for an extended period of time. This is very unlikely in an environment where people are undertaking a range of activities on a beach. As discussed in Section 5.4, the exposure time required to reach the threshold dose of 2 Gy would be about 20 hours for an object containing 100 kBq of ^{226}Ra (estimated to be a conservative activity content of an object of approximately 1mm diameter and which could, therefore, remain in stationary contact with the skin for some time). If the threshold value was reached, the severity of the effect would be relatively low and the skin would heal. Given these reassuring findings, the probability of encountering such objects is of secondary importance. However, it may be noted that the estimated annual probability of encountering any object on the skin (irrespective of ^{226}Ra content), either directly or from an object trapped in clothing or shoes, was less than about 10^{-3} for a typical beach user (1 in 1000 per year). The likelihood of getting an object on the skin containing 100 kBq of ^{226}Ra would be at least a factor of ten lower.

As noted in Section 5.2 the possibility of organ damage or bone marrow failure cannot be excluded following deliberate ingestion of a large, very high activity object, such as the object containing 76 MBq of ^{226}Ra found in autumn 2011. However, since only one such object has been found, and its size excluded the possibility of inadvertent ingestion, this does not change the overall public health risk to beach users.

The potential risks of deterministic effects from high activity objects mean that it is very important that objects that contain ^{226}Ra activity at levels that could give rise to localised skin ulceration or to organ/tissue damage from ingestion do not remain on the beach. HPA continues to recommend that frequent monitoring and recovery of contaminated objects is undertaken as part of a comprehensive monitoring strategy to ensure the on-going protection of the public.

7 ROBUSTNESS OF THE SCOPING ASSESSMENT OF OVERALL RISK TO BEACH USERS

A scoping public health risk assessment for people currently using the beach at Dalgety Bay was carried out at the request of the Scottish Executive Health Department. It was recognised that the scoping assessment was being undertaken prior to sufficient data being available for a full public health risk assessment. Cautious assumptions were made where the currently available data on the object characteristics are limited and there is uncertainty associated with the population of objects on the beach. In particular, it was assumed that the population of objects across the whole of Dalgety Bay accessed by the public was the same as that in the area of beach where the high density of objects was found between September and December 2011. It was also assumed that all objects can be encountered by the exposure mechanisms considered irrespective of their size and that they all contain 100 kBq of ^{226}Ra. It should be noted that over 80% of the objects detected and retrieved by SEPA from the area of the beach where the high density of objects were found had a ^{226}Ra activity below 10 kBq. The cautious assumptions that were made mean that is more likely that the health risks to beach users have been overestimated than underestimated.

It was noted in Section 4.1 that the number of low activity objects on the beach may have been underestimated as these are more likely to have not been detected, particularly if they are at depth. The other conservative assumptions made regarding the population of objects on the whole beach and the assumption that all objects have a

^{226}Ra content of 100 kBq when estimating the overall health risks are such that the health risks will not have been underestimated.

HPA has recommended that a detailed public health risk assessment needs to be commissioned and that this can only be carried out if actions are taken to obtain the quantitative information required to inform it. Specifically, this should include: comprehensive monitoring of the beach area over several seasons carried out with clear criteria on the capability of the detection system used; further characterisation of the different types of radioactively contaminated objects found including appropriate measurements from which potential doses to the skin from contact with objects can be evaluated; and a full survey of the usage of the beach to determine the activities that people engage in and the time they spend on the beach. It is also recognised that there may be other exposure pathways that warrant further investigation as more information becomes available. One such pathway is beach users getting a radioactive object in a wound while using the beach.

8 HPA'S ADVICE TO SCOTTISH GOVERNMENT

Having undertaken the scoping assessment, HPA advised that there was no public health reason for individuals to stop using the area and the public health advice provided previously in November 2011 remained valid. HPA maintained its advice that members of the public should not access the restricted area and should follow the advice given to beach users.

The text of the letter sent by Dr John Cooper, HPA to Arthur Johnston at the Scottish Government Health Department on the 1st February 2012, which was also copied to SEPA, NHS Fife, Food Standards Agency Scotland and Fife Local Council, is reproduced here. The text of the letter sent by Dr John Cooper, HPA to Paul Dale at SEPA on 28th November 2011 is also reproduced below.

