Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site

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ABSTRACT

Since 2006 an intensive programme of monitoring for radioactive objects has been carried out on beaches in the vicinity of the Sellafield site in West Cumbria. By the end of the summer of 2009, over 650 radioactive objects were identified and removed. These objects comprised particles with sizes smaller than or similar to grains of sand (less than 2 mm) and contaminated pebbles and stones. In 2007, the Environment Agency (EA) sought the advice of the Health Protection Agency (HPA) on the health implications of the findings of this beach monitoring and this advice has since been updated. In May 2008, EA asked HPA to undertake an assessment of the health risks to people using the beaches along the Cumbrian coast from contaminated objects on the beaches. This report describes the results of that work.

The assessment has addressed two key aspects. Firstly, estimates have been made of the likelihood that people using the beaches for various activities could come into contact with a radioactive object. Secondly, in the unlikely event that an individual does come into contact with such an object, the resulting radiation doses and associated health risks have been assessed. The conclusion, based on currently available information, is that the overall health risks for beach users are very low, and significantly lower than other risks that people accept when using the beaches. The ingestion of alpha-rich particles has the greatest potential to give rise to significant health risks. However, the very low likelihood of ingestion occurring means that the overall health risk remains very low in comparison to the levels of risk that the Health and Safety Executive (HSE) regards as being the upper level for an acceptable level of risk.

HPA has updated its formal advice to EA taking into account the findings of this study and the significance of the estimated health risks. HPA recommends three criteria for prompting an urgent review of health risks to beach users. These address risks from ingestion, overall fatal cancer risk and risk of deterministic effects to skin. It also recommends that continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that risks associated with radioactive objects in the environment remain very low.

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A supplementary report (Oatway et al, 2011) is also available that provides the full scientific basis for the statements made in this report and gives a detailed account of the assessment made together with descriptions of the methodology and data used.

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EXECUTIVE SUMMARY

Since 2006 an intensive programme of monitoring for radioactive objects has been carried out on beaches in the vicinity of the Sellafield site in West Cumbria. The term ‘object’ is used to cover contaminated particles, pebbles and stones found on the beaches. By the end of the summer of 2009, over 650 objects were identified and removed. These objects comprised particles with sizes smaller than or similar to grains of sand (less than 2 mm) and contaminated pebbles and stones. In 2007, the Environment Agency (EA) sought the advice of the Health Protection Agency (HPA) on the health implications of the findings of this beach monitoring and this advice has since been updated. In May 2008, EA asked HPA to undertake an assessment of the health risks to people using the beaches along the Cumbrian coast from contaminated objects on the beaches. This report describes the results of that work.

The assessment has addressed two key aspects. Firstly, estimates have been made of the likelihood that people using the beaches for various activities could come into contact with a radioactive object. Secondly, for the unlikely event that an individual does come into contact with such an object, the resulting radiation doses and associated health risks have been assessed.

The evaluation of health risks has been undertaken for five of the beaches closest to the Sellafield site; they are the beaches at Braystones, Drigg, Seascale, Sellafield and St Bees. For other beaches that have been monitored, there are insufficient monitoring data to enable a meaningful quantitative evaluation of health risks to be performed. Nevertheless, it is possible to provide some qualitative comments on the potential health risks to people using other beaches along the West Cumbrian coast.

The methodology adopted in this study to determine the likelihood of beach users coming into contact with a radioactive object on a beach made use of monitoring data obtained using the Groundhog Evolution 2™ detection system which was used up to August 2009 and is considered to be adequate for its intended purpose, ie, to determine whether risks to the health of beach users could be significant.

The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches. The highest calculated lifetime risks of radiation-induced fatal cancer are of the order of one hundred thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk (1 in a million) for members of the public and workers. It is also very unlikely that deterministic effects such as skin ulceration could occur from encountering an object.

The likelihood of members of the public ingesting a radioactive particle from the consumption of seafood and the associated health risks have also been estimated using a conservative scoping approach in consultation with the Food Standards Agency. The risks to local consumers of seafood have again been found to be very low.

The evidence from the beach monitoring programme and habit surveys suggests that users of other beaches along the West Cumbrian coastline are no more likely to come into contact with a radioactive object than they are on the five beaches considered in detail in this study. The monitoring on some of the beaches has been limited both in extent and frequency and so it cannot be ruled out that some relatively high activity objects may be present but have remained undetected. However, given that the highest activity objects which have been found on beaches close to the Sellafield site do not give rise to health risks of concern, it is highly unlikely that health risks would be of concern for the beaches further away.

HPA has previously advised the EA that the detection of alpha-rich objects with activities greater than 10^7 Bq of alpha-emitting radionuclides should prompt an urgent review of the risks to public health. No such objects have been detected to date, but continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that risks associated with radioactive objects in the environment remain very low.

A number of other recommendations are now made which HPA considers would provide further confirmation that protection of the public is adequate and may improve the assessment of health risks. In particular, a recommendation is made that an investigation should be carried out of the increases in the number of alpha-rich objects being found by the recently-introduced Groundhog Synergy beach monitoring system. This increased find rate does not necessarily mean that there is an increase in the number of objects actually present on the beaches, since the increase could be completely attributable to improvements in sensitivity, and hence the ability to detect particles containing ^{241}Am, that are expected from the Synergy system. A possible approach for such an investigation has been proposed. Following this investigation, a decision should be made as to whether there is a need to review the assessment of overall risk to beach users taking into account data on the increased number of objects detected by Synergy.

HPA has updated its formal advice to EA taking into account the findings of this study and the significance of the estimated health risks. HPA recommends that three criteria should be adopted for prompting an urgent review of health risks to beach users:

- finding an object with a total activity of alpha-emitting radionuclides greater than 10^7 Bq;
- estimation of an overall lifetime risk of radiation-induced fatal cancer for a beach user of greater than 1 in a million noting that this is unlikely to be the limiting criterion;
- a skin dose rate greater than 300 mGy per hour following characterisation of objects with a caesium-137 activity greater than 10^5 Bq.

CONTENTS

1 INTRODUCTION

Since 2006, an intensive programme of monitoring for radioactive objects has been carried out on beaches in the vicinity of the Sellafield site in West Cumbria. By the end of the summer of 2009, over 650 radioactive objects have been identified and removed. These objects comprised particles with sizes smaller than or similar to grains of sand (less than 2 mm) and contaminated pebbles and stones. These discrete objects have a much higher activity content that can be distinguished from the ambient homogeneous levels of contamination on the beaches; information on these levels can be found in the Radioactivity in Food and the Environment (RIFE) series of reports (eg, Cefas, 2009). In July 2007, the Environment Agency (EA) sought the formal advice of the Health Protection Agency (HPA) on the health implications of the findings of the beach monitoring; this advice was updated in September 2007 and January 2009. In May 2008, EA asked HPA to undertake an assessment of the health risks to people using the beaches along the Cumbrian coast from contaminated objects on the beaches. It was agreed with EA that the assessment should be based on the currently available knowledge at the time and monitoring data from the Groundhog Evolution2™ detection system which was in use up to August 2009. This work was in support of the Environment Agency’s programme of work set up to establish an overall understanding of the nature of the radioactive objects, their behaviour in the environment and the potential consequences of their presence. The EA programme aims to ensure that appropriate advice and information on public and environmental protection issues are provided to the relevant decision making authorities in a timely manner (EA, 2009). As part of this work, EA asked HPA to specifically address the following points.

- Whether a classification system can be defined for the contaminated objects based on their physical characteristics that would distinguish them from widely dispersed homogeneous contamination and enable the associated health risks to be evaluated;
- The production of an appropriate methodology for assessing the probability of encounter of objects on west Cumbrian beaches;
- Establishing suitable risk comparators so that perspective can be placed on the relative risks associated with radioactive objects on the beaches.

This work has drawn on the considerable experience that was gained from the assessment of contaminated beaches around the Dounreay site in Scotland and, where appropriate, a similar approach has been taken here. However, the nature of the contaminated objects found in the vicinity of the Sellafield site is very different to the fuel fragments found on beaches around Dounreay, as is the environment itself, and so any conclusions made by the Dounreay Particle Advisory Group (DPAG, 2006; 2008) cannot be directly applied to the situation in West Cumbria.

There are two main considerations when evaluating the risks to health from radioactive objects on the beaches. The first is an evaluation of the likelihood that people using these beaches for various activities will come into contact with radioactive objects that are on the beaches. The second is an evaluation of the health risks that may arise if an individual does come into contact with a radioactive object. Health risks can be evaluated by assessing the radiation doses. These two strands considered 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 beaches. This approach is consistent with that recommended by HPA for the designation of contaminated land where the contamination is due to hot particles (HPA, 2006).

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 west Cumbrian coastline have also been taken into account, using the results of a scoping study carried out in consultation with the Food Standards Agency (FSA).

The work undertaken in this study is presented in two reports. This report is intended for a non-specialist audience and presents the main conclusions of the study together with an assessment of the overall health risks to people using the beaches in the vicinity of the Sellafield site. The full scientific basis for the statements that are made can be found in a second report (Oatway et al, 2011) that gives a detailed account of the assessment of the health risks undertaken together with descriptions of the methodology and data used. It presents a detailed analysis of the probability of an individual encountering an object while using a beach and an assessment of the radiation doses and associated risks to an individual in the unlikely event that they come into contact with one of the radioactive objects. In the remainder of this report, Oatway et al (2011) is referred to as the Supporting Scientific Report.

2 MONITORING AND RETRIEVAL OF OBJECTS

The Environment Agency has placed a statutory requirement on Sellafield Ltd to monitor beaches between Ravenglass and the Solway for small radioactive objects and particles using the best techniques available. In 2006 Sellafield Ltd tested a new vehicle-mounted detector system, Groundhog Evolution2™, to monitor local beaches and this has been used routinely to survey beaches in the vicinity of the Sellafield site. The work is carried out by Nuvia Ltd on behalf of Sellafield Ltd. If radioactive objects are detected they are retrieved and sent to Sellafield for analysis. Figure 1 shows the extent of the beach monitoring that has been undertaken since November 2006. For the purposes of this study, data collected using Groundhog Evolution2™ during the monitoring period November 2006 to August 2009 have been used.

Monitoring conducted using the Groundhog Evolution2™ system between those dates identified a total of 676 radioactive objects over a monitored beach area of approximately 600 hectares. These objects comprise particles with sizes similar to or smaller than grains of sand (<2 mm) and contaminated pebbles and stones. Stones and pebbles account for about half the objects found. The objects retrieved from the beaches contain a range of radionuclides and levels of radioactivity.

