Strategy for the Assessment of the potential impact of Sellafield Radioactive Particles on Southwest Scotland

December 2007

CONTENTS

1. EXECUTIVE SUMMARY

This document provides a strategy for monitoring for radioactive particles, which may have been released from Sellafield into the environment. The monitoring strategy has been developed to assess the potential impact on the public in South-west Scotland. The strategy identifies a range of possible actions (including potential interventions) and recommendations which should be considered for protection of the public.

2. INTRODUCTION

Until recently, limited specific monitoring for radioactive particles has been undertaken around Sellafield to determine the extent of any contamination or potential risk to public health from radioactive particles. However, recent improvements using large area monitoring techniques by Sellafield Limited, as required by the Environment Agency, has resulted in the detection of further radioactive particles and other radioactively-contaminated objects such as pebbles. Distant monitoring by the site operator 15 km north of the site detected one radioactive particle. Modelling, carried out by The Centre for Environment Fisheries and Aquaculture Science (CEFAS) at the request of the Environment Agency, has shown that radioactive particles released from Sellafield could enter the Solway Firth and from there could be deposited on beaches along the Dumfries and Galloway coastline.

Due to its experience with radioactive particle issues, the Scottish Environment Protection Agency (SEPA) has been requested by the Environment Agency (EA) to provide assistance. However, as a result of this assistance, SEPA has become aware that there is only limited information available to demonstrate that the public in South-west Scotland is adequately protected from radioactive particles which may have been released from Sellafield. For this reason SEPA has asked for monitoring to be undertaken the results of which would enable SEPA to assess the likely exposure of the public in South-west Scotland to radioactive particles which may have arisen from Sellafield.

This monitoring, and any potential intervention strategy that may result, is based on an assumption that the originating source of the contamination is tens of kilometres away from the beaches being monitored. This monitoring strategy has not been developed for beaches close to the source, it is noted at these locations the occurrence of radioactive particle occurrence is likely to be greater than at more distant sites.

If a radioactive particle is detected this will be removed for analysis. However, the purpose of removal is not to act as an intervention action; it is to provide information to better understand the likely exposure of members of the public in South-west Scotland, and thus determine whether any intervention action is needed.

3. BACKGROUND

In November 2006 and then on to 2007, radioactive particles were detected by Sellafield Ltd using the Groundhog Evolution system (a large area monitoring technique developed by Nukem Ltd). Following this, SEPA was asked to attend a meeting with the Environment Agency (EA), Nuclear Decommissioning Authority (NDA), Food Standards Agency (FSA), Health Protection Agency (HPA), Copeland Borough Council, CEFAS and Sellafield Ltd to discuss the findings. During this meeting a technical report was discussed (Appendix 1) which detailed current knowledge of the issue. Following the discussion it became apparent that neither Sellafield Ltd nor the Environment Agency envisaged any information being available in the near term to assess the impact on South-west Scotland. As a consequence SEPA stated its position that it would ask for monitoring to be undertaken in South-west Scotland to determine whether the public was adequately protected. During the meeting the NDA agreed to fund this monitoring work.

4. ENVIRONMENT AGENCY MONITORING

Sellafield Ltd is scheduled to conduct beach monitoring for radioactive particles over an area of at least 100 Ha in the 2007-08 financial year. However, no monitoring is currently scheduled for South-west Scotland[1]. Information provided to date indicates that 69 radioactive items have been detected of which 44 are radioactive particles (defined by Sellafield Ltd as items of dimensions <10 mm), the range of analytical results of these is shown in Table 1.

Principal radionuclide	Min Activity (Bq)	Max Activity (Bq)
^{60}Co	9E-02	6E+03
^{106}Ru	< 4E+01	1E+03
^{125}Sb	< 1E+01	7E+02
^{134}Cs	3E+00	1E+02
^{137}Cs	5E-01	1.2E+05
^{241}Am	< 6E+01	4E+05[2]
^{238}Pu	< 8E+03	9E+04
^{239}Pu	1E+04	8E+04
^{241}Pu via ^{237}U	3E+05	1E+06

Table 1. Results of Analysis of Sellafield radioactive particles (data obtained from the EA).

For particulate contamination the radionuclides which have been detected in the current Sellafield monitoring campaign are ^{137}Cs and $^{241}Am/Pu$. However, it is also worth noting that 2 years ago what is suspected to be a ^{90}Sr particle was detected. There have also been finds of ^{60}Co-bearing particles in the past. Thus, there are at least four types of radioactive particle of concern. It is likely that the particles are present in the environment as a combination of both authorised and unauthorised discharges in the past, noting in particular that BNFL was prosecuted for an incident

[1] Monitoring of limited areas of the Solway is now scheduled to occur before the end of the financial year 2007/2008.
[2] SEPA is aware that a further particle with an activity of 6.3 E5 has been detected around Sellafield.

which led to contamination of the local beaches in 1983, (Environment Agency, 2007).

The Health Protection Agency has provided scoping advice about the hazard of the particle finds so far. This advice is included in Appendix 1: HPA scoping dose calculations. This scoping advice suggests that the main hazard from the finds so far would be an increased long-term risk of fatality from cancer from Pu/Am particles. Potential committed effective doses from ingestion of the highest hazard radioactive particle found to date are considered currently to lie in the range 2-200 mSv and 10-1000 mSv for an adult and 1 year-old child respectively. These ranges reflect the lack of knowledge about the intestinal absorption of Pu and Am from an ingested radioactive particle. Specific work undertaken by SEPA and HPA on Dounreay radioactive particles indicates low levels of absorption and therefore doses at the low end of the ranges. In principle, the maximum doses could be larger or smaller because the absorption rate is the mean of a range of studies considered by the International Commission on Radiological Protection (ICRP). However, using a mean rate is considered cautious by the HPA. (See Appendix 1 for further detail). Note that at a recent workshop held by EA, it was agreed that until experimental confirmation of gut transfer factor is obtained, a working value of 10^{-4} should be used for effective dose estimation. Thus for ingestion this would give lifetime doses of 20 mSv and around 100 mSv for adults and infants respectively for the particle with the highest ^{241}Am activity.

The HPA has considered the higher levels of the beta/gamma emitters found in the Sellafield radioactive particles compared with the Dounreay particles, and has concluded (preliminary) that short-term deterministic effects are unlikely from ingestion. However, for effects on the skin specialist preliminary analysis, carried out at Birmingham University, has been undertaken. The conclusions of these preliminary calculations of skin dose rate indicate upper estimates of several 10's of mGy h^{-1} for the more active Sellafield radioactive particles tabulated by British Nuclear Group Sellafield Limited (June, 2007). [However, the calculations do not take account of the possible presence of the pure beta emitters ^{90}Sr/^{90}Y]. This level of dose rate is comparable to the lower activity Dounreay fuel fragment radioactive particles, i.e. comparable with those found on Sandside beach in Caithness. It has therefore been concluded by HPA that such activities (for the particles found to date (based on the measured surface dose rates)) are not of concern in relation to deterministic effects.

There is limited information on the distribution and 'density' (numbers per unit area) of Sellafield radioactive particles in the environment. Some increased large area monitoring of public beaches in the Sellafield area commenced on a trial basis in 2006 and more routinely in May, 2007. Despite this increase in monitoring, these beaches have to date (June, 2007) received limited surveying of relatively small areas of sand in a few locations in areas up to 15 km north and a few km south of the site. At all locations surveyed, only a small area of the beach has been surveyed and this may be unrepresentative of the entire area. However, the limited monitoring undertaken so far has revealed much higher 'density' of finds at Sellafield beaches compared to more distant beaches. No large area surveillance of the seabed or terrestrial environment has yet been undertaken. In total, by June 2007, approximately 29 hectares of coast has been surveyed. Given the pathway of marine deposition, it is possible that these areas could be repopulated with further radioactive particles in the future. As the vast majority of these areas has only been subject to limited surveying on one occasion, the rate of any re-population is unknown.

5. DISCHARGE MODELLING STUDIES

At the request of the Environment Agency, CEFAS have provided a qualitative assessment of the potential wave-dominated transport pathways of Sellafield radioactive particles in the near-shore environment (Appendix 1: CEFAS report on Sellafield radioactive particles. Evaluation of potential littoral drift with recommendations for field sampling.). This is based on published information about geomorphology and spatial size distributions of natural sediments, and previous finds of radioactive items on beaches near Sellafield. An earlier scoping assessment by CEFAS (March 2007) considered the movement of sand from the area around the long outfall. This concluded that there is a strong onshore movement with radioactive particles reaching the coast within about 1.5 years, and, at this stage, being confined to the vicinity of Sellafield. This conclusion is insensitive to particle size (which is likely to be unrealistic). Modelling indicates that the wave and tidal stress is sufficient to keep the particle mobile most of the time, even for larger sizes (at Dounreay this assumption was questioned as particles are often buried and then re-emerge following storms). Once particles reach the near-shore environment the modelling is no longer able to characterise the numerous transport processes, which will most likely be dominated by wave driven currents and long shore drift. These will distribute particles north and south, depending on wave direction. The dominant transport direction is northwards, with St Bees Head acting as a key dividing point. If particles pass the ‘barrier’ at St Bees then the main sediment sink is the Solway Firth, with particles possibly moving on and off local beaches during the movement to the Solway. Information from the Dounreay contamination suggests that the physically smallest particles (generally with lower activities) move faster and further than the larger (and more active particles) which has been supported by the detection of a low activity particle at Dunnet Beach some tens of kilometres from the point of release. Thus, it could be assumed that even if particles had managed to move towards Scotland the activities would be most likely to be significantly lower than those detected around Sellafield.

Thus, there is a potential for radioactive particles to become deposited on local beaches in the Solway Firth and therefore a potential for exposure of the local population to radioactive particles which may have been released from Sellafield.

6. PROGRAMME OF WORK

6.1. Aim

The aim of this monitoring programme is to determine whether radioactive particles, which may have been released from Sellafield, pose a realistic chance of delivering, to members of the public in Scotland, doses in excess of the dose limit or could cause severe effects on health.

This requires limited monitoring to be undertaken to assess if radioactive particles are present on beaches in South-west Scotland.

As modelling studies detailing the movement of radioactive particles from Sellafield are imprecise, the sandy beaches that are most frequently visited by people will be targeted for monitoring.

6.2. Potential Hazard

Limited monitoring conducted around Sellafield has resulted in the detection of four types of radioactive particles in the environment which are dominated by the radionuclides of ^{137}Cs, or ^{241}Am/Pu, ^{60}Co or ^{90}Sr.

Currently, there is only a small amount of information on the potential hazard posed by Sellafield radioactive particles on human health. However, information in Appendix 1 and from the work undertaken for SEPA by HPA on Dounreay particles has allowed some estimates to be made for the activity (of the primary detectable radionuclide) necessary to deliver a dose of 1 mSv (with other dose contributing radionuclides). For ^{90}Sr particles, in particular, this approach may not be pessimistic due to the fact that strontium is readily absorbed by the body.

The activities required to deliver committed doses[3,4] of around 1 mSv are:

^{241}Am[5]	5,000 Bq
^{137}Cs	100,000 Bq[6]
^{90}Sr	27,000 Bq
^{60}Co	100,000 Bq[7]

6.3. Monitoring Capability

One proven system currently available in the UK for monitoring large areas for radioactive particles is the NUKEM Groundhog Evolution system. Information on Groundhog Evolution indicates that the current system can reliably detect 100,000 Bq ^{137}Cs to substantial depths (to 200 mm) (DPAG, 2006). It cannot detect ^{90}Sr and can only detect an activity of 50,000 Bq of ^{241}Am on the surface with a confidence of around 95% (Appendix 2). The system is theoretically unable to detect particles with ^{241}Am activity of less than 10,000 Bq. However, in practice, the system has demonstrated a capability of detecting particles with an activity of 60 Bq (Table 1).

6.4. Monitoring Location

Current estimates of the probable final location for radioactive particles released from Sellafield and being moved towards Scotland are uncertain. A model developed by CEFAS indicates that the most likely area for deposition is the Solway Firth. If it is assumed that the radioactive particles move with sand-sized grains, areas where sand accumulates are the most likely sinks for radioactive particles. Sandy areas also represent the area where members of the public are likely to spend significant periods of time and thus have the greatest potential for exposure. Although salt

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[3] In the absence of radionuclide data it has been assumed that all of the dose is from ^{241}Am

[4] This assumes all of the radionuclide can be absorbed and become committed doses – it is accepted that this is likely to be pessimistic; however there is no robust information to base any other assumption upon.

[5] This value is scaled on HPA information in Appendix 1 for particle # 1102166 and assumes a F_1 value of 10^{-4}.

[6] This assumes Sellafield Cs radioactive particles are comparable with Dounreay Cs radioactive particles.

[7] In the absence of any information on Co-60 particles, it has been assumed that the dose per unit intake is the same as that in ICRP-60. It is accepted that this may be an over-estimation.

marsh areas are known to have accumulated discharges from Sellafield, their vegetative cover means that the probability of exposure via ingestion, inhalation or direct skin contact is lessened. Salt marsh environments also tend to be finer-grained material which, if it is assumed that there is a direct relationship between activity and size, would contain lower hazard particles than those residing on sandy beaches. However, as it has been demonstrated at Dounreay there may be a need to assess these beaches as these may be the first beaches to receive radioactive particles. This monitoring is specifically not targeted to determine potential effects on the food chain as this is a responsibility of the Food Standards Agency.