Radioactive Contamination on Dalgety Bay Beach (1st February 2012)

I am writing to you with updated advice from the Health Protection Agency (HPA), following the agreement made at the meeting on Monday 21st November, chaired by Scottish Government, that HPA would undertake a scoping assessment of the health risks to beach users at Dalgety Bay.

The scoping assessment is based on the recent monitoring data and supporting information made available to HPA by SEPA. The approach adopted is consistent with that used by HPA for assessing the public health risks for contamination of beaches around the Dounreay and Sellafield nuclear sites by discrete radioactive objects (see references below). The scoping assessment has focussed on the coastal area where a large number of objects have been detected and removed between September and December 2011. Additional information on the characteristics of these objects and their radioactive content has been used, where available, although this is limited. Realistic times that people may spend on this area of the coastline have been assumed based on data for other northern UK beaches (assuming cautiously that individuals may also access the area of the beach that is currently cordoned off).

All credible mechanisms have been considered by which individuals who use the coastal area for various activities could come into contact with potentially contaminated objects on the beach. The mechanisms involve either an object entering the body or direct contact with it on the skin. Exposure to an object can occur from inhalation of air in which beach material is resuspended, from inadvertent ingestion of beach material and from contaminated objects being in stationary contact with a small area of the skin and the skin becoming externally irradiated. External exposures considered were from: an object directly on the skin; an object located under fingernails or toenails; an object located within clothes and an object located within shoes. External exposure to a person standing a short distance away from an object (or a few objects) is extremely small and has not been considered further in detail.

Based on current information on the objects recovered, the overall lifetime risk of radiation-induced fatal cancer from inadvertent ingestion or inhalation of resuspended material for a member of the public spending time during one year on this coastal area is estimated to be very low (much less than 1 in 100 million). Cautious assumptions have been made in this calculation, both of the likelihood that an individual using this area inadvertently ingests or inhales a contaminated object and of the radiation doses that could be received. This risk is significantly lower than the level the Health and Safety Executive considers to be the upper limit for an acceptable level of annual risk for members of the public (risk of death of 1 in a million) (see reference below).

For an object to deliver a radiation dose to the skin such that there is a likelihood of it giving rise to localised ulceration of the skin, it has to remain in stationary contact with the same small area of skin for an extended period of time. A few large objects (pebble-sized) recovered from the beach have a radioactivity content that has the potential to lead to the threshold doses for localised skin ulceration being exceeded if they are picked up and carried around in a pocket for some time. It is important, therefore, that the advice not to remove objects from the beach is followed. Very small contaminated objects could remain unnoticed on the skin for a period of time. However, the likelihood of this occurring for an object that has a radioactivity content high enough to cause localised ulceration of the skin is estimated to be low. Further investigation with SEPA of the potential doses to localised areas of skin that could be received is underway. In the meantime, HPA continues to recommend that the advice on the local signs about washing hands after leaving the beach and not removing objects from the beach is followed. Parents should also consider stopping their children digging in the sand. HPA further recommends that regular monitoring of areas where a large number of contaminated objects have been found, and which are subject to erosion during storms, is carried out to ensure that contaminated objects are detected and removed.

Having undertaken this scoping assessment using the currently available monitoring data and supporting information, the public health advice I provided to SEPA previously remains valid. There is no public health reason for individuals to stop using the area. We continue to advise that members of the public should not remove material from the beach and should not access the restricted area. Anyone who has been handling any material while using the beach should ensure that they wash their hands when they leave. Parents should also consider stopping their children digging in the sand.

HPA will continue to work closely with the other organisations involved and will take an active role on the Dalgety Bay Expert Group formed by SEPA, on which HPA sits as an observer.

Radioactive Contamination on Dalgety Bay Beach (28th November 2011)

I am writing to you with updated advice from HPA, following the meeting on Monday 21st November, chaired by Scottish Government. As HPA explained at the meeting, the additional information SEPA provided on Monday demonstrates that our previous assessment of the overall public health risk is subject to greater uncertainty than previously thought, but it does not provide evidence to change the conclusions. I am therefore writing to you to reiterate our earlier advice that a detailed public health risk assessment needs to be commissioned. Such a detailed public health risk assessment can only be carried out if actions are taken to obtain the quantitative information required to inform it. Such information will take time to obtain, so steps should be taken promptly to initiate the necessary work. Specifically, I advise that the following should be initiated as soon as possible.