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

Figure 1: Beaches monitored along the Cumbrian coastline (beaches are also monitored along the north Solway coast in Scotland and are not shown here)

Since September 2009, a new detection system, Groundhog Synergy, has been deployed with an improved detection capability for low-energy photon emitters, particularly americium-241 (^{241}Am) and the Bremsstrahlung radiation resulting from strontium-90/yttrium-90 (^{90}Sr/^{90}Y)*. Use of this system has resulted in the detection of increased numbers of alpha-rich objects. Some comments are made in the Supporting Scientific Report, Section 4.4, regarding the improved sensitivity of the system and the activity range of objects that would be expected to be detected with higher probabilities. Recommendations are given in Section 8 of this report on the work required to determine whether the increase in detected objects is completely attributable to improvements in sensitivity, or whether there is also an increase in the numbers of objects actually present on the beaches.

2.1 Classification of objects found on the beaches

Objects found during monitoring have been classified by size and type by Sellafield Ltd. Any object with an average size of 2 mm or greater is defined as a stone and objects smaller than 2 mm are defined as particles. The terms particles and stones are used throughout this report with this meaning. Once objects have been removed from the beach they are sent for further analysis which enables Sellafield Ltd to classify them based on their radionuclide content. This classification is also appropriate for estimating the radiation doses and health risks to individuals who could come into contact with a radioactive object on a beach. Objects are classified as alpha-rich, beta-rich or rich in cobalt-60; a full definition of this classification scheme is given in the Supporting Scientific Report (Section 2) and is summarised in Table 1. No objects have been detected directly through measurement of their ^{90}Sr/^{90}Y content. However, based on measurements made on objects selected for radiochemical analysis, the contribution of ^{90}Sr/^{90}Y to radiation doses is considered in the assessment of doses and risks to health (see Sections 5 and 6).

2.2 Summary of objects found on the beaches

Figures 2 and 3 show the distribution of alpha-rich and beta-rich objects found on the beaches along the Cumbrian coast between Ravenglass Estuary and St Bees Head. The Figures show that the majority of both alpha-rich and beta-rich objects have been found on Sellafield beach. Table 1 gives a summary of the number of objects found based on the classification criteria currently in use and the highest detected activity of an object in each classification group. Table 1 shows that almost all of the stones are beta-rich and these have almost all been found on Sellafield beach. Cobalt-60-rich objects are addressed in detail in the Supporting Scientific Report. However, as very few ^{60}Co-rich objects have been found on the beaches, they are not discussed further in this report. The likelihood that people using the beaches will come into contact with a ^{60}Co-rich object are significantly lower than for the other groups of objects and the health risks are not higher than those discussed for beta-rich objects.

* Strontium-90 is present in equilibrium with its radioactive progeny radionuclide, ytrrium-90 (^{90}Y).

Table 1 Summary of objects found using Groundhog Evolution2™ system

Class[a]	Total number of objects found[b]	Maximum activity, kBq[c,d]	Beach where the object with maximum activity was found
Alpha rich particles	59	634	Sellafield
Alpha rich stones	3	35.4	Sellafield
Beta-rich particles	219	109	Sellafield
Beta rich stones	368	875	Sellafield
^{60}Co rich particles	9	19.7	Sellafield
^{60}Co rich stones	0	23.5	Sellafield

a) Alpha-rich particles classified on positive measurement of ^{241}Am activity that exceed measured ^{137}Cs activity; beta-rich particles classified on positive measurement of ^{137}Cs activity that exceed measured ^{241}Am activity; ^{60}Co-rich particles classified on positive measurement of ^{60}Co activity that exceed measured ^{137}Cs activity.

b) Objects found by the monitoring programme conducted using the Groundhog Evolution2™ system between November 2006 and August 2009 for which classification enabled use in the study.

c) A kilo-Becquerel (kBq) is 1000 Bq.

d) Detected activity: americium-241(^{241}Am) for alpha-rich objects; caesium-137 (^{137}Cs) for beta-rich objects; cobalt-60 (^{60}Co) for ^{60}Co-rich objects.

1 0.5 0 1 Miles

1:100,000

4

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 MapRef:

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Figure 2: Alpha-rich objects found on beaches using the Groundhog Evolution2™ detection system. Objects found are marked with green dots

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Figure 3: Beta-rich objects found on beaches using the Groundhog Evolution2^{TM} detection system. Objects found are marked with orange dots

3 APPROACH FOR EVALUATING RISKS TO HEALTH

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 beaches 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 beaches 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.

The probability that an individual using the beaches could encounter an object has been estimated using a statistical approach in order to reflect the large variation in the habits of individuals using the beaches and the variability in the parameter values used to describe their exposure to the objects. A statistical program has been used to estimate the range of the probabilities of encountering an object using these ranges in the input parameters. The output is a probability distribution for the probability of encounter of an object which is described in terms of its 2.5 percentile, 50 percentile and 97.5 percentile; 2.5% of beach users have probabilities of encounter less than the 2.5 percentile, 2.5% of beach users have probabilities of encounter greater than the 97.5 percentile, and 95% of beach users having values between the two percentiles. Equal numbers of beach users have values above and below the 50 percentile (the median of the distribution).

In order to assess the risks to health if an individual comes into contact with an object on a beach, radiation doses have been assessed using the information available on the objects that have been retrieved as a result of the beach monitoring and object retrieval programme. 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 have been considered because both the probability that an individual using the beaches could encounter an object and the risks to health if an individual comes into contact with an object on a beach depend 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 have been 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 ensures that the highest health risks for young children who are active and mobile on the beach are assessed. Health risks have not been 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. Babies and infants that are not mobile have also been considered because there is the potential for them to receive higher radiation doses if they ingest an object. However, the probability of them being exposed to an object is very small compared to older infants and children who are mobile on the beaches. The potential health risks are discussed in Section 6.6.

In order to undertake a full evaluation of the health risks associated with people using the beaches along the west Cumbrian coastline, it is important to have sufficient data to be able to characterise the population of objects on each beach considered and the activities undertaken on those beaches. To identify beaches for which a complete assessment could be made, a review was carried out of the currently available monitoring and habit survey data. This review showed that it is possible to undertake a quantitative evaluation of the health risks for five of the beaches between Allonby and Silecroft. These beaches are those closest to the Sellafield site; they are (in alphabetical order): Braystones, Drigg, Seascale, Sellafield and St Bees. However, it should be noted that, even for these beaches, the information available is limited and robust assumptions have had to be made; the reliability of the assessment and the major areas of uncertainty are discussed in Section 7. For other beaches that have been monitored and for areas which it has not been possible to monitor using the vehicle based detection system (eg, the Nethertown and Coulderton ‘boulder fields’), there are insufficient monitoring data to enable a meaningful quantitative evaluation of health risks to be performed. Nevertheless, it is possible to provide some qualitative comments on the potential health risks to people using other beaches along the West Cumbian coast and this is done in Section 6.5.

4 PROBABILITY OF ENCOUNTERING AN OBJECT ON THE BEACHES

4.1 Estimating the population of objects on the beaches

The beach monitoring systems in use (Figure 4) are not capable of detecting all of the objects in the monitored area because the detection efficiency is typically less than 100%. In general, therefore, the detection of a single object at a particular depth on a beach may indicate the presence of more than one object at that depth within the area monitored. The population of objects (ie, number of objects actually present) may be estimated by dividing the number of objects found by a single scan of the beach (in this case, one) by the detection probability for that depth. The detection probability is the fraction of the number of objects present that are expected to be detected under a specified set of conditions (ie, radionuclide, activity, depth, scan speed and background level). When the detection probability is close to 100%, the population of objects is close to the number found. However, when a particular object is found at a depth where the probability of detection is low, the actual number of objects predicted is much larger than the number found.

Theoretical evaluations of the detection efficiency of the Groundhog Evolution2^{TM} system have been carried out and object detection probabilities calculated (Supporting Scientific Report, Section 4.1). These detection probabilities have been used to estimate the population of objects on each beach from data on the number of objects found by the beach monitoring programme.

4.1.1 Capabilities and limitations of beach monitoring

Object detection probabilities depend on the radionuclide present, its activity, the depth of the object below the surface of the beach, the speed of the monitoring system while transiting the beach and the background levels measured by the detectors. The monitoring systems in use are capable of detecting objects containing americium-241 (^{241}Am), caesum-137 (^{137}Cs), cobalt-60 (^{60}Co) and strontium-90/yttrium-90 (^{90}Sr/^{90}Y) through measurement of their photon emissions*. For buried objects in the top 10 cm of the beach, Groundhog Evolution2™ is most sensitive to objects containing ^{60}Co, followed in order of decreasing sensitivity by objects containing ^{137}Cs, ^{90}Sr and ^{241}Am. The sensitivity for all radionuclides decreases with increasing object depth, with detection probabilities ranging from 100% for an object on the surface containing 10 kBq of ^{60}Co to 0.2% for an object at a depth of 0.15 meters containing 100 kBq of ^{241}Am. Further information on detection capabilities is given in the Supporting Scientific Report, Section 4.1.

In some circumstances, uncertainties in the estimate of the number of objects present can be quite large. When the detection probability is close to 100%, uncertainties are low, but when a particular object is found at a depth where the probability of detection is low, uncertainties are greater. When only a few objects have been found at depth in a particular monitored area, the uncertainty in the estimate of the actual number of objects in that area can be large.

Figure 4: Vehicle mounted Groundhog beach detection systems (Evolution 2™ on left; Synergy on right) (copyright Sellafield Ltd)

* Although the radioactive decay of the beta-emitter ^{90}Sr does not directly result in the emission of gamma-ray photons, the deceleration of beta particles results in the emission of photons that can be detected.

4.1.2 Estimation of the population of objects on the beaches

The estimated population of objects on the beaches should be representative of the number of objects on the beach at any time that the beach is used. This quantity is not the same as the total number of object finds that have been detected and retrieved during the monitoring programme. For beaches that are monitored frequently and where the whole beach is monitored, the number of objects found during a complete, single scan of the beach, adjusted to take account of detection probability, may be taken to provide an estimate of the population of objects. However, the current situation is that it has not been possible to monitor the whole area of each beach, although many areas of the beaches have been monitored on a number of occasions. The area of the beach monitored over the whole monitoring programme therefore also has to be taken into account when estimating the population of objects from the total number of objects detected (Supporting Scientific Report, Section 4.2).