Around the Solway Firth there are a number of substantial public beaches which appear to be sandy which include Powfoot and Gillfoot Bay (Southerness). The beach at Powfoot is reportedly extensively used by the public (Habits Survey, 2002 and 2005). The beach at Gillfoot is further to the west in the Solway and the presence of a caravan site indicates that this beach is also widely used. Given the high uncertainty in modelling of particle discharges from Sellafield, SEPA has identified that both of these sites would be suitable for monitoring to provide information on whether large numbers of radioactive sand-sized particles were located on public beaches in South-west Scotland.

Following dialogue with Dumfries and Galloway Council, it has been suggested that the beach at Kirkcudbright may also be suitable as a beach for monitoring. Notably, the Council report that this beach is known to be impacted by discharges from Sellafield and has significant public occupancy. This beach is also routinely monitored by SEPA to determine the impact of Sellafield discharges on the public in Scotland. Occupancy at this beach is reportedly high (as reported by the local Council) and the habits survey conducted in 2002 reported a range of uses[8].

Inspection of these beaches by SEPA in early August 2007 confirmed that the beach at Gillfoot is sandy and extensively used by the public for a range of activities. However, the beach at Powfoot was silty rather than sandy. With the presence of a salt marsh, the relative occupancy of this beach is believed to be substantially lower than that around Gillfoot. Although there is a caravan park at Powfoot, the number of caravans was significantly smaller than that at Gillfoot. Due to the large number of uncertainties in the behaviour of the radioactive particles, it is SEPA's objective that monitoring should be undertaken at the beaches at these locations.

6.5. Monitoring Procedure

Monitoring will aim to include a representative area of each beach i.e. the monitoring area will include a swath of beach from the rear of the beach to low water springs.

6.6. Monitoring Area

The area of the beach to be monitored along the Dumfries and Galloway coastline is determined by an assessment of the probability of encounter. A model developed by SEPA (based on an assessment undertaken for SEPA by the HPA for Sandside Beach) for a radioactive contamination issue at Dalgety Bay in Fife, allows the probability for encounter of radioactive particles to be assessed in relation to the

[8] Planning of monitoring of this beach will require liaison with local landowners, Crown-Estate and Scottish Natural Heritage (if any area is designated under the terms of the Nature Conservation Act).

number of radioactive particles in a given area of beach. This model assumes particular areas of exposed skin for radioactive particle contact and these, and other assumptions, are detailed in Appendix 3.

This monitoring strategy is designed to demonstrate whether the numbers of radioactive particles that may have travelled from Sellafield to South-west Scotland and on to local beaches are such that there is either a realistic possibility of dose limits being breached or the potential for a high health impact event e.g. long-term skin damage or ill health. Thus, it will assess whether any potential user of the beach has a realistic chance of encountering[9] a radioactive particle which could give rise to a committed dose of 1 mSv (or skin dose of 50 mSv) on an annual basis. For the dose limits the probability of encounter will be based on occupancy of 2000 hours[10] for an adult using the beach[11]. The monitoring programme will also determine whether there is a reasonable possibility of a high health impact event.

6.7. Determination of Monitoring Area

The area required to be monitored is dependent on an assumed density of radioactive particles (number per unit area) and their potential effects.

6.7.1 Committed doses

One mSv is related to a probability of fatal lifetime risk of cancer of 1 in 20,000. For this to occur there is a need for a radioactive particle to be ingested and for a sufficient fraction of the ingested activity to be assimilated by particular (physiologically targeted) body tissues. The probability of ingestion is directly related to the density (number per unit area) of radioactive particles, occupancy of the beach and inadvertent ingestion rate. If there were high numbers of radioactive particles on the beach, the probability of contact increases. However, even if there were to be one radioactive particle on any area of 2 m^2, for an occupancy of 2000 hours, this could result in an annual probability of ingesting a radioactive particle of around 1 in 35,000. However, careful consideration should be given as to how representative this area of the beach would be.

6.7.2 Skin contact

If all areas of the beach were homogenous and radioactive particles were consistently distributed within the sand, a minimum monitoring area of $10m^2$ would be required to demonstrate whether there was a possibility (1 in 21 around 95%) that the skin dose limit would be exceeded over the course of one year (2000 hours occupancy) (Appendix 3B).

[9] An encounter has been defined as skin contact, ingestion or inhalation.

[10] In the absence of other data the (former) NRPB Generalised Habit Data is used. Two thousand hours is occupancy time for the representative adult critical group for the beach/intertidal area. (NRPB, W41, 2003). The maximum occupancy for mud and sand reported by NRPB (W41) is 1900 hours and for salt marsh is also 1900 hours. W41 details the highest occupancy for tidally washed pasture in Dumfries and Galloway of 320 hours for Haaf netter fishermen. The habits survey conducted by SEPA indicated the fishing was largely anglers on rocks which spent 320 hours per year on rock.

[11] This will be revisited when the habits survey currently being undertaken in South-west Scotland is completed and the data are available. Notably, the habits survey has not been altered for this purpose as was the case at Dounreay.

6.7.3 Trigger level

Guidance from the ICRP (1999) indicates an annual effective dose which approaches 100 mSv will almost always justify intervention[12] [13]. A skin dose of 10 Gray represents an ED50 (ED50 is the dose at which effects will be observable in 50 % of cases) from particulate contamination, (DPAG, 2007). For the purposes of this assessment it is assumed that it would be unlikely that a particle would remain in exactly the same position on the skin for a period of greater than one hour. This dose and dose rate have therefore been adopted as trigger values where some action to protect the public will almost always be necessary. It is recognised that for activities and resultant doses below this value action could be taken to protect the public but this would need to be evaluated on a case by case basis.

For all pathways, one radioactive particle over an area of 250 m^2 would give a chance of encounter of 1 in a million per visit (Appendix 3C). It is considered that this is a reasonable risk and is based upon principles from the Health and Safety Executive (HSE) advice of no danger being equivalent to an annual fatal risk of less than 1 in a million (Health and Safety Executive, 1988. Tolerability of risk from nuclear power stations). The most recent habits survey (2002) for Dumfries and Galloway area indicated a critical group occupancy of 1050 hours per year (average 1000) (Shellfish collectors). An area of 280,000 m^2 would be required to give a chance of encounter of 1 in a million per year (Appendix 3C). Around Southerness/Gillfoot the habits survey indicated a critical group over sand of 270 hours occupancy per year (bird watchers). Such an occupancy rate would require an area of 67,000 m^2 to be monitored to give a chance of encounter of 1 in a million per year (Appendix 3C). At Powfoot habits survey indicated a critical group over sand of 270 hours occupancy per year (bird watchers) and 180 hours for bait diggers on salt marsh. Such occupancy rates would require areas of 67,000 and 48,000 m^2 respectively, to give a chance of encounter of 1 in a million per year (Appendix 3C). Habit data for the beach at Kirkcudbright indicated a maximum occupancy over sand of 365 hours per year. This occupancy rate would require an area of 90,000 m^2 to be monitored to give a chance of encounter of 1 in a million per year (Appendix 3C).

Thus, using the information from the habits survey, the monitoring area required for this purpose is 67,000 m^2 for Gillfoot and Powfoot. However, this assumes that the monitoring apparatus is fully effective at detecting all radioactive particles present. It is known that the monitoring systems used do not have a 100% capability to detect ^{241}Am or ^{60}Co and thus, it could be argued that the area requires to be increased to compensate for this factor.

At Gillfoot Bay it is assumed that the critical group does not dig with any significant frequency into the sand, thus the most likely exposure pathway is from particles present on the surface of the sand. Hence, the area required to be monitored at this location does not need to be compensated for the changes in efficiency of detection at depth. This is also the case for the bird watchers at Powfoot. At Powfoot bait diggers actively dig into the sediment and thus it could be argued that there is a need to compensate for changes in detection capability with depth. However, in spending time digging at a specific location less time will be spent on other areas of the beach.

[12] It is accepted that this assumes that exposures will occur.

[13] Information provided by the HPA-RPD to the Environment Agency indicates that this value is below levels that could cause deterministic effects

Given that it is assumed that the distribution of particles is random and that regular beach turnover occurs to at least this depth (which seems reasonable at Dounreay), monitoring 10 m^2 to a depth of 1 cm will be the same as monitoring 1 m^2 to a depth of 10 cm. Thus, it is not considered appropriate to compensate for detection efficiency.

From the work outlined above, it is apparent that monitoring an area of 67,000 m^2 of representative beach would satisfy all of the monitoring objectives at Gillfoot and Powfoot. At Kirkcudbright an area of 90,000 m^2 would be needed. However, it is accepted that there are considerable uncertainties in these calculations and although these calculations are believed to be realistic based on the information available, it is prudent to add some caution to this value. To date, three beaches with public occupancy have been identified that are in the general area where the CEFAS model indicates the radioactive particles may be moving towards. Given the absence of sandy material at Powfoot, it is proposed that initial monitoring should be limited to beaches at Gillfoot and Kirkcudbright.

An alternative approach would be to sample a given area of the beach e.g. 1, 5 or 10%, to determine whether radioactive particles are present and then scale this up for the remainder of the beach. This approach would allow a beach to be assessed against a criterion of 1 in a million chance if the total area is 65,000 m^2 or less. As most beaches around South-west Scotland are substantially greater than 65,000 m^2 and as it is not known whether any radioactive particle could have reached Scotland, monitoring entire beaches would require large resources which may be disproportionate according to detriment. Equally, as there is no information on the potential number of radioactive particles which could be present, we have no basis for undertaking representative sampling (e.g. 1, 5 or 10 %) of the beach. However, the aim of the monitoring survey is not to determine whether radioactive particles are present, but rather, to determine whether radioactive particles released from Sellafield pose a realistic chance of delivering a dose to members of the public in Scotland in excess of the dose limit or could cause severe effects on health. This criterion demonstrates that there is no need to monitor large areas of beach to determine whether the public in South-west Scotland is adequately protected from particulate contamination.

However, given the uncertainties in the assessment it is proposed that, to introduce a measure of caution into the assessment, an area of 100,000 m^2 will be monitored at each of the beaches.

7. ACTIONS PRIOR TO MONITORING / MEDIA STRATEGY

The visibility of the monitoring of Solway beaches will be high and is likely to draw local interest. It is therefore proposed that prior engagement is required with the local community to provide information on why SEPA is monitoring the beaches. Information can be provided that SEPA is monitoring a number of local beaches to determine whether radioactive particles are present. The monitoring technique being used is a different technique to that used in SEPA's routine programme and will provide further information on the potential exposure of the public in Dumfries and Galloway from radioactive sources. SEPA expect that this particular monitoring survey will provide specific information on whether radioactive particles have travelled from Sellafield to South-west Scotland and, if so, whether they are sufficient in number or level of hazard to pose a risk to members of the public using the beaches.

Dumfries and Galloway Council fully supports the programme of monitoring and potential actions which may need to be undertaken.
In the event of a radioactive particle being detected, it is recommended that a forum be convened including SEPA, HPA-RPD, Dumfries and Galloway Council, NHS, FSA and Scottish Government to discuss the significance of the finding and any consequent recommendations and resultant actions which may be appropriate, as indicated below.

It is recommended that SEPA Communications team lead on this engagement.

8. ACTIONS FOLLOWING MONITORING

During or following the monitoring programme information may need to be provided to interested parties according to whether radioactive particles have been detected. Figure 1 provides a schematic flow diagram of the possible actions.

8.1. No radioactive particles detected

SEPA can inform interested parties that it has no reason to consider that a substantial number of radioactive particles, which could realistically pose a threat to human health, have been deposited in South-west Scotland.

8.2. Radioactive particle detected and information on activity is available

Information on the activity of any radioactive particle detected should be readily available assuming that it has been possible to recover the detected particle. If this is available actions can be targeted according to the potential hazard that such a radioactive particle could realistically pose to the public and the chance of encounter.

8.2.1. Trigger level radioactive particle

If a radioactive particle is detected which could result in effective doses of greater than 100 mSv or 10 Gray per hour skin dose, intervention must be considered and requires to be optimised. It is recommended that, as an absolute minimum, signage should be considered[14] to provide the public with information on the presence of the hazard. However, the responsibility for public health lies with the local council and health department. Dumfries and Galloway Council will be made aware of the work prior to the commencement of monitoring. Further monitoring of the same area should be carried out following a full tidal cycle (28 days). Should no (high-activity) radioactive particles be detected after further monitoring, consideration should be given to removal of any imposed intervention.

It is recognised that for small numbers of high-activity particles the overall risk[15] of premature death to members of the public will be small.

[14] Although signage may not be appropriate on strict radiation protection grounds, providing such signs is an effective method of informing the public of the presence of such hazards. It is believed that in most cases where trigger level radioactive particles have been detected, the recommendation that signs should be erected will be made.

[15] A dose of 100 mSv represents a lifetime risk of around 1 in 200 of contracting fatal cancer. As the areas for monitoring have been determined to assess the chance of encounter of 1 in a million, if a risk of death is to be

8.2.2. A radioactive particle is detected which could deliver a dose of less than 100 mSv /10 Gray

If a radioactive particle is detected which could deliver a dose of less than 100 mSv effective dose, the probability of the radiation dose being received needs to be taken into account. The following criteria should be used to determine the possibility of harm as significant where:

(a) the potential total effective dose multiplied by the probability of exposure is greater than 3 mSv per person per year; or

(b) the potential equivalent dose to the lens of the eye multiplied by the probability of exposure is greater than 15 mSv per year; or

(c) the potential equivalent dose to the skin multiplied by the probability of exposure is greater than 50 mSv per year.

If these conditions are not satisfied, then no action is required on radiation protection grounds. It is accepted that there will be a wider range of factors that the local authority may need to consider when determining the adoption of any action.

If any one of the criteria above is satisfied, intervention should be considered according to the magnitude of the hazard and the probability of encounter.