- Development of a comprehensive monitoring strategy for the area, with clear objectives for: the purpose of the monitoring and what actions will be triggered by specific results; the minimum levels of radioactivity that need to be detected; and, the frequency of, or triggers for monitoring. This needs to be agreed as soon as possible in order for monitoring and recovery of contaminated objects to be resumed, to further protect the public.
- Further characterisation of all types of radioactively contaminated objects found. (Contact measurements with passive detectors are required to assess potential skin doses since extrapolation using the inverse square law does not take account of the beta-particle dose. These measurements could use, for example, thermoluminescence or film dosemeters.)
- Full provision by MoD of their detailed information on any previous monitoring carried out or commissioned by them, in the Dalgety Bay area.
- A full survey of the usage of the beach to determine the activities people engage in and the time they spend on the beaches.

You have asked HPA to carry out a scoping public health risk assessment, on the basis of information currently available and that which becomes available in the next few weeks. We have undertaken to provide this by the end of January. In the meantime, the Agency continues to support SEPA's precautionary advice and the actions it has taken at Dalgety Bay. These steps will have reduced the risk of public exposure to radioactive material. We continue to advise that members of the public using the area should not remove material from the beach, and they should avoid the restricted area. Anyone who has been handling any material while using this beach should ensure that they wash their hands when they leave. Parents should consider stopping their children digging in the sand until more detailed monitoring has been carried out. Following the discussions at the meeting on Monday, I advise there are some additional protective actions you can take to ensure the public are protected, pending the result of a detailed public health risk assessment.

- Review whether there are ways to strengthen communication to the public of your current precautionary actions and advice, including demarcation of the area of beach that is restricted.
- As it is currently believed that erosion of the 'made' land close to the headland is the cause of the high number of objects recently found, HPA recommends that it is prudent to explore options for stabilising the exposed areas, so that they are protected from further erosion by winter storms. Precautions should also be taken to stop digging into this area of the headland.

Subject to this advice, HPA advises there is no reason for beach users to stop using the area. HPA remains of the opinion that, based on the data seen so far, the overall health risk is likely to be low. Whilst there is a risk of health effects if a radioactive object is swallowed, breathed in or is in prolonged contact with the skin, the chance of coming into contact with a radioactively contaminated object on the beach remains small.

HPA recognises that, following these recent finds and the press coverage, some local residents may become concerned regarding possible on-going contamination of their gardens with radium-226. HPA does not believe that there is a health risk to local residents using their gardens. It is very unlikely that the situation will have changed significantly since advice was given following previous monitoring of the gardens by NRPB in 1991 and by MoD more recently. However, in order to provide reassurance to the local residents, HPA offers its services to SEPA to monitor the gardens of agreed, relevant properties, if those residents request it. Our understanding is that the normal SEPA arrangements would then apply for the removal of any objects, if any are found.

We are pleased to see that the parties involved appear to be coming together to search for a resolution to the problems at Dalgety Bay. It is important that this momentum is maintained and that every effort is made to work towards a timely agreement on the long term management strategy for this situation.

9 UPDATE BASED ON CURRENT INFORMATION

Since the scoping assessment was carried out in January 2012, work has continued at Dalgety Bay. The monitoring programme to detect and retrieve contaminated objects from the beach has been maintained and strengthened and studies to further characterise the objects found and the in-situ contamination on the beach and surrounding land have continued. This work is being reported formally via the Dalgety Bay Expert Group; HPA was invited to join the Expert Group as an observer when it was formed in December 2011.

The scoping assessment adopted cautious, but not wholly unrealistic, assumptions that took full account of the dynamic situation and lack of knowledge surrounding the on-going contamination at Dalgety Bay. Further monitoring undertaken on the beach since

February 2012 has found a number of additional objects and these have been removed from the beach. One object recovered by SEPA in April had an estimated activity of about 2 MBq of ^{226}Ra; this object was found at a depth of about 35 cm and was outside the beach area that has been fenced off. In July, SEPA also reported finding 6 objects in the sandy area of New Harbour, where previously no objects had been detected. Based on the available information on the numbers of objects found since February 2012 and their estimated ^{226}Ra activity, the assumptions made in the scoping assessment on the population of objects on the beach remain valid and robust at the current time.