Two independent methods were developed to estimate the population of objects using data on the numbers of objects found, their depths and activities and their corresponding detection probabilities. The methods were intended to reduce uncertainties as far as possible, and were generally found to be in good agreement, showing no significant differences when considering all the uncertainties in the data from which they were obtained. Developing two independent methods has provided confidence in the estimated population of objects, which are given in Table 2 for each beach. Descriptions of the two methods and results for the estimated population of objects on each beach are given in the Supporting Scientific Report (Section 4.2).

The probability of detection was evaluated for object activities of 1, 10, 100 and 1000 kBq for each of the detected radionuclides (Supporting Scientific Report, Section 4.1.3). To allow this information to be combined with data on the number of objects found on each beach, the objects have been grouped into corresponding activity 'bands' whose geometric mean is approximately equal to the activity at which the probability of detection was determined. The bands are 3–30 kBq (represented by 10 kBq), 30–300 kBq (represented by 100 kBq) and >300 kBq (represented by 1000 kBq).

The following observations may be made about the results shown in Table 2. The population of lower activity objects are greater (usually much greater) than for higher activity objects for all the beaches and for all categories of objects, while the estimated population of alpha-rich objects is higher than that of beta-rich objects. Sellafield beach has the highest population of beta-rich objects per hectare, while the total population of alpha-rich objects per hectare is highest for Drigg beach. The latter finding should however be treated with caution, as discussed further in Section 8.2. The average numbers of objects that have been detected per hectare for each beach is also shown in Table 2. This clearly shows that the estimated population of alpha-rich objects is much higher than the number detected, reflecting the fact that the detection system is not capable of detecting all of the objects present on the beaches.

Objects containing radionuclides with activities less than a few kBq have not been included in the estimate of the population of objects on each beach because the evaluated detection probabilities for objects at this activity level are very low (less than 1%) even on the beach surface, and their use to estimate the number of objects present on a beach would represent a source of unreasonable uncertainty. Only 22 beta-rich objects have been detected with the Groundhog Evolution2™ system on the beaches with activities at this level (20 on Sellafield beach). The health risk arising from such objects is very low, as discussed further in Section 6.3. If a lot of very small, low activity objects are present on the beaches; they will become part of the ambient levels of contamination on the beach which are routinely monitored (see RIFE reports, eg, Cefas, 2009).

Table 2: The estimated population of objects on each beach

Beach	Object class	Number of objects[a] per hectare of beach[b]			
		10 kBq (3 kBq–30 kBq)	100 kBq (30 kBq–300 kBq)	1000 kBq (>300 kBq)	Average find rate by Groundhog Evolution2™ [c]
Braystones	Alpha-rich	1	0.1	0	0.04
	Beta-rich	0.4	0.02	0	0.09
Drigg	Alpha-rich	8	0.2	0	0.06
	Beta-rich	0.03	0.05	0	0.06
Seascale	Alpha-rich	0.06	0.05	0	0.01
	Beta-rich	0.2	0.02	0	0.14
Sellafield	Alpha-rich	1	0.3	0.003	0.37
	Beta-rich	2	0.2	0.02	1.16
St Bees	Alpha-rich	1	0.04	0	0.03
	Beta- rich	0.08	0	0	0.08

a) Objects includes particles and stones

b) The number of objects with activities of <3 kBq have not been calculated, as discussed in the text.

c) Data taken from Dalton, Sellafield Ltd, 2010

4.2 Beach usage and exposure pathways

In order to evaluate the likelihood of an individual being exposed to a contaminated object, information is needed on the activities people engage in and the time they spend on the beaches. Beach use defines how individuals can come into contact with sand and hence be exposed to radioactive objects on the beaches. 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 EA (Cefas 2008a; 2010). The habit surveys 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 provides a robust classification which can be used for other beach activities which were not identified during the habit surveys. Individuals using beaches were assigned to one of three groups; leisure activities, walking and fishing, including bait digging. The Leisure group includes 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 are 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 includes 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. This group is likely to get their hands covered in sand and, in warmer weather, some other parts of their bodies such as the lower legs. However, in general it can be assumed that they would be wearing a reasonable amount of clothing. Three age groups were considered: young children (aged 0–5 years); children (aged 6–15 years) and adults (over 16 years). Full details of the data used and assumptions made on annual beach occupancy, beach use and the exposure pathways considered are given in the Supporting Scientific Report (Section 5).

4.2.1 Beach occupancy

Although a considerable amount of data was collected from the habit surveys, once these data were divided between age groups and beach activities, some groups had insufficient or no data to allow a good statistical analysis to be made (that is, to define the 2.5%, 97.5% and median values). An alternative approach was therefore used. All of the occupancy data for the beaches surveyed as part of the two habit surveys were pooled together and suitable distributions of annual beach occupancy derived. These are taken to be representative of the range of beach occupancy on beaches along the West Cumbrian coast. This approach has the advantage that any statistical information derived from this dataset is from a large number of individuals, which gives more confidence in any values used. These pooled occupancy data were then assigned to all beaches where it was known or thought feasible that the identified groups spent time.

In addition to considering the distribution in beach occupancy across all beach users, people that spend the most time on each of the beaches considered were identified. For these individuals, single values for annual occupancy were assumed, which were the highest values observed on each beach for each beach activity and age group. A summary of the assumptions made about the time spent by individuals with high beach occupancy is given in Table 3.

Table 3: Assumptions made on annual occupancy for individuals with high beach occupancy (based on Cefas 2008a; 2010)

	Annual beach occupancy (hours per year)[a,b]								
Beach	Adult Leisure	Adult Walking	Adult Angler	Child Leisure	Child Walking	Child Angler	Young child Leisure	Young child Walking	Young child Angler
Braystones	820	730	900	300	20	280	260	-	-
Drigg	210	1100	620	210	200	60	170	-	-
Seascale	150	900	570	120	200	-	150	-	-
Sellafield	-	140	200	-	-	-	-	-	-
St Bees	370	730	400	50	70	60	150	280	-

- no people observed in this group during the habit surveys.

a) The values presented are rounded to the nearest 10 hours and should be regarded as indicative hours for these groups of individuals.

b) The value used is the highest occupancy identified for each group on each beach.

4.2.2 Exposure to objects

The potential for people to be exposed to objects (ie, both particles and stones) as a result of exposure to sand containing an object while using the beaches has been considered. The mechanisms by which individuals can come into contact with sand while using the beach and therefore be exposed to an object have been identified. 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 sand is resuspended, from inadvertent ingestion of sand and from sand being in stationary contact with a small area of skin and the skin becoming externally irradiated. 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 three exposure mechanisms. External exposures considered were from: an object directly on the skin (including in the ear or eye); 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 would be extremely small, even for the beta-rich (and ^{60}Co-rich) objects which have high energy gamma-ray emissions and are not considered further. This is discussed in more detail in the Supporting Scientific Report (Appendix C).

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 a beach. This is extremely unlikely; however an estimate has been made of the likelihood that an object could enter a wound, taking into account both the likelihood of an individual on the beach having an open wound and the likelihood that an object could enter a wound during a beach visit. This potential exposure pathway is discussed in more detail in the Supporting Scientific Report (Appendix E).

For all parameters used to describe how individuals can be exposed to objects on the beaches, ranges have been determined that reflect the variation across the population. For estimating exposure from objects entering the body, parameters describing inadvertent ingestion rates and inhalation rates of sand from activities undertaken on the beach have been used. For estimating exposure to objects in direct contact with the skin, a number of parameters are used including the areas of skin exposed to sand in warm and cold weather, the range of activities that people undertake on the beach and whether these are on dry or wet sand and the amount of sand that can be trapped under nails, in clothes and in shoes during a beach visit. All the parameters and the ranges on the values for these parameters that have been used in the study are described in detail in Section 6 of the Supporting Scientific Report. These ranges have been combined with the distribution of beach occupancies to calculate a distribution of the probability of encountering an object for the general population of beach users. For beach users who have a high annual occupancy, best estimate values have been 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 classified as stones (2 mm diameter or greater) 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 has therefore been assumed that for general beach users only the objects classified as particles

(<2 mm diameter) are likely to give rise to exposures resulting in radiation doses. It is recognised that there may be beach users who mouth and deliberately ingest large non-nutritional objects. Although the ingestion of stones is very unlikely, this has been considered in calculating the probability of encountering an object and is discussed in Section 4.3. As the upper size limits for objects adhering to the skin are of the same order as the size used to classify objects as particles or stones, and many of the objects that have been classified as stones are not significantly larger in diameter than 2 mm, some general comments are also made in Section 4.3 on the probability of skin contact from stones, for example from sitting on a stone.

4.3 Annual probability of encountering radioactive particles and stones

The estimated annual probability of encounter varies between beaches and is dependent on the estimated number of objects that could be on each beach, the activities undertaken on the beaches and the time members of the public spend on each beach. For typical beach users, only the probability of encounter of particles has been considered in detail, as discussed in Section 4.2.2. Across the five beaches considered, the median value of the probability of a typical beach user encountering any particle (ie, 50% of beach users will have a higher probability of encounter and 50% a lower probability) range from 1 10^{-7} (chance of 1 in 10 million per year) to 1 10^{-5} (chance of 1 in 100 thousand per year). Five percent of beach users are estimated to have a probability of encountering a particle of about 10 times higher than this. Based on the information available, the probability of encounter is highest for adult beach users, with values for children typically being about a factor of 2–3 lower. The majority of the particles are in the activity range of 3–30 kBq and the total annual probability is dominated by the probability of encountering such particles. The probability of encountering particles with activities greater than 300 kBq (the highest activity range considered) is much less than 1 in a 100 million per year and it should be noted that particles with activities in this range have only been detected on Sellafield beach.

The estimated annual probability of encountering an object for individual adult beach users with high annual beach occupancy ranges from 1 10^{-6} (chance of 1 in a million per year) to 4 10^{-5} (chance of 1 in 25 thousand per year). This is higher than the median value for typical beach users but within the range of values across all beach users.

On some of the beaches, contaminated stones (diameter >2 mm) have been found (see Table 1); these are predominantly beta-rich stones found on Sellafield beach. As discussed in Section 4.2.2, it is highly unlikely that general beach users will be exposed to these stones as they are generally too large to remain in stationary contact with a small area on skin (directly or in clothing and shoes) or to be taken into the body. However, if it is assumed that general beach users could be exposed to these stones, the total probability of encountering an object (ie, both particles and stones) would be effectively the same as that from encountering a particle for all beaches except for Sellafield beach, due to the very small estimated number of stones on these beaches. For Sellafield beach, the total probability of encountering an object would be higher than that for particles alone by about a factor of 2.