8.3. Radioactive particle detected but no information on activity available

If a radioactive particle is detected and no information is available on its activity, actions should be undertaken on a case by case basis. It is believed that this situation is highly unlikely as, at a minimum, some information should be available on dose rates or total count rates from the detectors.

8.3.1. Radioactive particle ownership

Should a radioactive particle be detected, SEPA could assume ownership of any such particle and could take it into possession.

8.4. Re-opening of beaches

If any imposed intervention necessitated the closure of a beach, the removal of this restriction should be considered when, following a full tidal cycle, a comprehensive survey of the beach fails to identity the presence of any radioactive particle that would result in beach closure.

8.5. Removal of signs

Removal of signs should be considered by the local council when, following a full tidal cycle, a comprehensive survey of the beach fails to identify the presence of any radioactive particles which could trigger actions detailed in 8.2.1 or 8.2.2.

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calculated, the probability of encounter and the potential doses need to be considered. For example, if monitoring were conducted over an area of 65,000 m^2 and a particle was detected, the probability of encounter would be around 1 in a million per year for high-rate users. If this particle could deliver 100 mSv committed effective dose, the hazard posed by this would be around 1 in 200 of contracting fatal cancer. Thus the overall risk of premature death would be around 1 in a million multiplied by 1 in 200, i.e. 1 in 200 million.

8.6. Re-survey

It is assumed that work conducted closer to the potential source of radioactive particles will be undertaken in the near future. Any resurvey of the area must take such work into account.

DECISION MATRIX

Flow diagram of actions following monitoring for any single beach

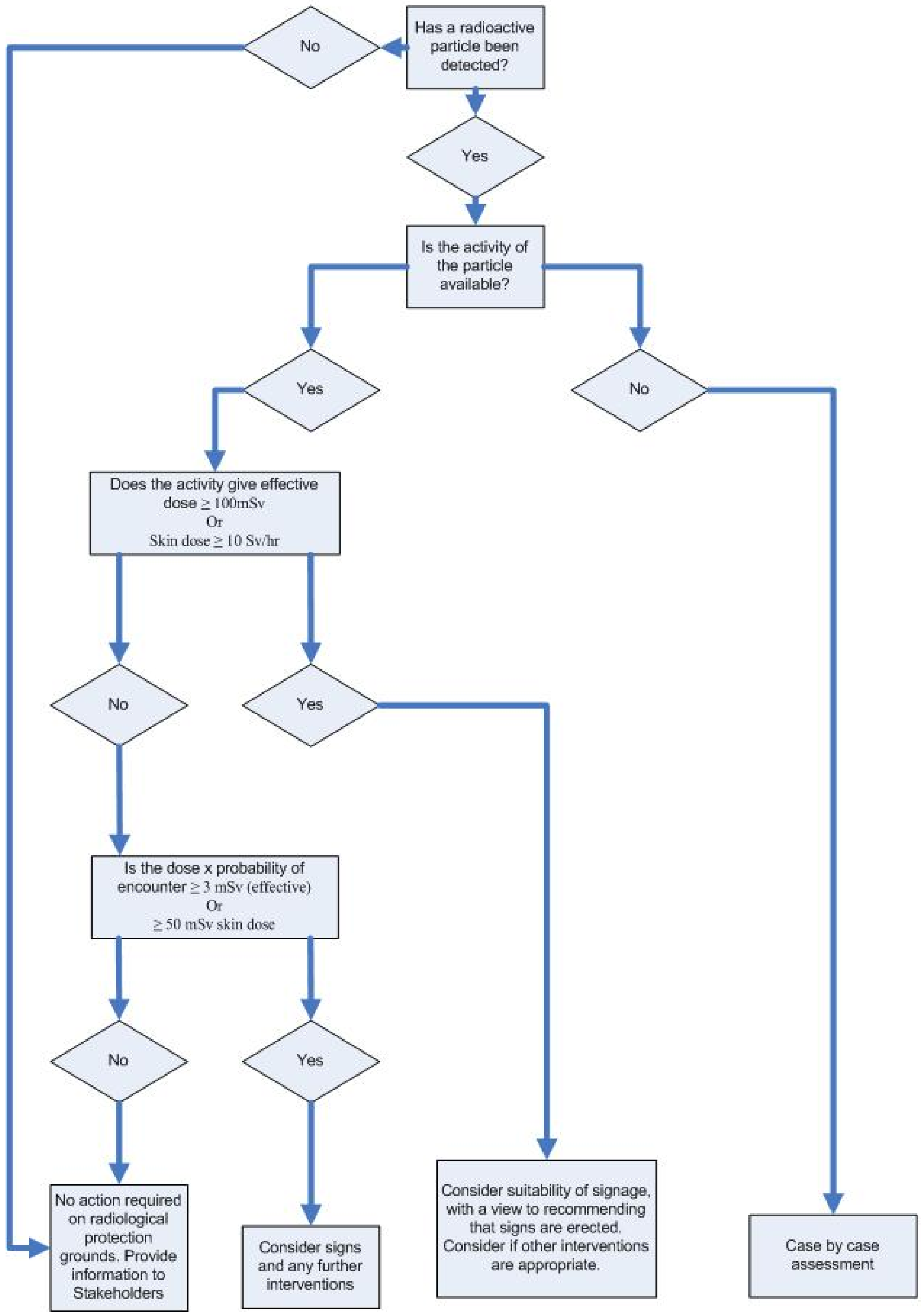


Figure 1. Schematic of actions following monitoring.

Appendix 1

EA Technical Document

Discussion paper

For a workshop on Sellafield radioactive particles in the environment – 28 June 2007

Section 1: Introduction and workshop objective

This paper has been written by the Environment Agency with the support and contributions from the Health Protection Agency (HPA), Birmingham University, Scottish Environment Protection Agency (SEPA), Centre for the Environment Fisheries and Aquaculture Science (CEFAS) and BNGSL. It provides background (status) to both facilitate and prompt discussion at a technical workshop to be held on 28 June 2007 on Sellafield radioactive particles in the environment being arranged by the Environment Agency.

The objectives of workshop are to:

- provide a broad understanding of the issue;
- identify the gaps in our knowledge and understanding;
- provide a central focus group to consider the implications of recent findings;
- allow responsible agencies to work collectively and minimise any duplication of effort; and
- provide information to allow agencies/councils to discharge their respective duties.

Considering this information and our preliminary understanding about the hazards and risks the Environment Agency will be seeking views on:

- The priorities and scope of the research and development programme.
- The role of the various agencies and the co-ordination and oversight of the R&D programme.
- Technical and quality assurance of the R&D programme.
- Transparency and public reporting of the issue.
- The range of options to ensure protection of people and the environment.
- Information to be provided to the public.

There is at least three distinct populations of particles in the environment, which are dominated by either Sr-90, Cs-137 or radionuclides of Am/Pu. For each of these populations the numbers and distribution is unknown[1]. Information on the origin, source or cause of particles or the contaminated items detected in the marine environment at, around and distant from Sellafield is also limited. We know that in 2007 the contamination extends at least 12 km to the north and a few km south, but our knowledge of the distribution of items has only recently been improving as consequence of new beach monitoring techniques.

For the purpose of this technical workshop it is proposed to focus on radioactive particles in the environment because (on the basis of current understanding) they represent the hazard and are numerically greater thus they present the greatest risk at this time. Unlike contaminated pebbles and other large items there is the potential for particles to be ingested or inhaled. The radiation risk posed by contaminated pebbles and stones is dominated by the external dose rate when the item is close. However, for particles three exposure pathways are possible, inhalation, ingestion and external doses. However, even for the external dose the possibility of particles sticking to the skin mean that for this pathway particles are far more hazardous than pebbles or stones. These pathways greatly increases the risk from the inherent hazard from these particles compared to pebbles and stones.

The Environment Agency is leading a separate programme of work examining the potential sources and pathways of particles to the environment from the Sellafield site. This work is specified in the Radioactive Substances Act 1993 authorisation and is outside the scope of this workshop.

At the workshop we shall consider what we know about:

- the characterisation of the particles;
- the hazard;
- the environmental setting;
- the distribution and density; and
- the probability of human contact.

The status of our knowledge is summarised in Section 2: Status of our knowledge.

Considering the status of our knowledge we shall then consider the gaps in the information and understanding of this issue. This shall assist in the later process of considering whether there is a need for any immediate actions due to the information provided or the absence of knowledge in key areas. A preliminary outline of current plans is provided in Section 3: Work programme.

[1] Historical monitoring (1980 – 2006) indicated that there was an unquantified legacy of particles in the environment around Sellafield largely as a result of past incidents at the site such as the 1983 'beach incident'. Recent improved beach monitoring suggests that the population could be much larger than anticipated.

We shall then consider how we fill the information gaps and collectively take our knowledge forward. Some initial suggestions for prompt action and options for consideration are provided in Section 4: Way forward.

Finally we shall discuss advice that should be given, considering the uncertainty in our knowledge and the plans to improve that knowledge. Although we have no direct evidence of harm[2] we shall consider whether, in the absence of key information, further precautionary action is necessary to ensure protection of people and the environment generally. In Section 5: Advice, there is a summary of the general radiological protection advice for contaminated land provided by the Health Protection Agency (HPA), a discussion of the uncertainty in our knowledge and the implications of the precautionary principle.

We intend to produce a workshop report in consultation with workshop participants. This report shall inform the work of the Environment Agency in working with others to better understand this issue and ensure protection of people and the environment.

Section 2: Status of our knowledge

2.1 Characterisation of Sellafield particles

Limited characterisation of Sellafield particles has been undertaken. According to the analysis scheme agreed with the Environment Agency most analysis so far has been limited to non destructive testing. Direct measurement[3] by gamma spectrometry has been undertaken on 31 of 44 particles recovered by BNGSL.

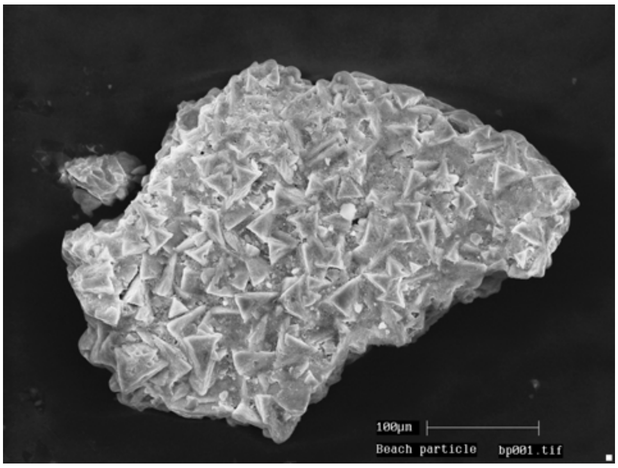
Table 1: Summary of beta/gamma emitting radioactivity in recent West Cumbria beach finds[4] (n= 69[5])

Principal radionuclides	No of determinations	Minimum activity (Bq)	Maximum activity (Bq)
60Co	69	9E-02	6E+03
106Ru	58	< 4E+01	1E+03
125Sb	58	< 1E+01	7E+02
134Cs	68	3E+00	1E+02
137Cs	69	5E-01	1.2E+05

[2] It is worth noting that the medical profession have yet to be alerted to the potential harm from Sellafield particles and therefore monitoring for harm has not been carried out in any systematic way i.e. checking for deterministic effects on the skin
[3] These data are likely to be subject to large uncertainties due to the physical properties of these particles.
[4] Also includes data for 25 contaminated items
[5] Data provided by BNGSL

241Am	60	< 6E+01	4E+05
238Pu	4	< 8E+03	9E+04
239Pu	4	1E+04	8E+04
241Pu via U237	4	3E+05	1E+06

Physical characterisation has again been limited. There are some data on size of beach finds based on laboratory measurements for the July 2003, November 2006 and February 2007 finds and estimates by the NUKEM operator, during recovery, for the subsequent finds. No data are currently available on chemistry, (including solubility) mass, density, shape or other physical characteristics for recent finds.



One particle retrieved in 2003[6] has been subject to detailed characterisation. This particle is considered unusual because from the analysis undertaken so far it can be assumed to be a particle dominated by Sr-90. It has been subjected to extensive analysis at the EU Karlsruhe laboratories. We have no similar information on the characteristics of the Am/Pu and Cs-137 particles. Gamma spectrometry of this 400 micron diameter calcite (some silica) particle showed low levels of Pu, Am and Cs (<10 Bq). There are however discrete observed elevated levels of uranium within the particle revealed by scanning electron microscope and energy dispersive X-ray analysis (SEM-EDX). Subsequent analysis of the uranium inclusions (email from T Parker 14/7/07) has given isotopic ratios typical of reprocessed magnox uranium. Significantly the particle was detected by a beta/gamma probe. The surface contact dose rate on the sand sample was 0.3 mSv/h (beta/gamma). Considering this measurement it has been estimated by Birmingham University that the particle contains 20,000 Bq of the 90Y/90Sr beta emitting radionuclides. *This type of particle would not be detected by the new beach monitoring system currently deployed at Sellafield.*

2.2 Radiological hazard

The Health Protection Agency have provided scoping advice about the hazard. This advice is included in Appendix 1: HPA scoping dose calculations . This scoping advice suggests that the main hazard from the Sellafield particles would

[6] The particle was found at 2 cm depth 700m North of the sea pipeline in the strand line associated with the most recent high tide.

be an increased long term risk of fatality from cancer from Pu/Am particles. Potential committed effective doses from ingestion of the highest hazard particle found to date are considered to currently to lie in the range 2-200 mSv and 10-1000 mSv for an adult and 1 year old child respectively. This high range reflects our lack of knowledge about the intestinal absorption of Pu and Am from an ingested particle.