SEPA have commissioned additional work to investigate the solubility of objects in the gut using two further small selections of objects retrieved from the beach. In May, SEPA reported to the Expert Group that the results on solubility from the second batch of objects suggested a maximum solubility of about 25%. They reported that initial results from a third batch of objects was suggesting a slightly higher maximum solubility of 33%, this being for a small object with a ^{226}Ra content of about 20 kBq. A large range of values of solubility have been measured with many of the objects having much lower solubility than the maximum values reported. The assumption made in the scoping assessment that all objects had 25% solubility in the gut remains a robust assumption for estimating ingestion doses and health risks.

The improved determination of doses and consequent health effects arising from radioactive objects remaining in contact with the skin is a high priority for the Dalgety Bay Expert Group. Recent, preliminary, work carried out by HPA in collaboration with the University of Stirling on the characteristics of some of the objects recovered from the beach during the autumn of 2011 suggests that contact dose rates to skin are broadly in line with those extrapolated from previous finds, and hence with the estimates of the scoping calculations. This work is continuing and will be reported to the Expert Group.

HPA concludes that, taking into account information that has become available since February 2012, the results of the scoping study remain robust. Therefore HPA considers the advice provided in the letter to Scottish Government, and reproduced in Section 8, remains valid.

10 ACKNOWLEDGEMENTS

The authors would like to thank Rick Tanner, John Eakin, George Etherington and Jenny Smith at HPA for their contributions to this work. We would also like to thank Paul Dale from SEPA and Andrew Tyler from Stirling University for providing information on monitoring data and the interpretation of the measurements made.

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APPENDIX A Overview of the methodology for determining the likelihood of beach users encountering radioactive objects on the beach

A summary of the methodology adopted in estimating the probability of encountering an object for individual beach users is given in this Appendix. The details of the methodology and the derivation of the parameter values used can be found in Oatway *et al,* 2011. Three groups of beach users were considered as described in Section 4.2; walkers, leisure activities and bait diggers / anglers. To simplify the methodology for the purposes of the scoping assessment, when estimating the probability of encountering an object for individual beach users from skin contact, parameter values for walkers were assumed to be representative of beach users carrying out both walking and leisure activities. This was a robust assumption because, although the contributions to the probability of encountering an object from skin contact from an object being directly on the skin, trapped under a fingernail or toenail or trapped in shoes and clothing varies for the different beach activities, the overall probability of encounter is very similar [Oatway *et al*, 2011].

A1 NUMBER OF OBJECTS PER GRAM OF SAND

When considering the exposure of individuals to radioactive objects, the likelihood of encountering an object depends on the mass of sand that an individual comes into contact with while carrying out the various beach activities, for example, the amount of sand they get on their skin. The number of objects per gram of sand was obtained by dividing the population of objects per hectare by the mass of sand in one hectare with a depth of 10 cm (see Section 4.1 and Table 2). The density of sand was taken to be $2\ 10^6$ g m^{-3}.

A2 INADVERTENT INGESTION

Inadvertent ingestion of discrete objects might occur via the consumption of sand, for example, on food eaten on the beach. For the purposes of this scoping assessment, it was assumed that all objects are of a size that can be inadvertently ingested when estimating the likelihood of individuals encountering an object via this route of exposure. The inadvertent ingestion rate of sand used in this assessment is given in Table A1. These are the best estimate values (mean of the distribution of values) used in the assessment described in Oatway *et al* (2011) where a detailed account of the derivation of the values is described.

Table A1 Inadvertent ingestion rate of sand

Activity	Age group	Inadvertent ingestion rate[a] (g h^{-1})
All	Young child	0.045
All	Children	0.009
All	Adult	0.0045

(a) Best estimate values from Oatway *et al* (2011).

A2.1 Calculating the probability of inadvertent ingestion of an object

The following equation was used to estimate the probability of inadvertently ingesting an object.

P_{ing} = N * ING * T

P_{ing} = Probability of ingesting a radioactive object on the beach

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

ING = Ingestion rate of sand, g h^{-1}, see Table A1

T = Time spent on the beach, h y^{-1}, see Table 3

A3 INHALATION

If an object is small enough, and the sand dry enough, then it could become airborne either through the action of the wind or by the activity of a person, for example when sand is thrown in the air while digging. If the object does become airborne then inhalation could occur.