When considering the likelihood that individuals will encounter an object on one of the beaches, there are some general observations that can be made on how the probability is likely to vary depending on beach use and 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 probability of inadvertently ingesting an object is very small and much lower than 1% of the total probability of encountering an object. The probability of inhaling an object is even smaller.

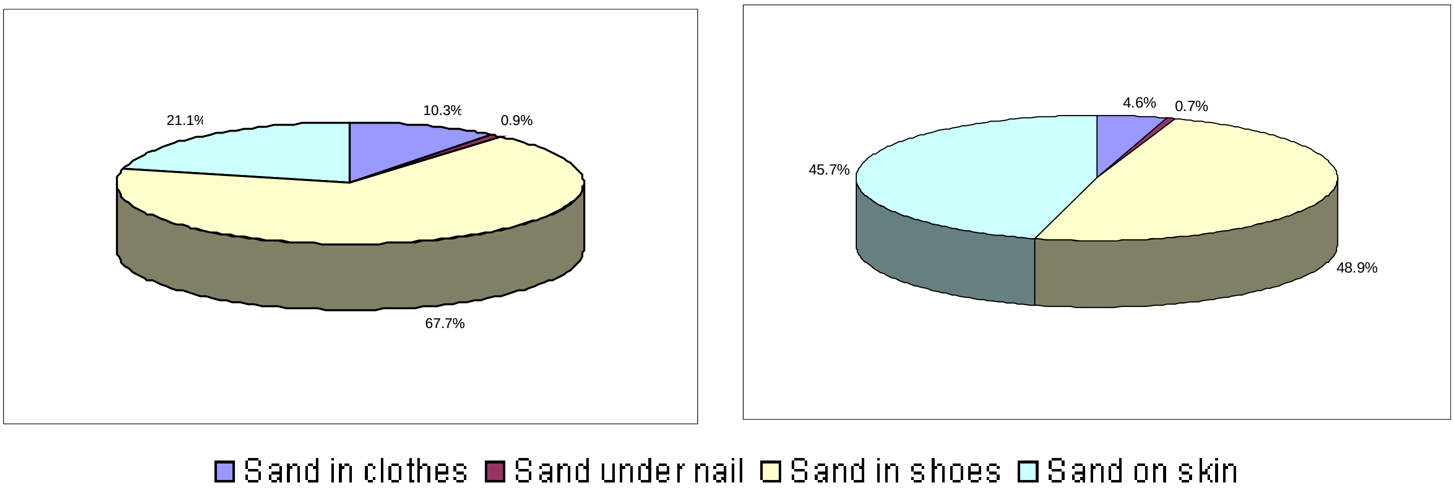

Figure 5: The relative contributions of exposure pathways to the total probability of encountering a radioactive object for walking (left) and leisure activities (right)

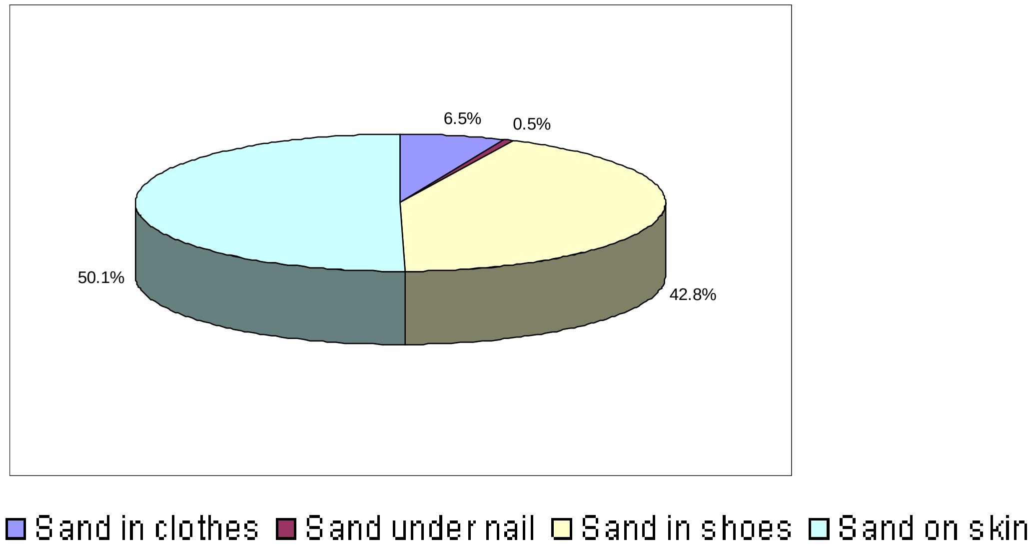

Figure 6: The relative contributions of exposure pathways to the total probability of encountering a radioactive object for angling activities

Figures 5 and 6 show the relative importance of the different ways an object can be encountered for a beach user walking or spending leisure time on a beach and for anglers, assuming that they also dig for bait. Figure 5 shows that the probability of encounter is dominated by exposure from contact with the skin and, for walkers, this is dominated by objects becoming trapped in shoes whereas for people carrying out leisure activities, although this pathway is still important, direct contact on the skin is likely to be relatively more important because of the higher likelihood of individuals having more contact with sand (and objects). For anglers (Figure 6), the most important exposure pathway is direct contact with significant amounts of sand during bait digging which could lead to particles adhering to the skin.

For the adult groups considered, it is estimated that anglers or walkers will have the highest annual probability of encountering an object. For walking and leisure activities, differences observed in the probabilities of encounter across the five beaches considered depend on the observed main use of the beach; for St Bees, for example, it is mainly walking while for Braystones, leisure activities are more important. For children, angling is typically less important, although on Braystones beach the habit surveys indicated a number of children who regularly fish. Young children are observed as predominantly playing on the beaches.

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

5.1 Classification of objects

For the purposes of evaluating doses and risks to health, radioactive objects on beaches in the vicinity of the Sellafield site have been classified as either “alpha-rich” or “beta-rich”. An alpha-rich object is one where americium-241 (^{241}Am) has been detected and the ^{241}Am activity is greater than the caesium-137 (^{137}Cs) activity. From the point of view of evaluation of doses and risks, ^{241}Am and the alpha-emitting isotopes of plutonium (Pu) (^{238}Pu, ^{239}Pu and ^{240}Pu) are the most important constituents of alpha-rich particles. A beta-rich object is one where ^{137}Cs has been detected and the ^{137}Cs activity is greater than the ^{241}Am activity. The most important constituents of beta-rich particles are ^{137}Cs and strontium-90 (^{90}Sr).

5.2 Effects on health from exposure to radioactive objects

Health effects can generally be categorised as:

- *stochastic effects*, which include cancers and heritable effects. 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*. Once the threshold is exceeded, the *severity* 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 Section, the highest activity content of each object type has been used in order to estimate the maximum doses and highest risks to health if an object is encountered. In the evaluation of the overall risks to health for a beach user (Section 6), effective doses and risks are determined for the range of activity content in the objects that have been detected and for which the population of objects has been determined. A full account of the evaluation of health effects that could arise due to exposure to radioactive objects is given in the Supporting Scientific Report, Sections 8 and 9.

It may be noted that, for beta-rich objects with similar total activities and sizes, those with lower $^{137}Cs/^{90}Sr$ ratios are associated with higher absorbed doses, equivalent doses and effective doses for all pathways because ^{137}Cs gives lower doses than ^{90}Sr. On the other hand, with the exception of absorbed dose rates to the skin, doses from alpha-rich particles are relatively insensitive to the $^{238}Pu:^{239/240}Pu^{*}:^{241}Am$ ratios as these radionuclides give similar doses.

5.3 Stochastic risks to health from radioactive objects on the beaches

In this study, the greatest potential for stochastic effects on health is from the ingestion of alpha-rich objects or beta-rich objects. Inhalation of alpha-rich particles or beta-rich objects, and irradiation of the skin by alpha-rich or beta-rich objects would all result in lower stochastic risks (Supporting Scientific Report, Sections 8 and 9). Doses and risks to health that could be associated with uptake from wounds in which an alpha-rich particle is embedded are also considered.

[*] The activity given for $^{239/240}Pu$ is the sum of the activities of these two radionuclides.

5.3.1 The relationship between effective dose and risk

Risks of stochastic effects were evaluated for intakes by ingestion of ^{238}Pu, ^{239}Pu and ^{241}Am for a 1 year old child and a 20 year old adult (Supporting Scientific Report, Section 8.4). Risks for a 10 year old child lie between the values for these two ages. The lifetime risks of radiation-induced fatal cancer that would result from an intake giving rise to a committed effective dose of 1 Sv are estimated to be 16% and 9% for the child and the adult, respectively. 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 lethality-adjusted cancer risk for adult workers of 4.1% Sv^{-1} (ICRP, 2007) because ICRP's value is averaged over ages between 18 and 64 and risks decrease with age because of decreasing life expectancy. Risks of stochastic effects have also been evaluated for a 3 month old infant and these are discussed in Section 6.6.

5.3.2 Ingestion of alpha-rich objects

The most important factor determining doses resulting from ingestion of an alpha-rich object is the fractional uptake of the alpha-emitting radionuclides to blood as the object passes through the gastro-intestinal (GI) tract. *In* vivo experimental studies of the intestinal absorption of alpha-rich particles carried out at HPA (Supporting Scientific Report, Sections 8.2, 8.3 and 8.4) have resulted in a recommendation that a particle uptake fraction of 3 10^{-5} should be used in calculations of equivalent doses to organs and effective dose, for both plutonium and americium. This recommendation should result in cautious estimates of doses.

The highest activity alpha-rich object recorded in Sellafield Ltd's Beach Monitoring Summary spreadsheet is a particle containing 84 kBq ^{238}Pu, 309 kBq $^{239/240}$Pu and 634 kBq ^{241}Am, with a total activity of these radionuclides of 1.03 MBq.

In the unlikely event that an alpha-rich particle with this activity was ingested, the assessed committed effective dose is 20 mSv for an adult and 55 mSv for a 1 year old child. The corresponding lifetime risk of death from all radiation-induced cancers arising from these doses can be estimated to be about 0.2% for an adult and 0.9% for a 1 year old child (Supporting Scientific Report, Section 8.4). It should be noted that the committed effective dose and corresponding lifetime risk of death from all radiation-induced cancers arising from these doses is expected to be higher for 3 month old infants. The effective doses and health risks to 3 month old children are discussed separately in Section 6.6.