As the HPA note suggests, specific work undertaken on Dounreay origin particles indicate low levels of absorption and therefore doses at the low end of the ranges. However we have no evidence that allows this information to be transferred to the Sellafield situation with any confidence. Potentially the maximum doses could be larger because the higher absorption rate is the mean of a range of studies considered by the International Commission on Radiological Protection (ICRP). However this higher rate is considered cautious by the HPA.

Considering the large range *there is an urgent need for specific information on the rate of intestinal absorption of Pu and Am from an ingested Sellafield particle.* This conclusion recommended by HPA is reflected in the section on programme objectives. It should be noted that experience from earlier work on Dounreay particles suggests heterogeneity may be an issue meaning that experimental work will need to be carried out on a statistically significant number of relevant particles (n>6) for both in vivo and in vitro work. This has implications for the large area beach monitoring programme discussed later under way forward.

The HPA have considered the higher levels of the beta/gamma emitters[7] in the Sellafield particles and have concluded (preliminary) that short term deterministic effects are unlikely from ingestion. However for effects on the skin they have sought more specialist preliminary analysis from Birmingham University (Appendix 2: Preliminary evaluation of skin dose rates for Sellafield beach finds – in particular for those classified as ‘particles’). The conclusions of these preliminary calculations of skin dose rate indicate upper estimates of several 10s of mGy/h for the more active Sellafield particles tabulated by BNGSL (June 2007). [However the calculations do not take account of the possible presence of the pure beta emitters Sr/Y-90[8]]. This dose rate is comparable to the lower activity Dounreay fuel fragment particles. These calculated doses are likely to be overestimated due to lack of treatment of self absorption – particularly for those particles where Cs-137 is the dominant radionuclide. A lower estimate (probably 5-10 times lower than calculated for particles dominated by Cs-137) seems to be supported by the evaluation of recorded contact dose rate data, measured using a survey instrument by BNGSL. More details of the survey instrument used to provide the dose rate data given by BNGSL are needed to confirm this. The preliminary estimates of skin equivalent dose rate presented here are compatible

[7] Did not include consideration of the 2003 90Sr particle
[8] An estimate of around 80 mGy/h has been provided for the 2003 particle find that is assumed to contain mainly 90Y/90Sr – although this is very much a preliminary estimate based on the recorded contact dose rate

with the doses measured and reported in 1985 for beach debris with a similar composition found at Sellafield in 1983.

It is suggested that experimental work should be carried out to directly measure the skin dose rate from some selected Sellafield samples using radiochromic dye film. This would avoid the uncertainties inherent in the present preliminary evaluation – as was done in the investigation of Dounreay fuel fragments. The Sr-90 type particles would be a priority for this experimental work.

Sr-90 particles and Sr-90 in beta/gamma particles should be a priority for further assessment with respect to skin doses

Interim conclusions from HPA are:
Deterministic or short term harm from Sellafield alpha and beta/gamma particles are not significant – however further experimental work necessary to determine skin dose rates.

2.3 Distribution, density and probability of encounter

There is very scarce information on the distribution and density (numbers per unit area) of Sellafield particles in the environment. Some increased large area monitoring of public beaches commenced on a trial basis in 2006 and more routinely in April 2007. Despite this increase in monitoring these beaches have to date (June 2007) received limited surveying of relatively small areas of sand in a few locations in areas up to 12 km north and a few km south of the site. At all locations surveyed only a small area of that beach has been surveyed and it must be considered that this may be unrepresentative of the entire area. The limited monitoring undertaken so far has revealed much higher density of finds at Sellafield beaches[9] compared to more distant beaches. No large area surveillance of the seabed or terrestrial environment has yet been undertaken. In total around 29 hectares of coast has been surveyed by June 2007. Given the pathway of marine deposition, it is likely that these areas have or will be repopulated with further particles in the future. As the vast majority of these areas have only been surveyed once[10], the rate of re-population is unknown.

Based on limited survey work the probability of contact with **radioactive particles** by people using the areas identified as contaminated around Sellafield is much greater compared to that around Dounreay. Notably, it has been assumed by BNGSL that the probability of encountering a Sellafield particle is the same as that of a Dounreay particle. We now have some information to test that assumption.

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[9] Some caution is needed. The more dense distribution at Sellafield may have been affected by a recent pipeline removal project.
[10] A small area of beach at Sellafield has been resurveyed

The estimated density of beta/gamma particles and Am/Pu particles[11] is determined by both the number of particles detected and the number of particles which have not been detected i.e. the detection efficiency. Information provided by RWE NUKEM indicate that the probability of detecting a Am/Pu particle of 10 kBq is less than 10% even on the surface of the sand. At a depth of 10 cm the probability of detecting a 1 MBq Am/Pu particle is around 30%. Increasing depth will decrease the activity that can be reliably detected further. This is important because 10 cm is considered the depth of sand routinely disturbed by incoming tides and wave action. The limited detection efficiency means that, unless monitoring techniques are improved, it will be practically impossible to ensure that significant particles can be detected and removed promptly. This restricts options to reduce potential public exposure if this is considered a desirable option that should be pursued in the future.

It is generally believed that at any one time there are around 2-4 particles on Sandside Beach near Dounreay. This beach has an area of around 300,000 m^2 and is surveyed on a monthly basis. In comparison the areas surveyed around St Bees (where 1 alpha bearing particle was found) the area monitored was 67,100 m^2. Work undertaken by SEPA suggests a probability of inadvertent exposure (all pathways) of around 1 in 2 million for a single 1 hour visit to the St Bees beach by an adult. For 2,000 1 hour visits (HPA generalised habit data) this rises to around 1 in 1000. For the reasons outlined above this may be a significant underestimate of the actual probability. Equally, due to the limited monitoring and isolated find the probability could be smaller.

At Ehen Spit (plus part of Sellafield North) 32 particles have been detected. By June 2007 not all of these particles have been sufficiently characterised to determine whether these are Cs-137 or Am/Pu dominated particles. However, making the assumption that all the significant particles present at this location were detected in the total monitored area (8.8 ha (88,000 m^2)) the probability of inadvertent exposure at this location is around 1 in 90,000 for a 1 hour visit and 1 in 45 for 2,000 1 hour visits for all types of particles detected.

Uncertainty

Given the low probability of detecting Am-241 particles and the almost zero probability of detecting Sr-90 particles (there is an absence of the detectable gamma emitting nuclides in the 2003 particle), coupled with a very small monitoring area, any estimates of the probability of encounter are likely to be very uncertain. However, at the locations monitored and at the time they were monitored the probability of contact was at least as calculated, but in reality probably significantly greater than that calculated.

The distribution of particles in the inter-tidal environment is unknown

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[11] The detection efficiency for Am/Pu particles is much more uncertain than for 137Cs particles. The estimate given here is based on preliminary work by Nukem on the detection capability of the current system.

Limited monitoring at St Bees beach resulted in a single find of an alpha bearing particle. However, given the low probability of detection for Am-241 and Sr-90 particles the density of finds at any location remains uncertain. More wide spread monitoring has not yet been undertaken to determine the extent of contamination.

2.4 Dispersion of particles in the environment

It has been assumed that the dispersion of radioactive particles in the marine environment at Sellafield mirrors the movement of similar size sand particles which needs to be tested.

There are limited data on the size and density of Sellafield particles (see section 2.1) and no information on the hydrodynamic equivalent of particles. This assumption has been made for Dounreay particles and is a working assumption that has been made in the limited dispersion studies undertaken by CEFAS.

CEFAS have provided a qualitative assessment of the potential wave-dominated transport pathways of Sellafield particles in the near-shore environment (Appendix 3: CEFAS report on Sellafield particles. Evaluation of potential littoral drift with recommendations for field sampling.). This is based on published information about geomorphology and spatial size distributions of natural sediments, and previous finds of radioactive items on Sellafield beaches. An earlier scoping CEFAS assessment (March 2007) considered the movement of sand from the area of the long outfall. This concluded that there is a strong onshore movement with particles reaching the coast within about a year and half, and at this stage being confined to the vicinity of Sellafield. This conclusion is insensitive to particle size (which is likely to be unrealistic). Modeling indicates that the wave and tidal stress is sufficient to keep the particle active most of the time, even for larger sizes (at Dounreay this assumption was questioned and particles are often buried and then reemerge following storms). Onshore movement is clearly suggested. Once particles reach the shore the modeling is no longer able to characterize the numerous transport processes, which will most likely be dominated by wave driven currents and long shore drift. These will distribute particles north and south, depending on wave direction.

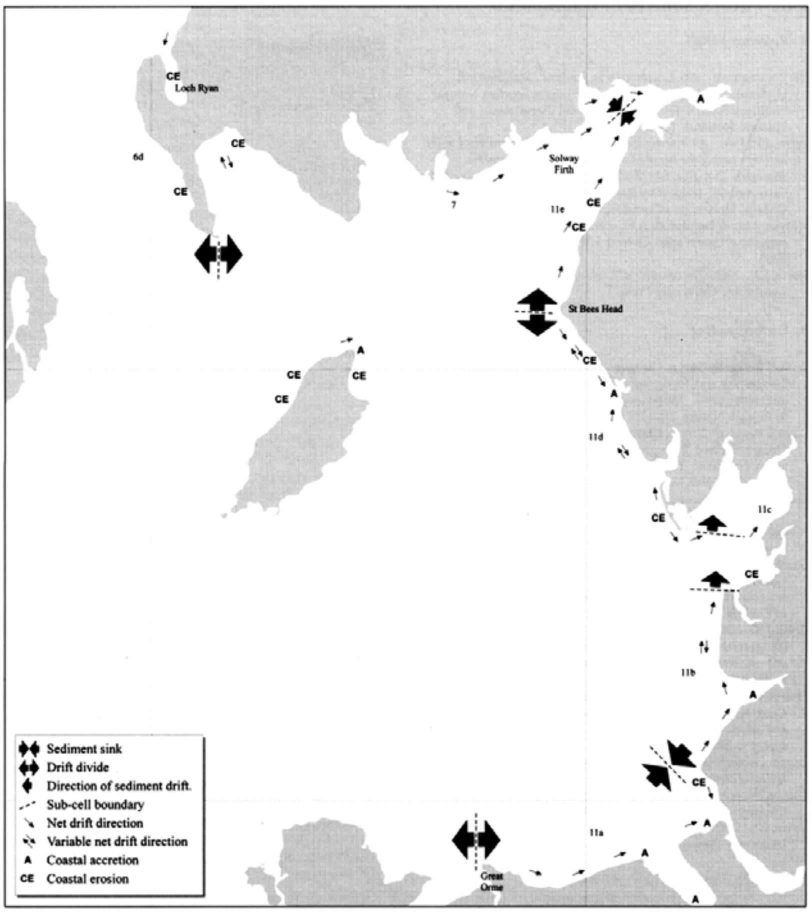
The dominant transport direction is northwards, with St Bees head acting as a key dividing point. If particles pass the barrier at St Bees then the main sediment sink is the Solway Firth. With particles moving on and off local beaches during the movement to the Solway.

According to CEFAS, St. Bees Head acts as a major shoreline drift divide, with northward transport to the north into the Solway Firth and southward transport to the south. The main sediment sinks for the area are the Solway Firth and Morecambe Bay. North of St. Bees Head, the northward littoral drift into the Solway Firth is moderate, and strongly uni-directional. The shores along this stretch of coast are predominantly erosional, but like all beaches they are likely to accumulate sediment in the Spring and Summer and be eroded in Autumn and Winter.

Between St. Bees Head and Morecambe Bay littoral drift processes are weak, and of variable direction. Local accumulation areas are the Esk and Duddon estuaries. Local drift divides are near the mouth of the river Annas and near the centre of the Isle of Walney.

As the rate, number and time of release of particles is currently unknown. Information predicting the current distribution of particles in the environment using models will be very uncertain.

2.5 Environmental setting



Between St. Bees Head and Morecambe Bay, beach sediments consist intermittently of sand and gravel. Areas with finer beach sediments than surrounding areas may act as sediment traps, whereas gravel indicates erosion and high transit rates.

A map of the area is included in Appendix 5: Map showing locations for area beach monitoring in 2007/8. Up to June 2007 limited monitoring has been undertaken in areas marked B, D, F & G. It is too early to provide useful numerical estimates of the density of finds. Any comparisons of finds will need to take account of the relative levels of confidence in early estimates for Sellafield beaches.

Section 3: Work programme

3.1 Environmental monitoring and surveillance

BNGSL are undertaking a scheme of beach monitoring agreed with the Environment Agency. This monitoring shall achieve 100 Ha coverage by March 2008. The monitoring shall cover the areas marked on the map in Appendix 5: Map showing locations for area beach monitoring in 2007/8. The detail of the areas to be covered in the areas marked on the map are provided in the table below:

Location	Monitoring Zone	Length metres	Area Ha
St Bees North	A	764	15
St Bees South to Seamill	B	486	6
Seamill to Baystones	C	4726	
Braystones North	D	1037	10
Sellafield North	E	3295	15
Ehen Spit	F	773	10
Seascale North	G	1921	9
Seascale South	H	780	9
Seascale to Barn Scar	I	1908	10
Barn Scar	J	976	10
Barn Scar to Drigg Point	K	3618	
Drigg point	L	1184	6
Monitoring Zones total			100

The monitoring system to have the capability to detect, with a probability of 95%, 1E+05 Bq of Cs-137 at 10cm depth in sand. Notably, the monitoring system is not designed to detect Sr-90 particles nor Am/Pu particles.

BNGSL, in conjunction with Environment Agency, has established the following objectives for further monitoring and analysis:

a) Determination of the risks to members of the public.

b) Identification of the source(s) of the particles.

c) Determination of a long term monitoring programme that represents BPM.