In the case of the inhalation exposure pathway, the concept of probability of encounter equates to the probability that an object is present in the volume of air that a person is breathing from at any time during the period of beach occupancy. Whether an object can be inhaled (that is, whether it can enter the nose or mouth) depends on particle size, breathing conditions, and ambient air velocity and direction. Inhalability, also known as the intake efficiency or aspiration efficiency, is defined as that fraction of particles in an aerosol that can enter the mouth or nose when the air in which it is suspended is inhaled. For a single particle, this fraction equates to a probability of inhalation.

After an object is inhaled, the location of deposition within the respiratory tract depends mainly on aerodynamic diameter, although factors such as breathing rate also have an influence. Particles larger than about 30 μm aerodynamic diameter deposit almost exclusively in the extrathoracic region, which comprises the anterior nose and the posterior nasal passages, larynx, pharynx and mouth. In ICRP's Human Respiratory Tract Model (HRTM) [ICRP, 1994], a cut-off of 100 μm aerodynamic diameter is suggested as an upper limit. Particles with aerodynamic diameters less than about 30 μm aerodynamic diameter may deposit in the airways of the lung (ie, the trachea, bronchi and bronchioles), but only particles smaller than 10 µm aerodynamic diameter are likely to reach the alveolar region of the lungs (see Oatway *et al* (2011) for further details).

To determine the probability of encounter by inhalation, data were needed on the sand loading in air above the beach and on the inhalation rate when undertaking various activities on the beach. The values for sand loading and inhalation rates used in this study are given in Table A2 and A3, respectively. The inhalation rates are based on information provided in ICRP Publication 66 [ICRP, 1994]. The values are best estimates (mean of the distribution of values) that were used in the assessment described in Oatway *et al* (2011) where a detailed account of the derivation of the values is described.

Table A2 Sand loading in air (g m^{-3})

Activity	Age group	Sand loading in air[a]
All	Young child /Child	$1\ 10^{-4}$
All	Adult	$5\ 10^{-4}$

(a) Best estimate values from Oatway *et al* (2011)

Table A3 Inhalation rates

Activity	Age group	Inhalation rate ($m^3\ h^{-1}$)[a]
Bait digging and fishing	Children[b]	0.87
	Adults	1.69
Leisure	Young child[c]	0.49
	Children[b]	0.87
	Adults	1.21
Walking	Young child[c]	0.49
	Children[b]	0.87
	Adults	1.21

(a) Best estimate values from Oatway *et al* (2011)

(b) For children, value for a 10 year old is used.

(c) This rate was based on data for a 5 year old as that represents the upper end of the age range for this group. The use of a higher inhalation rate represents a more cautious approach.

A3.1 Calculating the probability of encountering an object via inhalation

The following equation was used to estimate the probability of inhaling an object whilst on a beach.

$P_{inh,h}$ = N * Sl * INH * T

$P_{inh,h}$ = Probability that a radioactive object is inhaled

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

Sl = Sand loading in air, g m^{-3}, see Table A2

INH = Inhalation rate, m^3 h^{-1}, see Table A3

T = Time spent on the beach, h y^{-1}, see Table 3

A4 SKIN CONTACT WITH DISCRETE OBJECTS

The exposure situations considered where there could be skin contact with an object are: an object directly on the skin, an object located under fingernails or toenails, an object located within clothes and an object located within shoes. For these exposure situations, an assumption was made that the mass of sand on the skin would be continuously refreshed for the duration of the time spent on the beach and a robust assumption was made that the mass of sand present on the body or in clothing at any time represents the average mass accumulated over an hour spent on the beach. After an hour, any sand present was assumed to be replaced with an equal mass of sand from the beach. This is likely to be cautious as not every hour spent on the beach will result in attachment of sand to the skin or clothing and some sand is likely to be on parts of the body that will not result in a rapid exchange with new beach material. Any objects associated with the mass of sand being encountered were assumed to be attached at the same rate.

A4.1 Direct contact with the skin

It is expected that sand will get onto the skin during any visit to a beach. The mass of sand that becomes stuck on the skin, and by implication the probability that an object will also be on the skin, is dependent on a number of factors. These include the area of skin that is exposed to the sand, which in itself will depend to some extent on the weather because of the amount of clothing worn, and whether the sand is wet or dry. A discussion of how each of these factors affects the area of skin that could come into contact with sand for beach users throughout the year, and any differences between the different beach activities, is given in Oatway *et al* (2011).