Both doses and health risks may be assumed to scale with the activity of the object. Uncertainties on all lifetime fatal cancer risk estimates given in this report are likely to be large, particularly for children.

5.3.3 Ingestion of beta-rich objects

The highest activity beta-rich particle found up until August 2009 contained 110 kBq ^{137}Cs. The ^{90}Sr content was not measured, but the ^{90}Sr activity would be 180 kBq if the most conservative ^{137}Cs:^{90}Sr ratio measured to date applies. In the unlikely event that such a particle was ingested, committed effective doses are estimated to be 6.5 mSv and 15 mSv for an adult and a 1 year old child, respectively, if it is conservatively assumed that the ICRP default gut uptake fractions (f_1) apply. The corresponding lifetime risk of death from all radiation-induced cancers can be estimated to be 0.06% for an adult and 0.2% for a 1 year old child (Supporting Scientific Report, Section 9.4).

5.3.4 Inhalation of alpha-rich particles

Alpha-rich particles with the higher activities (greater than about 10 kBq ^{241}Am) are expected to have aerodynamic diameters in excess of about 200 µm based on current evidence (Supporting Scientific report, Section 8.5). Particles of this size are very unlikely to be inhaled in low wind speed conditions. Inhalability at higher wind speeds is uncertain, but any higher activity particles inhaled would be deposited in the extra-thoracic airways (the nasal passages, larynx, pharynx and mouth) rather than the lungs. For particle sizes that are likely to be inhaled, the effective dose resulting from inhalation of a single particle would be no greater than a few mSv for all age groups, based on currently available information. Corresponding lifetime risks for all age groups are therefore estimated to be very low (Supporting Scientific Report, Section 8.5).

5.3.5 Inhalation of beta-rich particles

The highest activity particle found that could deposit in the lungs if inhaled has an aerodynamic diameter of 29 µm and a ^{137}Cs activity of 8.4 kBq. If the ^{137}Cs:^{90}Sr ratio is pessimistically assumed to be 0.6:1, the effective doses for all age groups arising from inhalation of a beta-rich particle are estimated to be no more than 6 mSv, and are likely to be significantly less than this value. Corresponding lifetime risks for all age groups are therefore very low (Supporting Scientific Report, Section 9.5).

5.3.6 Alpha-rich objects irradiating the skin

Irradiation of the skin by 60 keV gamma rays from ^{241}Am, and gamma irradiation of other body organs, both contribute to effective dose. For an object that could result in an absorbed dose to the skin equal to the 2 Gy threshold for localised skin ulceration, effective doses for adults would only be a few µSv at most, while for children they would be no greater than 100 µSv. None of the objects that have been found would result in skin doses that approach the threshold for localised skin ulceration given any realistic exposure scenario (see Section 5.4.2) and these objects would give rise to even lower effective doses and so the corresponding lifetime risks to health are very low (Supporting Scientific Report, Section 8.7).

5.3.7 Beta-rich objects irradiating the skin

Beta-gamma irradiation of the skin, and gamma irradiation of other body organs, both contribute to effective dose. For an object that could result in an absorbed dose to the skin equal to the 2 Gy threshold for localised skin ulceration, effective doses for adults would only be a few µSv at most, while for children they would be no greater than 100 µSv. None of the objects that have been found would result in skin doses that approach the threshold for localises skin ulceration given any realistic exposure scenario (see Section 5.4.1) give rise to even lower effective doses and so the corresponding lifetime risks to health are very low (Supporting Scientific Report, Section 9.2).

5.3.8 Alpha-rich particles embedded at a wound site

Appendix E of the Supporting Scientific Report presents the results of a scoping calculation of the overall risk associated with alpha-rich particles embedded in a wound. The stochastic risk arising from uptake of radionuclides from the wound site is the most important factor to consider. It is concluded that overall health risks from uptake via a wound for alpha-rich particles are likely to be broadly similar to those from ingestion, as discussed in Section 5.3.2.

5.4 Deterministic effects on health from radioactive objects on the beaches

In this study, the exposure routes with the greatest potential for deterministic effects on health are direct beta-gamma irradiation of the skin resulting from stationary contact of beta-rich objects with the skin, and ingestion of beta-rich objects which could give localised doses to the gut. The likelihood that other exposure routes could give rise to deterministic effects is essentially zero. It may be noted that, for beta-rich particles with similar total activities and sizes, those with lower $^{137}Cs/^{90}Sr$ ratios are associated with higher absorbed doses and dose rates whatever the pathway. 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 threshold is usually set at the level of dose corresponding to a risk of 1% that the effect would occur.

5.4.1 Beta-rich objects irradiating the skin

As part of object characterisation work, SERCO carried out direct dose rate measurements on beta-rich particles and stones for Sellafield Ltd (Supporting Scientific Report, Section 9.1). Calculations of skin dose rates were also carried out by AMEC, using data provided by SERCO (Supporting Scientific Report, Section 9.1). The highest (1 cm^2, 70 µm) [*] dose rate for a beta-rich particle was calculated to be 29.7 mGy h^{-1}. The ^{137}Cs activity of this particle was 32.4 kBq and the $^{137}Cs{:}^{90}Sr$ ratio was about 0.6:1.

The exposure time required for a particle giving a dose rate of 29.7 mGy h^{-1} to reach the threshold for localised skin ulceration of 2 Gy is approximately 67 hours. For the highest activity beta-rich particle found up until August 2009 (110 kBq ^{137}Cs), and assuming a cautious $^{137}Cs{:}^{90}Sr$ ratio of 0.6:1, the (1 cm^2, 70 µm) dose rate would be approximately 100 mGy h^{-1}, and the exposure time required to reach the threshold would be approximately 20 hours (Supporting Scientific Report, Section 9.1). It should be noted that this threshold dose only applies for particles in *stationary* contact, and that if the particle moved by a distance equivalent to its own size, then the threshold value would

[*] Doses calculated for a skin area of 1 cm^2 at a depth of 70 µm are abbreviated as (1 cm^2, 70 µm).

be significantly higher. It is very unlikely that particles could remain in stationary contact with the skin for such lengths of time. It should be noted that if the threshold value was reached, there would still only be about a 1% risk that the effect would occur in the exposed individual, and the severity of the effect would be relatively low. As skin dose rates increase above the threshold, the risk of the effect and its severity would both increase.

For stones, the highest (1 cm^2, 70 µm) measured dose rate was 19.8 mGy h^{-1}. The threshold for ulceration resulting from contact with large radioactive sources such as stones is 10–20 Gy. The exposure time required to reach this threshold for a stone giving a dose rate of 19.8 mGy h^{-1} is 500 hours. For a stone with a ^{137}Cs activity equal to that of the highest activity beta-rich stone found up until August 2009 (875 kBq ^{137}Cs), the (1 cm^2, 70 µm) dose rate would be approximately 200 mGy h^{-1}, and the exposure time required to reach the threshold would be approximately 50 hours (Supporting Scientific Report, Section 9.1). It is extremely unlikely that stones could remain in contact with the skin for such lengths of time.

5.4.2 Alpha-rich objects irradiating the skin

For alpha-rich particles, the main component of the absorbed dose to the skin arises from gamma irradiation by the 60 keV photon emission from ^{241}Am. Alpha irradiation is not expected to irradiate the sensitive cells in the skin to any significant extent (Supporting Scientific Report, Section 8.6.2). The particle with the highest ^{241}Am content recorded in Sellafield Ltd's Beach Monitoring Summary spreadsheet contained 84 kBq ^{238}Pu, 309 kBq $^{239/240}Pu$, 4.97 MBq ^{241}Pu and 634 kBq ^{241}Am. The calculated skin dose rate (1 cm^2, 70 µm) from this particle is approximately 8 mGy h^{-1}.

The exposure time required to exceed the 2 Gy threshold for localised skin ulceration is about 250 hours. It is very unlikely that particles could remain in contact with the skin for such lengths of time (Supporting Scientific Report, Section 8.6).

5.4.3 Ingestion and inhalation of beta-rich objects

For the highest activity beta-rich particle found up until August 2009 (110 kBq ^{137}Cs), and making the conservative assumption that the ^{90}Sr activity is 180 kBq (^{137}Cs:^{90}Sr ratio of 0.6:1, the lowest value found in the SERCO study), the maximum absorbed doses to the rectosigmoid colon in the unlikely event of ingestion of such a particle is estimated to be 20 mGy and 41 mGy, for an adult and a 1 year old child, respectively. It should be noted that the absorbed dose to the rectosigmoid colon for a 3 month old infant would be higher and this is discussed further in Section 6.6.

The highest activity object found up until August 2009 was a stone with an average diameter of 35 mm containing 875 kBq ^{137}Cs. Such an object could not be inadvertently ingested, but it could be deliberately ingested by adults and older children. In the unlikely event that such an object was ingested, conservative estimates of the upper bounds for the maximum doses resulting from ingestion of such an object are 21 mGy and 42 mGy, for an adult and a 1 year old child, respectively.

These calculated absorbed doses for ingestion of a beta-rich object are approximately one thousand times less than the threshold value for acute effects in the colon, which is estimated to be 23 Gy (Supporting Scientific Report, Section 9.3).

Since effective doses arising from inhalation of beta-rich particles are low, the probability of deterministic effects arising from inhalation is essentially zero (Supporting Scientific Report, Section 9.5).

5.4.4 Ingestion and inhalation of alpha-rich particles

Deterministic effects would not be expected to occur unless absorbed doses to the gastro-intestinal tract, lungs and red bone marrow approach very high values, in excess of threshold values for acute exposure of 23 Gy, 5.5 Gy and 2.2 Gy, respectively. The absorbed doses calculated for the objects with the highest content of alpha emitting radionuclides are very much lower than these thresholds (Supporting Scientific Report, Section 8.8).

6 OVERALL RISKS TO A BEACH USER

The annual probability of coming into contact with an object while spending time on a beach has been estimated for both alpha-rich and beta-rich objects (Section 4.3, and Supporting Scientific Report, Section 7). 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 (Section 5.4 and Supporting Scientific Report, Sections 8 and 9).

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 (Section 5.3 and Supporting Scientific Report, Sections 8 and 9). 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 from alpha-rich and beta-rich objects on the five beaches considered are discussed below in Sections 6.1 (stochastic risks) and 6.2 (deterministic effects). Some general conclusions on the health risk to people using other beaches along the Cumbrian coastline are presented in Section 6.5.