3.2 Analysis

BNGSL have developed the following standard analysis cascade (and hold points). This includes the following analysis methods:

i) calibrated high resolution gamma spectroscopy
ii) scaled colour photography
iii) autoradiography
iv) scanning electron microscopy
v) x-ray fluorescence
vi) contact dose rate measurements
vii) mass determination
viii) density determination
ix) dissolution in seawater
x) dissolution in simulated human gut fluids
xi) solution content determination of Total beta, Sr-90, Tc-99, Cs-137, Total alpha, Pu238, Pu239/240, Pu-241, Am-241, U235, U237, U238.
xii) solid content determination of Total beta, Sr-90, Tc-99, Cs-137, Total alpha, Pu238, Pu239/240, Pu-241, Am-241, U235, U237, U238.

Steps i) and ii) will be carried out for all finds. Subsequent analyses will only be applied to the extent that they provide information necessary to meet the overall monitoring objectives (in development).

3.3 Environmental modelling

Some limited environmental modelling of the movement of particles in the offshore sediments has been undertaken by CEFAS. This modelling made the assumption that the long outfall was the source of the particles and that these particles have similar density to sand. There is currently no evidence to support or refute this assumption.

3.4 Reducing uncertainties in understanding of hazard and probability of contact

The Environment Agency has requested preliminary advice from HPA on the hazard of these particles – scoping advice is included here in Appendix 1. The Environment Agency has requested that CEFAS extends the routine habit survey to consider in more detail the habits of people that use local beaches. This survey is being undertaken this summer and should be complete in xxx [to check].

3.5 Wider environmental impact

We have been focussed on the protection of people. Protection of the wider environment shall need to be considered in the medium term. We cannot assume that protection of people shall necessarily provide adequate protection of biota.

We shall be undertaking some preliminary work on the wider environmental implications as and when the information on numbers and distribution improve.

3.6 Understanding the source(s) and pathways of contamination

The Environment Agency has commissioned work with an independent consultancy to build a conceptual model of the source(s) and pathways of contamination of the environment. This work builds on earlier work by BNGSL and is programmed to be complete by late summer 2007.

Section 4: Way forward

We think this report suggests that the following actions should be given priority for consideration.

Short-term high intensity monitoring of local Sellafield beaches with the aim of recovering a significant number of alpha particles for experimental work[12]

To assist with this objective and for wider reasons – short term improvements in the detection efficiency for alpha particles.

Once a sufficient population has been recovered, undertake experimental work to determine the *rate of intestinal absorption of Pu and Am (experimental design can duplicate that undertaken for Dounreay particles) – we need to give a high priority to reducing the uncertainties in the hazard assessment.*

We shall be seeking confirmation from workshop participants on the above

Other options for consideration include:

Increased beta radionuclide monitoring – change from narrow strip monitoring to large area beach monitoring using new techniques[13]
We do not know the size of the population of the pure beta type of particles.

Undertake seabed monitoring for particles
We do not know the density of particles – this means we do not know whether there is potentially a cache of particles that are denser than sand in the offshore sediments near to the Sellafield pipeline outfall. If particles are of similar density to sand we would expect them to be transported to beaches in around 1.5y – however if they are more dense transport would be much slower and may be delayed until particles have corroded, broken up or heavy elements leached.

[12] In the medium term this may require a review of monitoring techniques – currently required by the Environment Agency for alpha type particles
[13] Suggest large area plastic s scintillators are considered – operational experience in the US for contaminated land

Undertake density measurements
Related to understanding the dispersion of particles in the environment

Undertake beach monitoring more distant from the site to determine the extent of the contamination.
Considering the littoral transport of sand in the NE Irish Sea, CEFAS advice is to target beach monitoring to establish the likelihood for particles to pass the natural barriers to transport. One or more likely accumulation locations should be selected between the divides, and at the most likely end destinations in Morecambe Bay and Solway Firth.

Section 5: Advice

The Environment Agency is required to ensure that public doses from practices are ALARA and below relevant dose limits. This requirement is in the form of a Direction from Government. The relevant dose limits are 1 mSv/y effective dose and annual equivalent doses of 50 mSv/y for the skin and 15 mSv for the eye from a practice. Currently there is no clear evidence of continuing release of particles (nor is there any evidence that they are not currently being released). However there is the potential for these limits to be challenged if similar particles are released inadvertently as a result of current practices at the site.

The HPA have provided advice to Government on the dose criteria for the designation of radioactively contaminated land (HPA, March 2006). These have been taken into account by Government in determining the Radioactive Contaminated Land Regulations, 2007 (for England and Wales). There is a need under the regulations to consider whether there is a lasting exposure above 3 mSv/y or annual dose equivalents to the lens of the eye and to the skin are above 15 millisieverts and 50 millisieverts respectively. Lasting exposure is unlikely for heterogeneous contamination by hazardous particles.

In the case of heterogeneous contamination where exposure to the radiological hazard is not certain, such as the presence of radioactive particles, the HPA has defined criteria for the designation of radioactively contaminated land as follows:

<table>
<tr><td>Annual dose (mSv)</td><td></td><td>Status</td></tr>
<tr><td rowspan="2">Effective dose ≤50 and
Equivalent dose to lens ≤15
Equivalent dose to skin ≤50</td><td>Effective dose × probability ≤ 3 mSv/y</td><td>Not radioactively contaminated land.</td></tr>
<tr><td>Effective dose × probability > 3 mSv/y</td><td>Radioactively contaminated land</td></tr>
<tr><td>Effective dose >50 and/or
Equivalent dose to lens >15 and/or
Equivalent dose to skin >50</td><td colspan="2">Decisions on whether land is radioactively contaminated land or not will need to be taken on a case by case basis with consideration of:
- possibility and severity of deterministic effects,
- the potential non-linearity of the dose-response relationship for stochastic effects (for doses above 100 mSv),
- the probability of doses being received,
- practical issues related to delectability and remediation.</td></tr>
</table>

This advice is reflected in the regulations – however for the purposes of the workshop we should just note that the interpretation of the regulations requires consideration of the uncertainties with respect to probability.

There is also discretion for the local authority to consider that the possibility of harm being caused is significant having regard to the guidance issued in relation to the regulations.

According to the scoping assessment undertaken by HPA there is no evidence of deterministic effects[14] from the information we have on the beta/gamma and alpha Sellafield particles. If the absorption into the blood stream of actinides found within the alpha type particles is found to be similar to occupational settings then doses from ingestion of particles would exceed 50 mSv. However experiments conducted on Dounreay particles recovered from the environment showed much lower absorption. We would anticipate similar low absorption because these particles have been in the environment for 10 years or more. However we cannot yet make this assumption with any confidence. Therefore information on solubility and absorption of actinides are therefore required before firm conclusions on the hazard of these particles can be made. As discussed earlier we have limited data on the number of these particles and their

[14] The isolated Sr-90 particle has not considered

distribution giving low confidence in the estimates of probability of encountering these particles.

If land is formally designated as radioactively contaminated then remediation must be considered. The formal definition of “remediation” means action to assess the condition of the contaminated land or land adjoining or adjacent to that land and keeping this under review. It also includes work or operations or steps in relation to any such land for the purpose of preventing or minimising, or remedying or mitigating the effects of, any harm or restoring the land to its former state. In taking these steps there is a need to ensure that—
(a) any such area is demarcated;
(b) arrangements for the monitoring of the harm are made;
(c) any appropriate intervention is implemented; and
(d) access to or use of land or buildings situated in the demarcated area is regulated.

In summary, there will be a need in the future to formally assess the status of the land to determine if it is contaminated land. If this assessment leads to a formal designation then there are steps that shall need to be taken. In the meantime there are a number of near term options available:

- Do nothing new – i.e. continue with the current and planned improvements e.g. enhanced routine monitoring carried out by Sellafield Ltd as required by the Environment Agency.
- Refine the monitoring – consider supplementary monitoring using techniques[15] that are more sensitive to beta and alpha particles.
- Make a commitment to review the information within an agreed timeframe when it is predicted the uncertainties shall have been significantly reduced.
- Ensure effective communication of the levels of contamination and hazard to the public to allow them to make more informed choices.
- Posting of signs to ensure people entering these areas are aware of the hazards and risks.
- Restricting access to people who are entering these areas due to the nature of their work and have undertaken a risk assessment and taken appropriate precautionary measures.
- Etc

There is also a need to ensure protection of people from contamination of food. We would need to continue to ensure that the Food Standards Agency is given all necessary assistance and advice to ensure that they can protect people from potential harm via food pathways.

[15] Large area plastic scintillators would be more effective at detecting Am-241 and would also be sensitive to Sr-90 particles at or near the surface of the beach

These and other options shall be a topic for discussion at the workshop.

We, as joint Agencies, have a responsibility[16] to be guided by the precautionary principle (see Appendix 4: The precautionary principle) in this context where there is scientific uncertainty and a threat to human health. Action in response to the precautionary principle should accord with the principles of good regulation, i.e. invocation of the precautionary principle should:

a) lead to action that is:

- proportionate to the required level of protection;
- consistent with other forms of action;
- targeted to the risk; and

b) be invoked in a process that is:

- transparent; and
- accountable to stakeholders and ultimately to the political process.

We shall capture views from the joint Agencies in a workshop report and ensure that these views are considered by decision makers when considering precautionary action.

P J Orr
Nuclear Regulator
18 June 2007

[16] See report of the INTERDEPARTMENTAL LIAISON GROUP ON RISK ASSESSMENT THE PRECAUTIONARY PRINCIPLE: POLICY AND APPLICATION, 2002.
The purpose of ILGRA is to help secure coherence and consistency within and between policy and practice in risk assessment as undertaken by Government, and help disseminate and advance good practice. ILGRA reports to Ministers.

Appendix 1: HPA scoping dose calculations

Hot Particles found at Sellafield and nearby beaches: scoping dose calculations

This short note draws upon the dose calculation methodology used in RPD-RE-11-2005, which dealt with Dounreay fuel fragments, to make preliminary dose estimates for ingestion of the hot particles described in the list entitled *Beach Finds Description – Current and Dounreay Definitions.*

Radionuclide activities are given for beta/gamma emitters such as ^{60}Co, ^{134}Cs and ^{137}Cs as well as alpha emitters ^{238}Pu, ^{239}Pu and ^{241}Am. In the in RPD-RE-11-2005 methodology two main components of dose are considered:

Doses to the walls of the sections of the colon from beta/gamma emitters (the range of alpha particles in lumen and tissue is too small to deliver a dose to the colon);

Doses to all tissues of the body (expressed numerically as the effective dose) from activity that becomes dissolved and is subsequently taken up into body fluids.

Colon doses

Doses to the recto-sigmoid section of the colon are the highest of the three sections into which the ICRP model divides the colon. Doses were calculated by tracking electrons as they pass out of a spherical hot particle consisting of a uranium/aluminium alloy (density 3.1 g/cc, 15% uranium) through the lumen of the gut and into the colon wall. Doses were assessed for ^{90}Y, ^{90}Sr and ^{137}Cs, and the published results (Fig. 3.9, p44) allow a rough estimate of the dose from ^{137}Cs alone to be derived. Thus for a particle containing 10^5 Bq ^{137}Cs executing a random path through the lumen of the colon the absorbed dose to the recto-sigmoid section is about 0.1 mGy.

The highest activities of ^{137}Cs reported to date are around 5 10^4 Bq, eg. for # 1102169. This, and other, particles also contain other beta/gamma emitters, usually with activities substantially lower than for ^{137}Cs, but published information does not allow quantitative dose estimates to be made. However, these additional doses are unlikely to raise the dose to over 0.1 mGy.

For a particle that traverses the colon adjacent to the wall, doses could be higher by about a factor of 6, and doses to the infant could be higher by a further factor of about 3. Taking these two factors into account the absorbed dose would be around 2 mGy which is well below the threshold for any tissue reactions (formerly known as deterministic effects).

It should be noted that the calculations for Dounreay particles were based on a specific particle composition, density and shape (sphere). Thus there are considerable uncertainties in applying the results of RPD-RE-11-2005 to particles of Sellafield origin. In addition it is noted that some of the Sellafield particles are described as ‘pebbles’, thus the question of whether or not the ‘particle’ could be ingested should be taken into account.

Effective doses

Following partial dissolution in the alimentary tract, actinides will be taken up across the intestine wall into body fluids. The gut uptake of actinides is generally low, typically between $1\ 10^{-3}$ and $1\ 10^{-5}$ of the ingested amount. In the calculations for RPD-RE-11-2005 information from *in vitro* dissolution experiments and from *in vivo* uptake work in rats was used to estimate that $1\ 10^{-5}$ of the ingested activity was absorbed. Applying this same factor here results in committed effective doses to adults of about 2 mSv for particle # 1102166, which appears to be the highest actinide-bearing particle discovered to date. Results for 1-year-old children could be higher by about a factor of 5, ie approaching 10 mSv. Clearly these results are above the dose limit to the public (1 mSv) but are unlikely to be of concern due to the small risk of ingestion, and its one-off nature.

Clearly the critical issue here is the solubility of the actinide content of particles. The use of an f_1 value of $1\ 10^{-5}$ for intestinal absorption may be reasonable but is unsubstantiated. For ^{241}Am and Pu isotopes, effective dose is directly proportional to the f_1 value used and so the conservative assumption that the ICRP value of $1\ 10^{-3}$ (for more soluble chemical forms) might apply would result in a dose estimate for particle # 1102166 of around 200 mSv. We recommend that *in vivo* or *in vitro* solubility studies are undertaken.