Different approaches for estimating the probability of encountering an object on the skin were used depending on the beach activity. These largely follow the method used in the assessment of the health implications of fuel fragments on beaches around Dounreay [Smith and Bedwell, 2005] and around the Sellafield site [Brown and Etherington, 2011]. Table A4 presents parameter values used in assessing the probability of encountering an object directly on the skin.

Table A4 Parameters for assessing the probability of an object being present on the skin

	Best estimate value[a]
Dermal loading of sand, g m^{-2}	50
Exposed skin area of a young child, m^2	0.02826[b]
Exposed skin area of a child, m^2	0.05959[b]
Exposed skin area of an adult, m^2	0.1001[b]

a) The number of decimal places does not represent a correspondingly high degree of accuracy in these values; these are the values calculated using the method described in Oatway *et al* (2011).

b) These values are for beach walkers.

Skin exposure from leisure and walking activities

The following equation was used to estimate the probability of encountering an object on the skin whilst walking or using a beach for leisure activities. The derivation of this equation is given in Oatway *et al* (2011).

$$P_{skin} = T * N * M_{sand,w} * A$$

Where

P_{skin} = Probability of encountering a radioactive object on the skin

T = Time spent on the beach, h y^{-1}, see Table 3

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

$M_{sand,w}$ = Mass of sand adhering to the skin per hour spent on the beach, g h^{-1}, see Table A4

A = Skin area exposed to sand, see Table A4

For this scoping assessment the approached described in Oatway *et al* (2011) was simplified and the conservative assumption was made that the entire time a person is on the beach is during warm weather when less clothing is worn and hence more skin is potentially exposed to sand.

Skin exposure during bait digging and fishing activities

The methodology used in this assessment was the same as that used in the study on the health impact of fuel fragments on the beaches around the Dounreay site [Smith and Bedwell, 2005] and the Sellafield site [Brown and Etherington, 2011]. For this group of beach users it was assumed that sand will mostly get on the skin during bait digging when the individual is digging in the sand and mud on a beach looking for bait to use when fishing. Once the angler has collected bait it was assumed that hands would be washed before fishing to remove most of the sand on them. Therefore, exposure to material on the skin was only been considered for the time spent bait digging rather than the whole time spent on the beach.

Skin exposure during bait digging was considered to result from wet sand coming into contact with the hands as a result of handling bait that has been dug up, regardless of the weather, and so the effect of weather conditions was not included.

The parameter values used are given in Table A5.

Table A5 Parameters used for estimating the probability of encounter during bait digging and fishing

	Best estimate value[a]
Fraction of time spent digging	0.13
Amount of sand per bait item (g)	30
Number of items picked per hour	60
Fraction of sand contacting skin	0.05
(a) Values from Oatway *et al* (2011)	

The following equation was used to estimate the probability of encountering an object on the skin whilst bait digging.

P_{dig} = $N * T * F_b * M_b * N_b * F_b$

P_{dig} = Probability of encountering a radioactive object per hour of bait digging

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

T = Time spent on the beach, $h\ y^{-1}$, see Table 3

F_b = Fraction of the total time on the beach spent bait digging, see Table A5

M_b = Mass of sand adhering to each item picked up during bait digging, g, see Table A5

N_b = Number of items picked up per hour whilst bait digging, see Table A5

F_b = Fraction of sediment on an item that will come into contact with skin, see Table A5

Objects trapped under a fingernail

When the hands and feet are exposed to sand, then sand particles and any associated radioactive objects may become trapped under fingernails or toenails. In this scoping assessment the estimation of the probability of encountering an object from this exposure route was only carried out for objects trapped under fingernails. This is a robust assumption as the mass of sand under a toenail, and hence the probability of an object becoming trapped under a toenail, was estimated to be a factor of three less than that under a fingernail in Oatway *et al* (2011) and it is reasonable to assume that for the majority of the year beach users will be wearing shoes. In addition, any time spent on the beach was considered to result in sand becoming trapped under a fingernail. The estimated the mass of sand that could become trapped under fingernails is given in Table A6.