The overall risks discussed are derived using cautious assumptions about the probability of encountering an object and the activity content of these objects. In most cases, risks are evaluated assuming that the objects contain the highest activity content of all objects retrieved from the beaches in each activity range considered. It is also assumed that the highest probabilities of encountering an object apply (using the 97.5th percentile of the distribution across all beach users). Beach users with higher than average beach occupancy are included within these cautious estimates.

6.1 Overall risks of fatal cancer for a beach user from exposure to particles

The overall risk to a beach user of fatal cancer must take into account both the probability that a particle may be encountered by the person and the risk of fatal cancer in the unlikely event that the person does encounter such a particle. The probability of encounter depends on the activity of the particle, (with lower activity particles being associated with higher probabilities of encounter), and so the overall risk to the beach user has been determined separately for each of the activity bands defined in Section 4.1.2.

As noted in Section 5.3, the greatest potential for stochastic effects on health is from the ingestion of alpha-rich and beta-rich particles and, based on the objects considered in this study, the highest risks to an individual beach user are from the ingestion of alpha-rich objects. Table 4 shows the highest estimated lifetime risk of radiation-induced fatal cancer for an adult resulting from one year's potential exposure by ingestion. The estimated probability of ingesting a particle (corresponding to the 97.5th percentile of the distribution) and the resulting overall risk to the beach user is shown for the highest activity particle in each activity band. Table 5 shows the same information for young children (1 year old).

In this study, ingestion of alpha-rich particles gives rise to overall risks that are about ten times higher than those for the ingestion of beta-rich particles for adult beach users and about two hundred times higher for young children. Nevertheless, the highest overall risks are estimated to be very small, with the chance of dying from cancer as a result of one year's potential exposure being less than 1 in 100,000 million (for ingestion of an alpha-rich particle by a 1 year old child). The highest overall risks are from the lower activity particles because the probability of encountering these is at least a thousand times higher than for the highest activity particles, as shown in Tables 4 and 5. The probability of ingesting an alpha-rich particle with the highest activity found (containing 634 kBq ^{241}Am) on the beaches around the Sellafield site is extremely low, a factor of 10,000 times less than the values for the 3–30 kBq ^{241}Am band.

Tables 4 and 5 present the overall risk that a radiation-induced fatal cancer from ingestion could occur during the lifetime of a beach user arising from use of the beach over a period of one year. Making the pessimistic assumption that the population of objects on the beaches remains at current levels over the lifetime of a beach user, the overall risk from a lifetime's potential exposure is still very low, being less than 1 in 1000 million.

Table 4: Highest estimated overall risks of fatal cancer for an adult beach user associated with possible ingestion of alpha-rich and beta-rich particles as a result of using a beach for a period of 1 year

Activity band, kBq	Highest activity particle in activity band, kBq[a]	Effective dose[b], mSv	Lifetime risk of cancer if particle ingested, % [c]	Highest annual probability of ingesting a particle[d]	Overall risk of fatal cancer
Alpha-rich					
1000 (>300)	634	20	0.2	$4\ 10^{-12}$	$8\ 10^{-15}$
100 (30 – 300)	200	6	0.06	$2\ 10^{-10}$	$1\ 10^{-13}$
10 (3 – 30)	30	0.8	0.007	$1\ 10^{-8}$	$7\ 10^{-13}$
Total					$8\ 10^{-13}$
Beta-rich					
1000 (>300)[e]	-	-	-	-	-
100 (30 – 300)	100	6.5	0.06	$2\ 10^{-11}$	$1\ 10^{-14}$
10 (3 – 30)	30	1.8	0.02	$4\ 10^{-10}$	$8\ 10^{-14}$
Total					$9\ 10^{-14}$
Total overall risk					$9\ 10^{-13}$

a) Activity of radionuclide detected: ^{241}Am for alpha-rich particles; ^{137}Cs for beta-rich particles.

b) Calculated doses take account of other radionuclides measured in the particles that will contribute significantly to the dose. For alpha-rich particles, the dose is from ^{241}Am, ^{238}Pu and ^{239}Pu. For beta-rich particles, the dose is calculated for ^{137}Cs and ^{90}Sr and a conservative ratio of 1.0: 1.6 ^{137}Cs :^{90}Sr has been assumed.

c) Lifetime risk is calculated for the highest activity particle in each activity band.

d) Value is the 97.5th percentile of the distribution across all beach users (taken from Section 7 of the Supporting Scientific Report).

e) No beta-rich particles have been found in this activity band.

It is recognised that the perception of risk is not based simply on numerical estimates of the probability of occurrence of effects on health and that it may be helpful to compare the overall risks estimated from radioactive objects on the beaches with other every day health risks that are relevant to beach users. Table 6 presents some risks for the general population of the UK that can be associated with beach use. These risks are much higher than the risks of radiation-induced fatal cancer from encountering a radioactive object on a beach along the west Cumbrian coastline. Further details are given in the Supporting Scientific Report (Section 10).

Table 5: Highest overall risks of fatal cancer for a 1 year old child beach user associated with possible ingestion of alpha-rich and beta-rich particles as a result of using a beach for a period of 1 year

Activity band (central value), kBq	Highest activity particle in activity band, kBq[a]	Effective dose[b], mSv	Lifetime risk if particle ingested, %[c]	Highest annual probability of ingesting a particle[e]	Overall risk of fatal cancer
Alpha-rich					
1000 (>300)	634	55	1	-[e]	-
100 (30 – 300)	200	17	0.3	$6\ 10^{-10}$	$2\ 10^{-12}$
10 (3 – 30)	30	2	0.04	$3\ 10^{-8}$	$1\ 10^{-11}$
Total					$1\ 10^{-11}$
Beta-rich					
1000 (>300)[f]	-	-	-	-	-
100 (30 – 300)	100	15	0.2	$7\ 10^{-11}$	$1\ 10^{-13}$
10 (3 – 30)	30	4	0.06	$3\ 10^{-10}$	$2\ 10^{-13}$
Total					$3\ 10^{-13}$
Total overall risk					$1\ 10^{-11}$

a) Activity of radionuclide detected: ^{241}Am for alpha-rich particles; ^{137}Cs for beta-rich particles.

b) Calculated doses take account of other radionuclides measured in the particles that will contribute significantly to the dose. For alpha-rich particles, the dose is from ^{241}Am, ^{238}Pu and ^{239}Pu. For beta-rich particles, the dose is calculated for ^{137}Cs and ^{90}Sr and a conservative ratio of 1.0: 1.6 ^{137}Cs :^{90}Sr has been assumed.

c) Lifetime risk is calculated for the highest activity particle in each activity band.

d) Value is the 97.5th percentile of the distribution across all beach users.

e) Particles of the activity only found on Sellafield beach and there is no evidence that young children spend time on this beach.

f) No beta-rich particles have been found in this activity band.

Table 6: Representative every day risks[a]

Probability	Risk
10^{-5} – 10^{-4}	Annual risk of death from malignant melanoma of the skin
10^{-6} – 10^{-5}	Annual risk of death from all leisure activities in UK coastal waters Risk of blindness from toxocara parasite
10^{-7} – 10^{-6}	Annual risk of death when angling in UK coastal waters Annual risk of death when swimming in UK coastal waters Annual risk of death in UK marine waters reported to the Marine Coastguard Agency for the summer months (start May – end September)
10^{-8} – 10^{-7}	Annual risk of death from a dog bite Annual risk of death when canoeing in UK coastal waters Annual risk of death in UK marine waters reported to the MCA for the winter months (start October – end April) Annual risk of death from insect stings

a) Sources of information are given in the Supporting Scientific Report, Section 10.7.

6.2 Likelihood of deterministic effects from exposure to particles

As noted in Section 5.4, the exposure routes with the greatest potential for deterministic effects on health are direct beta-gamma irradiation of the skin resulting from stationary contact of beta-rich and alpha-rich objects with the skin, and ingestion of beta-rich objects. 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.

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. This is very unlikely in an environment where people are undertaking a range of activities on a beach.

The threshold dose for localised skin ulceration is approximately 2 Gy, and for beta-rich particles the predicted skin dose rate from the highest ^{137}Cs activity particle found up until August 2009 would be approximately 100 mGy h^{-1} (making a conservative assumption about the ^{90}Sr content of the particle, as discussed in Section 5.4). The exposure time required to reach this threshold is 20 hours.

The skin dose rate from the alpha-rich particle with the highest ^{241}Am activity found up until August 2009 is approximately 8 mGy h^{-1} and the exposure time to reach the same threshold is about 250 hours (Section 5.4). The skin dose rates arising from beta-gamma emitters that have been found in some alpha-rich particles are negligible in comparison. It is very unlikely that particles could remain in stationary contact with the skin for times as long this, and it can reasonably be concluded that skin dose thresholds could not be exceeded by objects with these activities.

The threshold dose for deterministic effects to the gastro-intestinal tract is 23 Gy, and the highest assessed absorbed dose to the rectosigmoid colon from ingestion of beta-rich particles is 41 mGy, a factor of 500 less than the threshold. Clearly, the threshold dose could not be exceeded.

Given these reassuring findings, the probability of encountering such objects is of secondary importance. However, it may be noted that the annual probability of encountering a beta-rich object on the skin, either directly or from an object trapped in clothing or shoes, will be less that 10^{-5} (1 in 100,000 per year) based on the 97.5th percentile of the distribution of beach users. For a typical beach user, the likelihood of getting an object on the skin is at least a factor of ten lower.

6.3 Objects with low activity levels

It is not possible to conclude from the monitoring data whether there are very few objects on the beaches containing less than a few kBq or whether they mostly cannot be detected with the available detection systems. The risk of fatal cancer from ingestion of alpha-rich particles with this activity content is estimated to be much less than 1 in a million, the level of risk that HSE considers to be the upper limit for an acceptable level of risk (2001). Even if probabilities of encounter approach unity, the overall risk to a beach user would not exceed this. For beta-rich particles, it is estimated that tens of particles would each have to remain in stationary contact with the same small area of skin for several days before any localised skin ulceration would occur: this is not a realistic scenario. It should also be noted that if a lot of very small, low activity objects are present on the beaches, they will become part of the ambient levels of contamination on the beach which are routinely monitored (see RIFE reports, eg, Cefas, 2009).

6.4 Overall risks from exposures to stones

As noted in Section 4.2.2, 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. In the unlikely event that an adult with pica spends time on the beaches, the overall risk associated with ingesting an alpha-rich stone is estimated to be at least ten times lower than the probability of ingesting a particle. For beta-rich stones, the overall risk is about the same as that for beta-rich particles. As discussed in Section 4.3, the majority of beta-rich stones have been found on Sellafield beach, which it should be noted is used by very few individuals; the risks to users of other beaches from the ingestion of beta-rich stones would be extremely low and about one hundred times lower than that from ingestion of beta-rich particles.