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John Harrison
June 2007

Appendix 2: Preliminary evaluation of skin dose rates for Sellafield beach finds – in particular for those classified as 'particles'

1. Skin dose evaluation – general points

Dalton (A P Dalton, 2007, Phase 1 beach finds: number and analysis summary) has reported 71 beach finds in the environs of Sellafield in 2006-7, 44 of which are classified as 'particles'. The criterion for this classification appears to be linear dimensions less than 10 mm. It should be noted that 'hot particles' are generally assumed to have rather smaller dimensions .1 mm[1,2].

The evaluation of contact dose rates from the Sellafield particles would be best determined by direct measurement using a passive dose meter such as radiochromic dye film - as used for the Dounreay fuel fragments[3,4]. This would avoid uncertainties regarding:

- radionuclide composition
- elemental composition, density and shape of the particle matrix – which affects self absorption

In the short term, only crude estimates of skin dose rate are possible - based on calculations using an assumed radionuclide composition, and/or the use of dose rates reported by Dalton – presumably measured using a survey instrument.

Most of the 41 Sellafield beach finds which have an ascertained radionuclide composition appear to be of nuclear fuel origin. Many also contain the neutron activation product Co-60 which usually originates from in-core activation of steels. The higher beta energy emitters will be the major contributors to skin dose and it is clear that in many cases the relevant activity is dominated by Cs-137. In some cases there is a significant amount of Ru-106 (the high energy beta emitter Rh-106 is assumed to be present in secular equilibrium with its low energy beta emitting parent Ru-106). Some particles have high levels of alpha emitters such as Pu-238, Pu-239 & Am-241 (e.g. particle 1102166). The range of these alpha particles (5.2-5.5 MeV) is about 40 μm – less than the nominal 70 μm recommended by ICRP/ICRU for skin dose evaluation in routine radiation protection[1,5,6]. For general purposes alpha irradiation of the skin can therefore be neglected. However, some body sites in some people have a skin thickness less than this nominal value and more detailed consideration of alpha dose may be necessary if this is considered relevant – using for example the code ALDOSE[7].

The very large Cs-137 to Cs-134 ratio for many particles indicates low burn up/long cooled fuel. Some microphotography/SEM studies such as those carried out for the Dounreay fragments, and judicial evaluation of radionuclide ratios, would help to elucidate the nature and origin of the sources – as well as providing information that would assist dosimetric evaluations.

Sr/Y-90 levels are not reported, but this is presumably because no evaluation of its presence has yet been made. Sr/Y-90 was a significant contributor to skin dose for MTR fuel fragments at Dounreay. The Cs-137: Sr/Y-90 ratio in Dounreay fuel fragments was subject to some debate and extensive radiochemical measurements were carried out to study this. The measurements were not straightforward due in part to the difficulties of dissolving some of the samples.

2. Skin dose evaluation
Using the reported contact beta/gamma dose rate

It is possible to make an approximate estimation of skin dose rate from a radioactive particle source using the contact beta/gamma dose rate reading from a survey instrument. Dalton has presented beta/gamma dose rates for 23 of the 71 beach finds. Because of geometrical factors (due essentially to the large area and volume of most survey instruments) the reading is a factor of several hundred times less than the skin dose rate (evaluated at a depth of 7 mg cm^{-2} and averaged over an area of 1 cm^2 – as recommended by the ICRP). The exact factor depends on the design of the survey instrument and the radiation quality. For Dounreay fuel fragments the factor for a Smart-Ion dose rate meter was about 300[8] (measured of course with the window of the survey instrument in the open position). The ratio was somewhat lower (150-250) for other survey instruments such as the Eberline range of RO meters. Since most of the Sellafield particles have a high relative Cs-137 content – similar to the Dounreay fuel fragments -I think a similar CF value is likely.

In the case of the Sellafield particle with the highest Cs-137 activity (particle 1102169, Cs-137 activity 5.39×10^4 Bq) a measured contact beta-gamma dose rate of 40 μ Sv/h was recorded. On the basis that this measurement was obtained with a SmartIon or RO meter, with window open, in contact with the particle, the skin equivalent dose rate would thus be estimated to be:

40 μ Sv/h x 150 - 300 ~ 6-12 mSv/h (7 mg cm^{-2}, 1 cm^2)♣

3. Skin dose evaluation
Calculated on the basis of radionuclide composition

It is possible to calculate the skin dose rate using a Monte Carlo radiation transport code for electron and gamma transport (such as MCNP) – or using a

♣ I shall use the shorthand notation (X mg cm^{-2}, 1 cm^2) to refer to the skin dose evaluated at a mass thickness depth X mg cm^{-2} and averaged over an area of 1 cm^2. A depth expressed in mass thickness terms of 1 mg cm^{-2} is equivalent in tissue to a linear thickness of 10 μm.

semi-empirical code such as VARSKIN[9]. Both of these methods were used for the Dounreay fuel fragments and agreed well[3].

Particles with high Cs-134/137 content

The majority of particles with measured radionuclide activities are characterised by a large ratio of Cs-137/Cs-134, a major contribution to total activity from Cs-137 and a smaller but significant fraction of the total activity in the form of Ru/Rh-106.

Consider again for example the Sellafield particle with the highest Cs-137 activity (particle 1102169, Cs-137 activity 5.39 x 10^4 Bq). The radionuclide composition has been given by A P Dalton and is listed below in table 1. This indicates that activity is dominated by Cs-137 and Ru-106. The high energy beta-gamma emitter Rh-106 (beta E_{max} 3.54 MeV) is assumed to be present in secular equilibrium with its low energy, pure beta emitting parent Ru-106 (E_{max} 39.4 keV). The alpha/gamma emitter Am-241 (alpha energy 5.4-5.5 MeV) gives rise to the decay product Pu-241 level which can be assumed to have an activity of 10 x the Am- 241 level (Peter Orr, personal communication) – but since Pu-241 is an extremely low energy beta emitter (~ 20 keV, similar to tritium) it does not contribute to skin dose.

Table 1
Radionuclide composition for Sellafield particle 1102169 (Activity in Bq) (From Dalton)

^{60}Co	<	7.89E+00
^{106}Ru	<	1.05E+03
^{125}Sb	<	4.47E+02
^{134}Cs	<	1.98E+01
^{137}Cs		5.39E+04
^{241}Am	<	2.83E+02

The dimensions for particle 1102169 are given as ~ 8 mm. This presumably implies that all 3 linear measures (x,y & z) are in excess of a few mm. Some other particles are much smaller and have only slightly lower activities (e.g. 1073873 – dimensions <1mm, Cs-137 activity 2.25 x 10^4 Bq).

Under the circumstances, with little detailed information on the particle characteristics, I have calculated the skin dose on the assumption of a point source. i.e. no self absorption has been assumed and all activity is in contact with the skin surface. The semi-empirical beta/gamma dosimetry code VARKIN version 3[9] has been used. This has recently been validated for use on US power plants by the US NRC. I have however tested this software during its development and it retains some problems and needs to be used with care.

The calculated skin equivalent dose rate (7 mg cm^{-2}, 1 cm^2) is 76.8 mSv/h. More than 99.5% of this dose rate is from Cs-137 and Rh-106:

Cs-137 74.5 mSv/h
Rh-106 1.97 mSv/h

This calculated skin dose rate is more than 6 times the value evaluated on the basis of the dose rate measurements above – in line with likely self absorption due to distributed radioactivity in a large source.

The depth of the basal layer (skin thickness) on some body sites such as the face, for some people, is thinner than the ICRP nominal value of 7 mg cm^{-2}. A value of 4 mg cm^{-2} is representative of these areas[10]. The calculated skin equivalent dose rate at this shallow depth (4 mg cm^{-2}, 1 cm^2) is 98.8 mSv/h. About 99.5% of this dose rate is from Cs-137 and Rh-106:

Cs-137 96.0 mSv/h
Rh-106 2.29 mSv/h

Particles with high Ru/Rh-106 content

Several particles have similar activities of Cs-137 and Cs-134, and relatively high levels of Ru/Rh-106 in excess of that from Cs-137.

Consider for example the Sellafield particle with the highest actinide activities (1102166):

^{60}Co	<	1.01E+01
^{106}Ru	<	1.23E+02
^{125}Sb	<	3.94E+01
^{134}Cs	<	1.72E+01
^{137}Cs	<	1.69E+01
^{241}Am		9.80E+04
^{238}Pu	<	8.44E+03
^{239}Pu		8.19E+04
^{237}U		1.03E+01

No dimensions are provided by Dalton for this find but it is classed as a particle. A measured contact beta-gamma dose rate of 1 μSv/h is given. Using a conversion factor of 150-300 this gives an estimated skin equivalent dose rate of 0.15–0.3 mSv/h (7 mg cm^{-2}, 1 cm^2).

I have used VARSKIN 3 to evaluate the skin dose from beta/gamma sources. Alpha doses and beta dose from Pu-241 have not been included for reasons already given.

The calculated skin equivalent dose rate (7 mg cm^{-2}, 1 cm^2) is 0.32 mSv/h. About 72% of this dose rate is from Rh-106:

Cs-137	0.02 mSv/h
Cs-134	0.02 mSv/h
Sb-125	0.03 mSv/h
Co-60	0.01 mSv/h
Rh-106	0.23 mSv/h

The calculated skin equivalent dose rate (4 mg cm^{-2}, 1 cm^2) is 0.39 mSv/h. About 70% of this dose rate is from Rh-106:

Cs-137	0.03 mSv/h
Cs-134	0.03 mSv/h
Sb-125	0.04 mSv/h
Co-60	0.02 mSv/h
Rh-106	0.27 mSv/h

In this case there is good agreement between the calculated dose rate based on the radionuclide composition, and the dose rate estimated on the basis of the measured value using a survey instrument. This agreement may be fortuitous but is consistent with the expected reduced importance of self absorption for high energy beta sources such as Rh-106, which are dominant for this particle.

4. Sellafield particles in perspective

The skin dose averaged over an area of 1cm^2 at a depth of 7 mg cm^{-2} (70 μm) is a good indicator of the probability of gross tissue damage (deterministic effects) in skin and other tissues from hot particle sources[1,2]. Moreover this is relatively independent of the beta radiation energy[1,2]. This has been discussed at some length in the publications related to Dounreay fuel fragments[3,4,11]. The radiobiological effects of Sellafield hot particles should thus be similar to those from Dounreay fuel fragments when compared in terms of skin dose rate (7 mg cm^{-2}, 1 cm^2). Many of the Sellafield 'particles' are rather larger than usually considered under the category of 'hot particles'. This means that the dose from Sellafield particles will be deposited over a larger area than from a hot particle and the biological effects will be less.

The Cs-137 activity and the calculated skin dose rate for particle 1102169 have been plotted in figure 1 which relates Cs-137 activity to skin dose for Dounreay fuel fragments. This may facilitate consideration of the likely biological effects of Sellafield particles using the considerable discussions available for Dounreay fuel fragments[11]. The actual skin dose is likely to be less than the calculated value used here due to self absorption. Clearly this Sellafield particle appears to represents a low level of concern for deterministic effects.

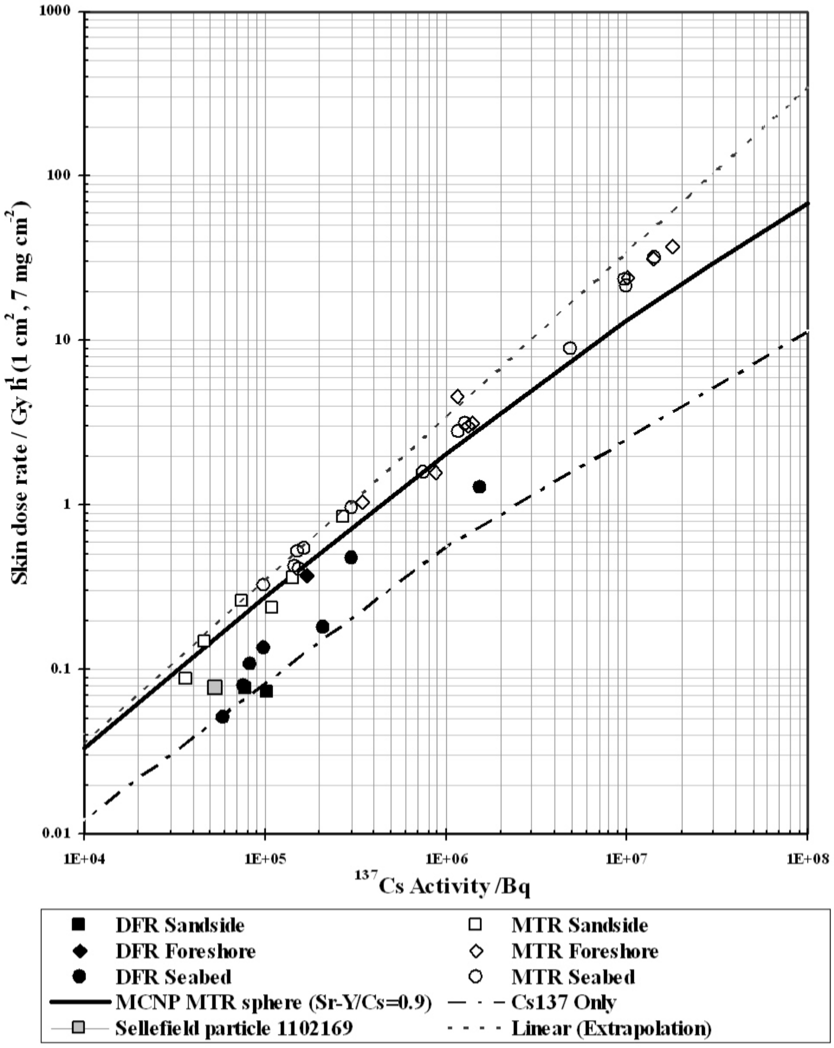

Figure 1. Skin dose rate vs Cs-137 activity for MTR and DFR Dounreay fuel fragments. The Sellafield particle 1102169 is indicated. The upper dotted line is a linear extrapolation from the low activity particles and thus represents predicted doses assuming low self absorption.