Table A6 Mass of sand trapped under a fingernail per hour on a beach [a,b]

Age group	Best estimate value (g)[c]
Young child	0.036
Children	0.072
Adult	0.120

(a) Assumes the density of sand is 2 10^6 g m^{-3}

(b) These masses were calculated and the number of decimal places does not imply detailed knowledge of the potential mass of material that could be trapped under a fingernail. Values from Oatway *et al* (2011)

(c) Representing sand trapped under 5 fingernails

The following equation was used to estimate the probability of encountering an object under a fingernail.

P_{nail} = T * N * M_f

P_{nail} = Annual probability of a particle becoming trapped under a nail

T = Time spent on the beach, h y^{-1}, see Table 3 of the main text

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

M_f = Mass of sand under a fingernail per hour on a beach, see Table A6

A4.2 Objects adhering to clothes

While an individual is on a beach, sand can adhere to clothes or become trapped next to the skin. The mass of sand that adheres to clothing will depend on both the type of clothing worn, as some fabrics are able to trap more sand than others, and the amount of clothing worn. A conservative approach was described in Oatway *et al* (2011) which is used here.

It was cautiously assumed that, for the time spent on a beach, the same clothes were worn and that the clothes had sand adhering to them for the whole time. The areas of clothing which could have sand adhering to them are given in Table A7 and the mass of adhered sand is given in Table A8. Between visits it was assumed that clothes are removed and washed and any particles present are removed. It should be noted that the assumption is implicitly made that any particle adhering to clothing that is in contact with the skin remains in stationary contact with a small area of skin. To be consistent with other skin contact exposure pathways, the area of clothing was assumed to be that appropriate for walkers. The area of clothing worn by leisure users is unlikely to be greater than for walkers and so this assumption will not lead to the probability of encountering an object for this pathway being underestimated.

Table A7 Area of clothing which sand could adhere to

Activity	Age group	Best estimate value (cm^2)[a]
Walking	Young child	4240 [(b)]
	Child	8960 [(b)]
	Adult	15200 [(b)]
Angling	Child	8960 [(b)]
	Adult	15200 [(b)]

(a) The number of decimal places does not represent a correspondingly high degree of accuracy in these values; these are the values calculated using the method described in Oatway *et al* (2011).

(b) 80% of the total body surface area, representing someone wearing a t-shirt and trousers.

Table A8 Mass of sand trapped in clothing

	Age group	Best estimate value (g cm^{-2})[a]
Mass of sand per unit clothing area	All	10^{-4}

(a) Value from Oatway *et al* (2011)

The following equation was used to estimate the probability of encountering an object adhering on clothing.

P_{cl} = T * N * A_c * M_c

P_{cl} = Annual probability of a radioactive object adhering to clothing becoming trapped next to the skin when on a beach

T = Time spent on the beach, h y^{-1}, see Table 3 of the main text

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

A_c = Area of clothing that is exposed to sand, cm^2, see Table A7

M_c = Mass of sand per unit area of clothing, g cm^{-2} per hour on the beach, see Table A8

A4.3 Objects trapped in shoes

While an individual is on a beach, it was assumed that sand and any associated radioactive objects could get into shoes or sandals. Table A9 presents the mass of sand trapped in shoes per hour spent on the beach that was assumed in this scoping assessment and is taken from Oatway *et al*, 2011. In the absence of data specifically for different ages and beach activity the value in Table A9 was applied to all age and beach activity groups. It should be noted that the assumption was implicitly made that any particle trapped in shoes remains in stationary contact with a small area of skin.

Table A9 Mass of sand that can become trapped in shoes per hour on a beach

Beach activity	Age group	Best estimate value (g)[a]
All	All	10

(a) Value from Oatway *et al* (2011)

The following equation was used to estimate the probability of encountering an object in shoes.

$P_{shoe} = T * N * M_s$

P_{shoe} = Annual probability of having a radioactive object trapped in shoes that is in contact with the skin

T = Time spent on the beach, h y^{-1}, see Table 3

N = Number of radioactive objects per gram of sand, g^{-1}, see Table 2

M_s = Mass of sand in shoes per hour spent on the beach, g h^{-1}, see Table A9

A5 REFERENCES

Brown J and Etherington G (2011). Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site. HPA-CRCE-018, April 2011.

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