The threshold dose for skin ulceration as a result of contact with a stone, at 10 Gy, is higher than that for a particle because a stone is a distributed source rather than a point source. The skin dose rate from the beta-rich stone with the highest ^{137}Cs activity found up until August 2009 would be approximately 200 mGy h^{-1} and the exposure time to reach the threshold is about 50 hours. It is very unlikely that an object could remain in stationary contact with the skin as long as this and it can reasonably be concluded that skin dose thresholds could not be exceeded by objects with these activities.

6.5 Risks for other beaches

The evidence from the beach monitoring programme and habit surveys suggests that users of other beaches along the West Cumbrian coastline are no more likely to come into contact with a radioactive object than they are on the five beaches considered in detail in this study. The monitoring on some of the beaches has been limited both in extent and frequency and so it cannot be ruled out that some high activity objects may be present. However, given that the highest activity objects which have been found on beaches close to the Sellafield site do not give rise to health risks of concern, it is highly unlikely that health risks would be of concern for the beaches further away.

6.6 Overall health risks for three month old infants

If a 3 month old infant ingested an object, the committed effective doses received would be higher than those for a 1 year old child. In the unlikely event that an alpha-rich particle with the activity given in Section 5.3.2 was ingested, the estimated dose would be in the region of 300 mSv with the corresponding lifetime risk of death from all radiation-induced cancers estimated to be about 4% (Supporting Scientific Report, Section 8.4). For a beta-rich particle with the activity given in Section 5.3.3, the estimated committed effective dose would be in the region of 40 mSv if it is conservatively assumed that the ICRP default gut uptake fractions (f_1) apply. The corresponding lifetime risk of death from all radiation-induced cancers is estimated to be about 0.6% (Supporting Scientific Report, Section 9.4). Ingestion of stones has not been considered because this is not a realistic exposure pathway for infants.

As 3 month old infants are not mobile, the probability of encountering an object on the beach will be significantly lower than the values estimated for a 1 year old child given in Table 5. Even if it is very cautiously assumed that the probability of a 3 month old infant encountering an object is the same as that of a 1 year old child, the lifetime risk of death from all radiation-induced cancers is very low and less that 10^{-10} per year. In reality, the risks will be lower than those for young children who are mobile on the beach.

Considering deterministic health effects from ingestion of a particle, the calculated absorbed dose for a 3 month old infant from ingestion of a beta-rich particle with the activity given in Section 5.4.3 would be approximately 100 times lower than the threshold value for acute effects in the colon (23 Gy) (Supporting Scientific Report, Section 9.3).

7 RELIABILITY OF THE ASSESSMENT OF OVERALL RISK TO BEACH USERS

7.1 Robustness of the approach

The approach adopted in this study, as described in Section 3, made use of all information available at the time of the study, including monitoring data from the Groundhog Evolution2^{TM} detection system which was in use up to August 2009. This is considered to be adequate for the intended purpose of determining whether risks to the health of beach users could be significant. Estimates of the population of objects on beaches were based on data on object finds from the beach monitoring programme and on information on the sensitivity of the detection system. All monitoring data collected up until August 2009 has been taken into account; the adequacy of beach monitoring for the assessment of risks to health is discussed in Section 7.2. It is considered that detection sensitivity is well characterised for detection of objects containing ^{241}Am, ^{137}Cs and ^{60}Co; the characterisation of capabilities for direct detection of ^{90}Sr in objects is discussed in Section 8.1.2.

A comprehensive investigation of activities engaged in by beach users was carried out, making use of detailed habit surveys. Distributions rather than single values were defined for the time spent on beaches by each of the beach use groups and age groups identified, and specific consideration was given to beach users with high annual occupancy (ie, people for whom time spent on the beaches is at the upper end of these distributions). These distributions allowed full account to be taken of the range of beach occupancy times and beach activities in determining probabilities than a radioactive object could be encountered.

Radiation doses and risks to health have been assessed for all significant pathways by which a person could encounter a radioactive object and incur a radiation dose. Specific assessments have been made of the radiation doses that would result from encountering the highest activity objects that have been found by the beach monitoring programme. Dose assessments used the most up-to-date information, data and models, and are considered to provide reliable assessments of risks to health. There are inevitably uncertainties associated with the estimation of the likelihood that beach users encounter an object while using the beaches. All potential exposure pathways that could lead to beach users coming into contact with an object have been considered. The use of distributions on the parameter values that describe the exposure pathways encompasses both the variability across the population and the uncertainty in the parameter value. The uncertainty in the calculated probabilities of encountering an object is not of significance in relation to the low levels of overall health risks that have been determined.

7.1.1 Overall risks of fatal cancer from consuming locally caught seafood

It is possible that individuals who regularly use the beaches are also high consumers of locally caught seafood. No direct monitoring of offshore sediments has been carried out that can be used to clarify the quantity and nature of radioactive particles that could become incorporated in seafood along the west Cumbrian coastline, although this is being considered for the future. In the meantime, for completeness, the likelihood of members of the public ingesting a radioactive particle from the consumption of seafood and the associated health risks has been estimated using a conservative scoping approach. Currently available information has been used and the assumption made that an individual is a high-rate consumer of all species of shellfish identified during the latest habit survey in 2008 (Cefas, 2009). (Supporting Scientific Report, Section 6.6). The overall lifetime risk of radiation-induced fatal cancer to an individual with high beach occupancy as well as a high consumption of seafood is still very small and lower than 1 in 100 million (10^{-8}) per year. It should be noted that an investigation of the Cefas monitoring database for incidences of high activities in mollusc samples (Cefas, 2008b) did not identify any samples where the activity levels recorded approached those in analyses of particles found on the beaches.

7.2 Adequacy of beach monitoring

The detection capability of the beach monitoring systems (Groundhog Evolution2™ and Synergy) is such that any beta-rich object that would give rise to skin ulceration could easily be detected with 100% detection probability to a depth of 30 cm through measurement of their ^{137}Cs content, provided it can be assumed that objects do not have Cs:Sr ratios significantly less than the lowest value found to date (ie, 0.6:1). Only if such objects had Cs:Sr ratios below about 0.25:1 would it be possible for some of them to remain undetected.

Capabilities of the beach monitoring systems for detection of alpha-rich objects are more limited because of the fundamental physical nature of the detection process, specifically because of the absorption within the beach material of the low energy photons resulting from radioactive decay of ^{241}Am. The ingestion of alpha-rich particles has been found to be the exposure pathway that has the greatest potential to rise to significant health risks if a particle is encountered and then only if the particle activity approaches or exceeds that of the most active particles found. An alpha-rich particle containing 100 kBq ^{241}Am can be detected by Groundhog Evolution2™ with a probability greater than about 5% only to a depth of 5 cm and an alpha-rich particle containing 1 MBq ^{241}Am can be detected with a probability greater than about 5% only to a depth of 10 cm. Given the doses that would result from ingestion of the most active alpha-rich particle found to date, which contains 1.03 MBq of ^{238}Pu, $^{239/240}$Pu and ^{241}Am (Section 5.3.2), the capabilities of beach monitoring systems for detection of alpha-rich objects at depth may not meet the requirements arising from a consideration of the health effects in the event that ingestion of an object occurs. The performance of the recently-introduced Synergy system should offer improved sensitivity, but it is very unlikely that it will be capable of detecting 1 MBq ^{241}Am particles with 100% efficiency at depths of 10–15 cm.

8 RECOMMENDATIONS FOR FURTHER WORK

The sources of major uncertainty in this assessment of risks to health and recommendations for future work are discussed in Section 12 of the Supporting Scientific Report. The most important topics where further work would reduce uncertainties in the assessment are described below. Those recommendations that would help to confirm that protection is adequate are distinguished from those that would improve the assessment of risks to health.

8.1 Confirmation that protection is adequate

8.1.1 The beach monitoring programme

HPA has previously advised the EA that the detection of alpha-rich objects with activities of greater than 10^7 Bq of alpha-emitting radionuclides should prompt an urgent review of the risks to public health (Appendix A). No such objects have been detected to date, but continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that risks associated with radioactive objects in the environment remain very low.

8.1.2 Detection of objects containing ^{90}Sr

To date, objects containing ^{90}Sr have never been detected through direct measurement of their ^{90}Sr content, but rather as a result of detection of their ^{137}Cs content. Whether there may be significant numbers of objects on the beaches that contain only ^{90}Sr, or have very low ^{137}Cs:^{90}Sr ratios, is therefore an open question. There is some doubt as to whether the Groundhog Evolution2™ system achieved the expected performance for detection of ^{90}Sr particles (Supporting Scientific Report, Section 4.1.5). Therefore, it is recommended that further work should be carried out to determine the reasons for this discrepancy, with the aim of improving detection capabilities for objects that contain predominantly ^{90}Sr, if practicable. If objects with very low ^{137}Cs:^{90}Sr ratios are present, the aim should be to improve detection of objects with ^{90}Sr activities in excess of 400 kBq with the objective of detecting particles that could result in skin doses equal to the 2 Gy threshold for ulceration over an exposure period of 8 hours.

8.1.3 Inhalation of small alpha-rich particles

The size and the activity of alpha-rich particles appear to be closely linked; the larger the particle, the higher its activity (Supporting Scientific Report, Section 8.5). The minimum detectable activity (MDA) of the Groundhog Evolution2™ system corresponds to particles with an aerodynamic diameter of about 300 µm, and this raises the question whether particles with activities lower than the MDA and with diameters smaller than 300 µm are present but remain undetected by beach monitoring. For particle sizes that are likely to be inhaled (that is, entering the nose or mouth), the effective dose resulting from inhalation of a *single* particle would be no greater than a few mSv. The possibility remains that larger numbers of particles at the smaller particle sizes, perhaps resulting from the sequential break-up of larger particles, could be inhaled. If small enough (ie, with aerodynamic diameters less than about 30 µm), these particles could penetrate to and deposit in the lungs.