5. Conclusions

These preliminary calculations of skin dose rate indicate upper estimates of several 10s of mGy/h for the more active Sellafield particles tabulated by Dalton. The calculations do not take account of the possible presence of the pure beta emitters Sr/Y-90. This dose rate is comparable to the lower activity Dounreay fuel fragment particles. These calculated doses are likely to be overestimated due to lack of treatment of self absorption – particularly for those particles where Cs-137 is the dominant radionuclide. A lower estimate (probably 5-10 times lower than calculated for particles dominated by cs-137) seems to be supported by the evaluation of recorded contact dose rate data, presumably measured using a survey instrument. More details should be provided of the survey instrument used to provide the dose rate data given by Dalton. The preliminary estimates of skin equivalent dose rate presented here are compatible with the doses measured by Woodhead[12] and reported in 1985 for beach debris with a similar composition found at Sellafield in 1983.

It would be useful to directly measure the skin dose rate from some selected Sellafield samples using radiochromic dye film to avoid the uncertainties inherent in the present preliminary evaluation – as was done in the investigation of Dounreay fuel fragments.

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14 June 2007

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Appendix 3: CEFAS report on Sellafield particles. Evaluation of potential littoral drift with recommendations for field sampling.

Rationale

'Hot' particles associated with the Sellafield nuclear plant have been studied for many years (e.g. Kershaw et al. 1986). This memo presents a qualitative assessment of the potential wave-dominated transport pathways of this material in the near-shore environment based on published information about geomorphology and spatial size distributions of natural sediments, and previous finds of beached radioactive material. The aim is to fill the gap in the results generated by the offshore transport model. Advice for limited, targeted field observations are given. The methods used are suitable to obtain a quick, general estimate. More detail may be achieved from a dedicated modeling study.

Background

It is believed hot particles are shavings originating from the fuel rod activation process, and are assumed to be transported in the marine environment in a way similar to sand grains. Transport simulations using a shelf-sea model have indicated that a considerable proportion of these particles move in an on-shore direction into shallow water where wave-induced littoral transport processes, which the model does not include, become important. This transport process typically acts within and just outside the surf zone, up to a water depth comparable to the wave height.

Coastal morphology: sediment traps and obstructions

A study of littoral transport and coastal cells (Motyka & Brampton, 1993) concluded that St. Bees Head acts as a major drift divide, with northward transport to the north into the Solway Firth and southward transport to the south. The main sediment sinks for the area are the Solway Firth and Morecambe Bay. North of St. Bees Head, the northward littoral drift into the Solway Firth is moderate, and strongly uni-directional. The shores along this stretch of coast are mostly erosional.

Between St. Bees Head and Morecambe Bay littoral drift processes are weak, and of variable direction. Local accumulation areas are the Esk and Duddon estuaries. Local drift divides are near the mouth of the river Annas and near the centre of the Isle of Walney.

St. Bees Head is a rocky cape that is subdivided into the North Head and South Head, with a pocket beach in-between (Ordnance Survey, 1998). Between St. Bees Head and Morecambe Bay, beach sediments consist intermittently of sand and gravel (Ordnance Survey, 1981; Ordnance Survey, 1998). Areas with finer beach sediments than surrounding areas may act as sediment traps, whereas gravel indicates erosion and high transit rates.

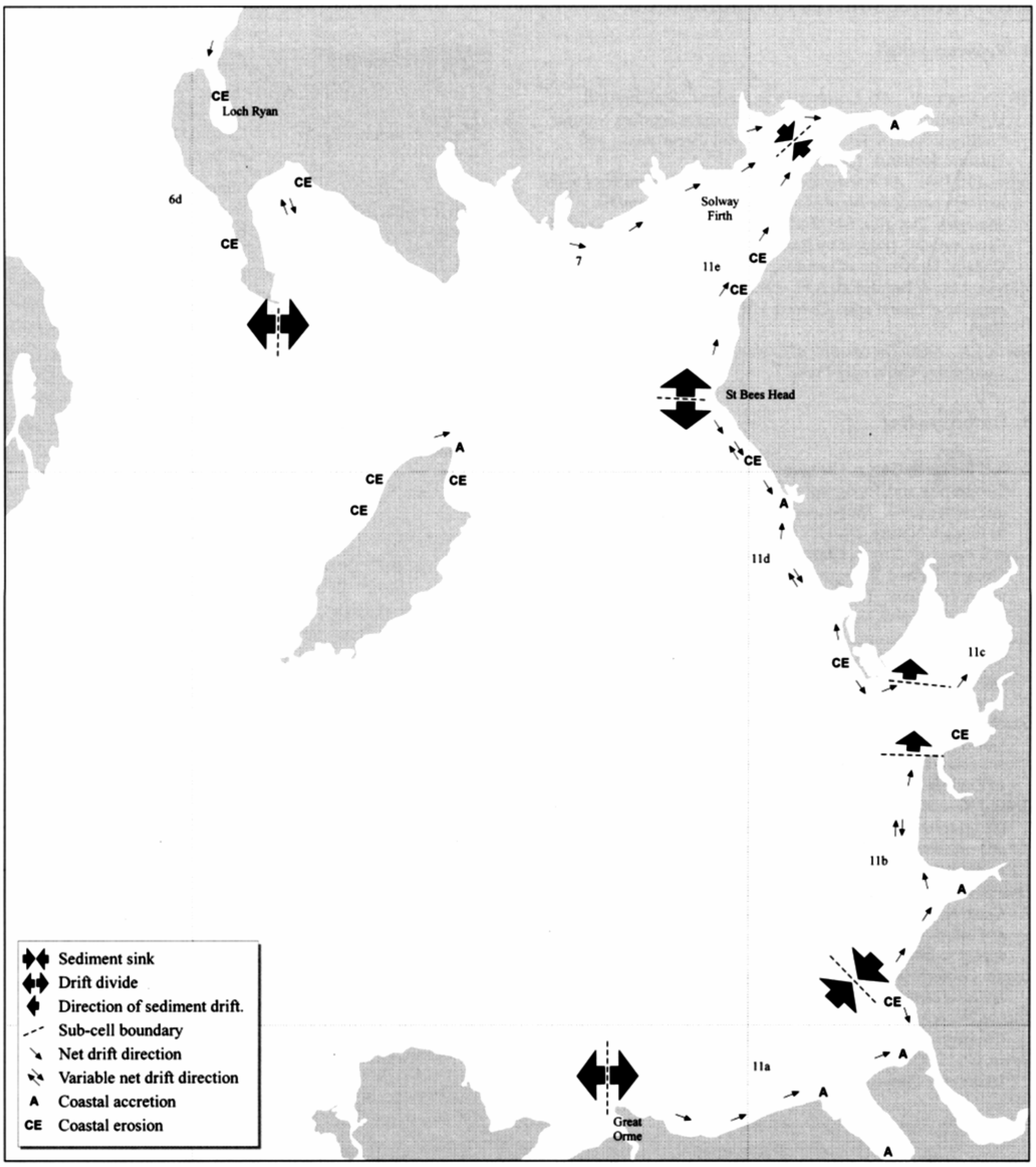

Figure 1. **Littoral drift directions and coastal cells. From: BGS, 1996 after Motyka & Brampton, 1993.**

Spatial size distribution of natural sediments

Seabed sediments between the 5 m and 15 m depth contours show a fining trend from the nuclear plant towards St. Bees Head, indicating a potential northward transport direction (Brown, 1983). It is possible, however, that the finer sediments are erosive and hence not indicative of a transport trend. To the south, there is no apparent gradient. Size information of shallow sediments south of the town of Annaside is not available.

Previous surveys

In the early 1980's, hot particles near the outfall pipe (observed in water depths of more than 10 m) were predominantly dispersed in a northward direction because discharges were predominantly made on the north-flowing ebb tide (Kershaw et al., 1983). Substantial numbers of hot particles have been found in the Esk estuary (Hamilton, 1981; Hamilton & Clarke, 1984). After the discharge incident in November 1983, radioactively contaminated material was found on the beaches from Lowca north of St. Bees Head to Selker Bay (Preston, 1984). Some of this material consisted of floating debris, however, which is likely to be transported by different processes than hot particles.

Discussion and recommendations
Hot particles transported by littoral processes that enter one of the estuaries (Solway Firth, Esk, Duddon, inter tidal areas between Walney and the main coast, Morecambe Bay) or harbours (Silloth, Maryport, Workington, Whitehaven, Sellafield) are likely to accumulate and remain there. On the open coast, pocket beaches and stretches of beach with finer sediments than the surroundings are likely to act as (temporary) accumulation areas. St. Bees Head may act as a major obstruction to northward transport through littoral drift. Southward transport through littoral drift may be obstructed by, subsequently, deposition in the Esk estuary, the drift divide near the river Annas, the Duddon estuary, and the drift divide at the Isle of Walney.

Sorting processes are likely to influence the hot particles, with coarser particles remaining on the beaches or in tidal channels, and finer particles to be deposited on mudflats or in salt marshes. Particles that end up on mudflats or in salt marshes, or in muddy harbours are likely to have been transported by tidal currents rather than littoral processes, however.

The field sampling programme should be targeted at establishing the likelihood for hot particles to pass each of the barriers mentioned above. One or more likely accumulation locations should be selected between the divides, and at the most likely end destinations in Morecambe Bay and Solway Firth.

If time and money is a severely constraining issue, the strategy of halving intervals could be adopted, as follows:
Sample at the end destination
Sample at approximately the half-way point
If hot particles are found at the half way point and not at the end point, sample in-between the two. If hot particles are not found in both points, sample between the source and the half way point
Etc.

Finding hot particles present at any of these sites can not be interpreted as proof that littoral processes have been responsible for the transport, as an alternative route could be through transport through offshore currents and subsequent beaching. Estuaries in particular may contain particles arriving through this mechanism.

Potential sampling sites could be:
Grune, Skinburness, behind spit head
(Skinburness, marshes)
Silloth, harbour
Beckfoot, north beach
Heatherbank, Alonby, beach
Maryport, beach north of northern harbour pier
Maryport, harbour
Workington, beach north of northern harbour pier
Workington, harbour
Whitehaven, beach north of northern harbour pier
Whitehaven, harbour
St. Bees Head, pocket beach between North and South Heads
St. Bees, beach
Silecroft, beach
Haverigg, beach/tidal flats SW of harbour entrance
Walney, inside both spit ends
(Walney, north end marsh near end of spit)
(Walney, marsh at South End Haws)
(Rampside, marsh)
Rampside, sand flats
Bardsea, beach

Aerial photography (FutureCoast CD's) should be used to establish exact sampling locations, which should be in clear deposition areas.

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26/4/07

Appendix 4: The precautionary principle

Definition of the precautionary principle
There is no universally accepted definition of the precautionary principle. The Sustainable Development White Paper[17], set out the Government's commitment to use the precautionary principle by reference to the 1992 Rio Declaration[18] on Environment and Development:

'Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation.'

Since 'Rio', however, the UK has signed a number of international agreements which include different formulations of the precautionary principle, reflecting the context and negotiating circumstances.

Although the precautionary principle was originally framed in the context of preventing environmental harm, it is now widely accepted as applying broadly where there is threat of harm to human, animal or plant health, as well as in situations where there is a threat of environmental damage.

Key Point
The purpose of the Precautionary Principle is to create an impetus to take a decision notwithstanding scientific uncertainty about the nature and extent of the risk, i.e. to avoid 'paralysis by analysis' by removing excuses for inaction on the grounds of scientific uncertainty.

Policy guidelines on the precautionary principle agreed by the Interdepartmental Liaison Group on Risk Assessment (ILGRA).