It is recommended that environmental monitoring data should be reviewed to determine whether this potential pathway of exposure needs further evaluation. Results of the existing high-volume air sampling programme should be reviewed to determine whether the alpha-contamination component of the aerosol at or near the beaches being monitored is of any radiological concern. An analysis should be performed to determine whether the sequential break-up of larger particles could give rise to a component of contamination on the beaches or in the local atmospheric environment that is distinguishable from the ubiquitous contamination present in the beach environment. If so, data from routine environmental monitoring programmes should be reviewed to determine if the available data indicate whether this component is present. Consideration should also be given to the additional monitoring and measurements that might be performed to identify and characterise a possible component of environmental contamination that might result from the sequential break-up of larger particles on the beaches. It should be noted that there is routine monitoring of ambient contamination levels in beach sediments and an assessment of radiation doses to members of the public who use the beaches arising from these (see RIFE reports, eg, Cefas, 2009).

8.2 Improvements in the assessment of health risks

8.2.1 Beach monitoring systems

In August 2009 a new system, Groundhog Synergy, was brought into operation as a replacement for the Groundhog Evolution2™ system (Supporting Scientific Report, Section 4.4). The new system is more sensitive to particles containing ^{241}Am and as expected the number of alpha-rich objects being found has increased. This increased find rate does not necessarily mean that there is an increase in the number of objects actually present on the beaches, since the increase could be completely attributable to improvements in detection sensitivity. Further work is needed to resolve the issue. Firstly, a comparison should be made of the numbers of objects found and their activities, before and after the introduction of Synergy. The comparison should be made for measurements made over the same areas of beach. Since detection probability for ^{241}Am decreases rapidly with increasing object depth, the comparison is best made for objects detected on or very close to the surface, although comparisons at greater depths may also be useful. Secondly, the detection probabilities for Synergy should be quantified by carrying out an investigation analogous to that carried out for Groundhog Evolution (Supporting Scientific Report, Section 4.1). A decision should then be made as to whether there is a need to review the assessment of overall risk to beach users taking into account data on the increased number of objects detected by Synergy.

Capabilities of the beach monitoring systems for detection of alpha-rich objects at depth are limited by the physical nature of the detection process and also by currently available technology. These capabilities may not meet the requirements needed to ensure the detection of particles that could give rise to a significant risk to health in the event that ingestion occurs. If technical advances are made that would allow reliable detection of alpha-rich objects at greater depths than is currently achievable either with the Evolution2™ or the Synergy systems, consideration should be given to their implementation for monitoring of the beaches in the vicinity of the Sellafield site.

8.2.2 Beach Monitoring

In some circumstances, uncertainties in the estimate of the number of objects present can be quite large. If only a few objects have been found and particularly where they are present at depths where the probability of detection is low, the uncertainty in the estimate of the actual number of objects in a given monitored area can be large.

This is particularly noticeable for Drigg beach, where only a small number of alpha-rich objects have been found, but the estimated population of objects is higher than for any of the other beaches considered (Table 2). Only 30% of Drigg beach has been monitored, whereas for Braystones, Seascale, Sellafield and St Bees beaches, the total areas monitored exceed the area of each beach because of repeated monitoring. Uncertainties in the estimates for Drigg beach can only be reduced as more monitoring data become available.

The accuracy of the assessment of the population of objects (Supporting Scientific Report, Section 4.2) would be improved if more accurate data were available on the depths of particles detected and retrieved as a result of the beach monitoring programme. Current procedures could be reviewed to determine whether more accurate and reliable measurements of depth could be made.

9 HPA'S FORMAL ADVICE TO THE ENVIRONMENT AGENCY

EA has requested HPA to update its formal advice concerning the health risks posed by radioactive objects detected on beaches around Sellafield, taking account of the results of the study presented in this report. This Section gives a concise explanation of the scientific basis for the advice, making reference to other sections of this report where further information can be found.

This study has identified that, based on the currently available information, the highest stochastic risks to health for a beach user are associated with ingestion of objects with large actinide contents (ie, alpha-rich objects) as explained in Section 5.

For risks associated with alpha-rich objects, HPA is recommending to EA that two criteria should be adopted for prompting an urgent review of health risks to beach users. The first criterion is related to the risk of radiation-induced fatal cancer that is judged to be on the borderline of acceptability for a beach user, regardless of the probability that the particle might be ingested. To ensure that this criterion can be readily applied, it is expressed in terms of a measurable quantity, that is, the activity of the object. HPA is recommending, as it has previously, that finding an object with a total activity of alpha-emitting radionuclides greater than 10^7 Bq should prompt an urgent review of health risks to beach users. A dosimetric calculation based on the final results of HPA's in vivo studies of intestinal absorption (Section 5) indicates that ingestion of a particle of this activity would give rise to a committed effective dose in the region of 200 mSv for a 20 year old adult and a lifetime risk of fatal cancer of about 2%. Doses per Bq intake for a 1 year old child are estimated to be about twice the adult value. The factor of 10 between the dose per unit intake factors for 1 year old child and 3 month old infant results from ICRP's recommendation that the gut uptake fraction should be higher for a 3 month old than for other age groups by a factor of 10, but this factor may well be conservative. It is noted that the highest activity of alpha-emitting radionuclides found in an object is about an order of magnitude less than this trigger level, ie, about 10^6 Bq. The second criterion is based on a consideration of the overall risk, which takes into account both the probability of intake of an object by a beach user and the doses and risks to health that would result from the intake of such an object (see Section 6). HPA is recommending to EA that the estimation of an overall lifetime risk of radiation-induced fatal cancer for a beach user of greater than 1 in a million (the Health and Safety Executive (HSE) upper limit for an acceptable level of risk (Supporting Scientific Report, Section 10) should also prompt an urgent review. It should be noted that the highest calculated overall lifetime risks of radiation-induced fatal cancer for a beach user resulting from ingestion of an object are of the order of one hundred thousand times smaller than HSE's upper limit for an acceptable level and so this criterion is unlikely to be limiting.

HPA is also recommending that it would be prudent to develop a criterion that would prompt an urgent review of health risks to beach users for objects with a high content of beta emitting radionuclides (specifically, ^{90}Sr and ^{137}Cs). Deterministic effects would not be expected to result from exposure to any of the objects for which data are currently available, considering any reasonable scenario. The greatest potential for deterministic effects is associated with irradiation of the skin by particles containing beta emitters (ie, beta-rich particles) (see Section 5). Specification of the criterion in terms of measurable quantities is made somewhat more complicated because, whereas the ^{137}Cs content of a particle is routinely measured, the largest contribution to the (1 cm^2, 70 µm) skin dose rate may result from the ^{90}Sr/^{90}Y content of the particle, which is not routinely measured.

HPA is recommending to EA that objects with a ^{137}Cs activity greater than 10^5 Bq should, as soon as possible, be characterised in terms of size and chemical composition, and the ^{90}Sr content should be measured. The (1 cm^2, 70 µm) skin dose rate should then be determined, either by calculation or measurement, and if greater than 300 mGy per hour, an urgent review should be initiated. For a particle giving this skin dose rate that remains in stationary contact with the skin, an exposure time of 7 h would be needed to reach the 2 Gy threshold for localised skin ulceration. The (1 cm^2, 70 µm) skin dose rate for a particle containing 10^5 Bq ^{137}Cs but no ^{90}Sr is expected to be in the region of 10 mGy h^{-1}. If such a particle also contained ^{90}Sr with a ^{137}Cs:^{90}Sr ratio of about 0.6:1, close to the lowest value found (see Section 5), the skin dose rate would be expected to be significantly higher, in the region of 100 mGy h^{-1}. It should be noted, however, that dose rates are dependent on particle size, density, and distribution of activity within the object, as well as on radionuclide content, and could exceed these expected values. This recommendation should ensure that information on Cs/Sr content is obtained for all objects that could give a skin dose rate in excess of 100 mGy h^{-1}, and that all objects giving rise to skin dose rates in excess of 300 mGy h^{-1} are identified and characterised.

The available evidence indicates that the main contribution to the skin dose rate for stones arises from their ^{137}Cs content, but is also dependent on the surface area of the stone (Supporting Scientific Report, Section 9). Although skin dose rates per unit activity are likely to be lower for stones compared with particles, the setting of urgent review trigger levels specifically for stones would involve additional complexity that is considered to be unjustified. Should the use of the trigger levels described above result in characterisation work on stones which are eventually found to give rise to relatively low skin dose rates, the use of a separate trigger level for stones could be considered.

The identification of alpha-rich and beta-rich objects that would trigger urgent review of health risks to beach users would not necessarily prompt action to limit access to beaches, but would justify thorough monitoring in the area so that a comprehensive radiological evaluation of the risks to the public could be carried out.

The reliable detection of alpha-rich objects with a large actinide content is required to support HPA's recommendations for urgent review. The first criterion for alpha-rich objects relies on the detection of objects with a total alpha activity greater than 10^7 Bq but these objects may remain undetected at depths below about 10 cm. If technical advances are made that would allow reliable detection of 10^7 Bq objects at greater depths than is currently achievable, consideration should be given to their implementation for monitoring of the beaches. The second criterion for alpha-rich objects relies on the detection of lower activity objects because the estimates of overall risks from the intake of such of objects are dominated by those with activities less than 10^5 Bq. Any improvements in detection capability for such objects would therefore also be desirable.

10 CONCLUSIONS

The conclusion of this study, based on currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using beaches. Based on the information available at the time of this study, the highest calculated lifetime risks of radiation-induced fatal cancer are of the order of one hundred thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk (HSE, 2001) (Supporting Scientific Report, Section 10.7). It is also very unlikely that deterministic effects such as skin ulceration could occur from encountering an object.

The ingestion of alpha-rich particles has the greatest potential to give rise to significant health risks. However, the very low likelihood of ingestion occurring means that the overall health risk remains very low and less than one in ten thousand million (10^{-10}) per year.

Continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that risks associated with radioactive objects in the environment remain very low.

Individuals who regularly use the beaches may also be high consumers of locally caught seafood. The overall health risk to an individual with high beach occupancy as well as a high consumption of seafood is also estimated to be very small.

A number of recommendations have been made with the objective of providing further confirmation that protection of the public is adequate and improving the assessment of health risks (see Section 8 and Supporting Scientific Report, Section 12). In particular, a recommendation is made that an investigation should be carried out of the increases in the number of alpha-rich objects being found by the recently-introduced Groundhog Synergy beach monitoring system. This increased find rate does not necessarily mean that there is an increase in the number of objects actually present on the beaches, since the increase could be completely attributable to improvements in detection sensitivity for particles containing ^{241}Am that are expected from the Synergy system. A possible approach for such an investigation has been proposed. Following this investigation, a decision should be made as to whether there is a need to review the assessment of overall risk to beach users taking into account data on the increased number of objects detected by Synergy.

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