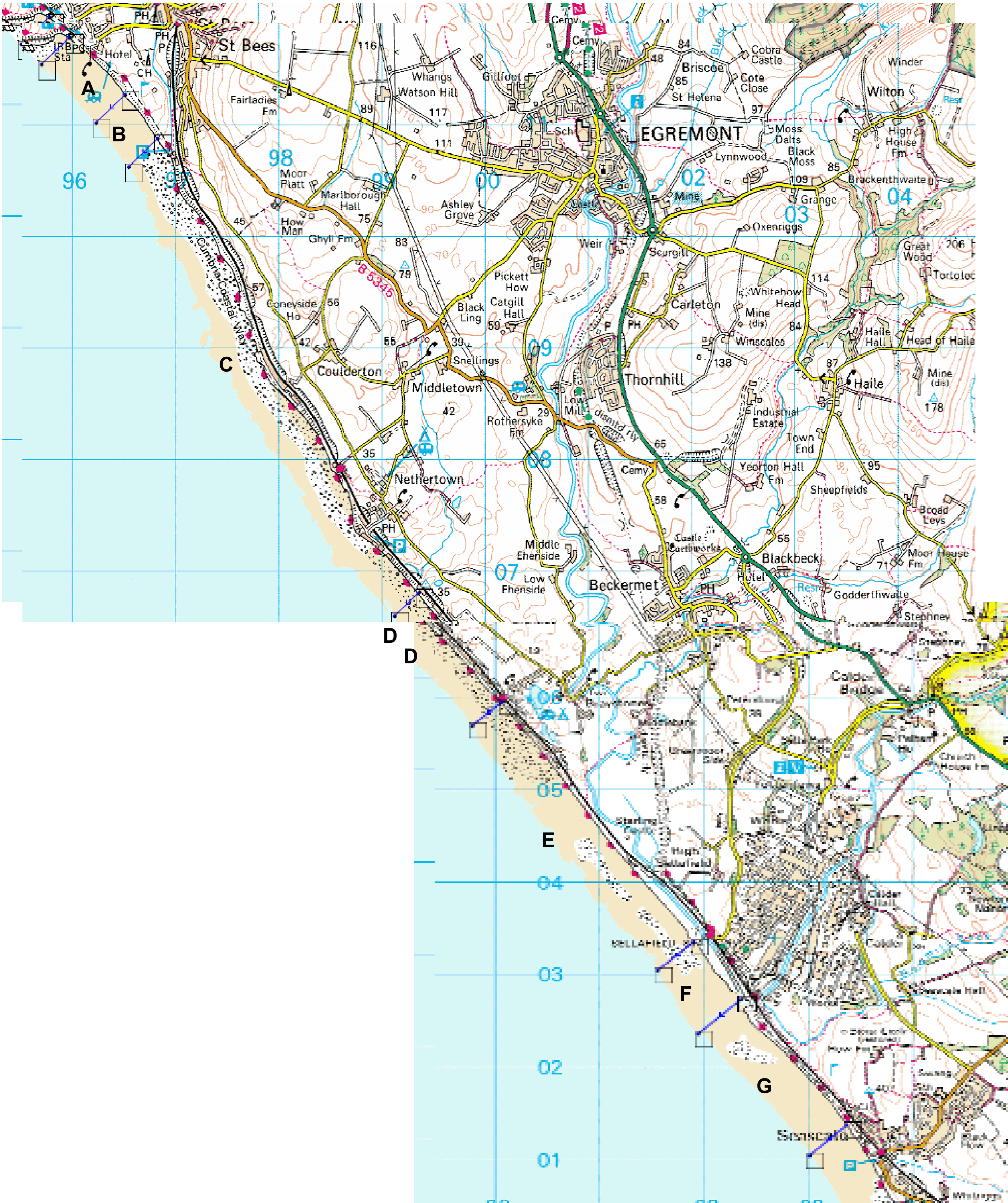
The key points are:

[17] *A better quality of life: a strategy for sustainable development for the UK,* White Paper (May 1999), http://www.sustainable-development.gov.uk/uk_strategy/
Also see Securing the future, 2005. The UK Government Sustainable Development Strategy, March 2005. http://www.sustainable-development.gov.uk/publications/pdf/strategy/SecFut_complete.pdf

[18] *Rio declaration on environment and development*, made at UNCED 1992, ISBN 9 21 100509 4,
http://www.unep.org/Documents/Default.asp?DocumentID=78&ArticleID=1163

- The purpose of the precautionary principle is to create an impetus to take a decision notwithstanding scientific uncertainty about the nature and extent of the risk.
- Although there is no universally accepted definition, the Government is Committed to using the precautionary principle, which is included in the 1992 Rio Declaration on Environment and Development.
- The precautionary principle should be invoked when:
  - o there is good reason to believe that harmful effects may occur to human, animal or plant health or to the environment; and
  - o the level of scientific uncertainty about the consequences or likelihood of the risk is such that the best available scientific advice cannot assess the risk with sufficient confidence to inform decision-making.
- The precautionary principle should be distinguished from other drivers that require caution such as society's view on the extent of protection afforded to children or others considered to be vulnerable, or the wish to ensure that conventional risk assessment techniques deliberately over rather than under-estimate risk.
- Action in response to the precautionary principle should accord with the principles of good regulation, i.e. be proportionate, consistent, targeted, transparent and accountable.
- Applying the precautionary principle is essentially a matter of making assumptions about consequences and likelihoods to establish credible scenarios, and then using standard procedures of risk assessment and management to inform decisions on how to address the hazard or threat.
- Decision-making should bring together all relevant social, political, economic, and ethical factors in selecting an appropriate risk management option.
- Invoking the precautionary principle shifts the burden of proof in demonstrating presence of risk or degree of safety towards the hazard creator. The presumption should be that the hazard creator should provide, as a minimum, the information needed for decision-making.
- Decisions reached by invoking and applying the precautionary principle should be actively reviewed, and revisited when further information that reduces uncertainty becomes available.

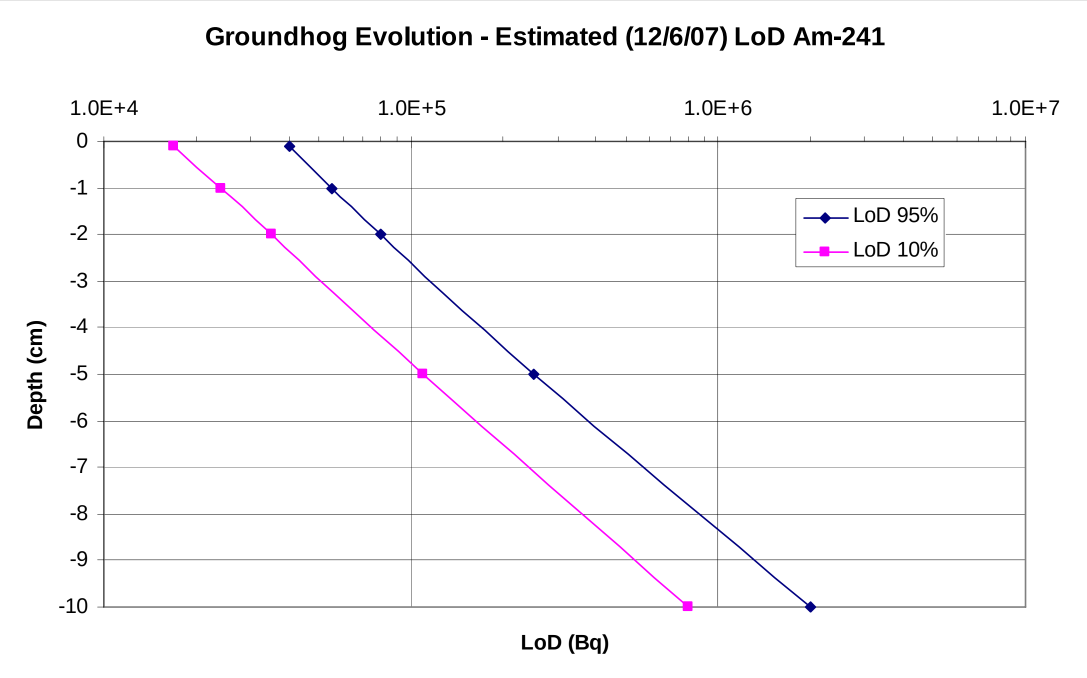
Appendix 5: Map showing locations for area beach monitoring in 2007/8



Appendix 2

Am-241 detection profile from NUKEM

(via the Environment Agency)


Groundhog Evolution - Estimated (12/6/07) LoD Am-241
1.0E+4
1.0E+5
1.0E+6
1.0E+7
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Depth (cm)
LoD (Bq)
LoD 95%
LoD 10%

Appendix 3

Dalgety Bay Assessment Tool

PROBABILITY OF ENCOUNTER CALCULATION SHEET v-2007-3

Assessment Methodology

This methodology is based on the SEPA work on the likelihood of encountering a radioactive fragment on Sandside Bay. This work was completed by a contractor, the Health Protection Agency - Radiation Protection Division. The Report reference is RPD-EA-9-2005. This tool was developed by SEPA and first used in 2006 for the contaminatation at Dalgety Bay in Fife.

1. Estimate Number of Fragments per square metre of beach

No. of fragments detected	Nf	1 fragments	(Value is hypothetical)
Area surveyed	As	100000 m^2 of beach (surveyed)	
Area of beach	Ab	100000 m^2 of beach (total)	
No of fragments per m^2	Fa	0.00001 per m^2 of beach	
Total fragments on beach	Ft	1.00000 fragments	

Occupancy Data

	O_R	
	Per Visit (h)	Per Year (h)
Adult	1	2000
Child	1	300
Infant	1	30

2. Calculating Fragment Density

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

Density of sand is calculated as an average of the following values
http://www.simetric.co.uk/si_materials.htm

	Density (kg m^{-3})	
Sand, wet	1922	
Sand, wet, packed	2082	
Sand, dry	1602	
Sand, loose	1442	
Sand, rammed	1682	
Sand, Water Filled	1922	
Sand with Gravel, dry	1650	
Sand with Gravel, wet	2020	
Average Sand Density	1790.25	kg m^{-3}

Known Data

Depth of monitoring (d)	0.10 m
Fragments per m^2 (Fa)	1.00E-05 fragments
Density of sand	1.79E+06 g/m^3

Therefore,

Fragment Density (Fd) 5.59E-11 per g of sand

3. Probability of Inadvertent ingestion of a fragment with sand
(Page 28, RPD-EA-2005)

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

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

Fragment Density Fd 5.58659E-11 per g of sand

Specific Data

Inadvertent Ingestion Rate

	I_R Per Visit ($g\ h^{-1}$)	I_R Annual ($g\ y^{-1}$)	
Adult	0.005	10.0	(based on occupancy x I_R)
Child	0.01	3.0	
Infant	0.05	1.5	

Occupancy Rate

	O_R Per Visit (h)	O_R Annual ($h\ y^{-1}$)
Adult	1	2000
Child	1	300
Infant	1	30

Calculated Probability of Inadvertent Ingestion

	P_{ing} Per Visit
Adult	2.7933E-13
Child	5.58659E-13
Infant	2.7933E-12

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{ing,ann} = 1 - P_{n\_ing,vis}^{O_R}$$

$P_{inh,ann}$ is the annual probability of ingestion
O_R is the annual occupancy rate
$P_{n\_ing,vis}$ is the probability of not ingesting an item on a single visit, which is calculated as follows:

$$P_{n\_ing,vis} = 1 - P_{ing,vis}$$

$P_{ing,vis}$ is the probability of ingesting an item per visit

Specific Data

	$P_{ing,vis}$ (Per Visit)	O_R (Annual, h)
Adult	2.79330E-13	2000
Child	5.58659E-13	300
Infant	2.79330E-12	30

Calculated Data

	$P_{ing,\ ann}$ (Annual)
Adult	5.5866E-10
Child	1.6760E-10
Infant	8.3800E-11

4. Probability of a fragment coming into direct contact with the skin

DRY SAND
(Page 31, RPD-EA-2005)

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

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

Fragment Density	F_d	5.59E-11	per g of sand
Dermal Loading of dry sand	$D_{L,D}$	0.0001	g cm^{-2}
Readherence Factor	D_s	2	-

Specific Data

	Skin Areas (m^2)						
Age Group	**Lower Arms**	**Lower Legs**	**Hands**	**Palms & outstretched fingers**	**Feet**	**Soles of feet**	**Total Body**
Adult	0.11	0.24	0.099	0.05	0.13	0.065	1.9
Child	0.059	0.13	0.059	0.03	0.085	0.043	1.12
Infant	0.026	0.049	0.028	0.014	0.037	0.019	0.53

therefore

	S_1 (cm^2)	S_2 (cm^2)
Adult	1150	3500
Child	2170	1890
Infant	980	750

Calculated Probability of fragment in direct contact with skin (dry sand)

	$P_{skin,dry}$ Per Visit
Adult	3.24022E-11
Child	3.48045E-11
Infant	1.51397E-11

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{skin,dry,ann} = 1 - P_{n\_skin,dry,vis}^{O_R}$$

$P_{skin,dry,ann}$ is the annual probability of skin contact with dry sand
O_R is the annual occupancy rate
$P_{n\_skin,dry,vis}$ is the probability of not coming into contact with an item in dry sand on a single visit, which is calculated as follows:

$$P_{n\_skin,dry,vis} = 1 - P_{skin,dry,vis}$$

$P_{skin,dry,vis}$ is the probability of coming into contact an item through dry sand per visit

Specific Data

	$P_{skin,dry,vis}$ (Per Visit)	O_R (Annual, h)
Adult	3.24022E-11	2000
Child	3.48045E-11	300
Infant	1.51397E-11	30

Calculated Data

	$P_{skin,dry, ann}$ (Annual)
Adult	6.4804E-08
Child	1.0441E-08
Infant	4.5419E-10

WET SAND

(Page 31, RPD-EA-2005)

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

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

Known Data

Fragment Density	Fd	5.58659E-11	per g of sand
Dermal Loading of wet sand	Dlw	0.005	g cm^{-2}
Readherence Factor	Dsw	2	-

Specific Data

	Skin Areas (m^2)						
Age Group	**Lower Arms**	**Lower Legs**	**Hands**	**Palms & outstretched fingers**	**Feet**	**Soles of feet**	**Total Body**
Adult	0.11	0.24	0.099	0.05	0.13	0.065	1.9
Child	0.059	0.13	0.059	0.03	0.085	0.043	1.12
Infant	0.026	0.049	0.028	0.014	0.037	0.019	0.53

therefore

	S_3 (cm^2)	**S_4 (cm^2)**
Adult	1150	3500
Child	2170	1890
Infant	980	750

Calculated Probability of fragment in direct contact with skin (wet sand)

	$P_{skin,wet}$
	Per Visit
Adult	1.62011E-09
Child	1.74022E-09
Infant	7.56983E-10

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{skin,wet,ann} = 1 - P_{n\_skin,wet,vis}^{O_R}$$

P $_{skin,wet,ann}$ is the annual probability of skin contact with wet sand
O_R is the annual occupancy rate
P $_{n\_skin,wet,vis}$ is the probability of not coming into contact with an item in wet sand on a single visit, which is calculated as follows:

$$P_{n\_skin,wet,vis} = 1 - P_{skin,wet,vis}$$

$P_{skin,wet,vis}$ is the probability of coming into contact an item through wet sand per visit

Specific Data

	$P_{skin,wet,vis}$ (Per Visit)	O_R (Annual, h)
Adult	1.62011E-09	2000
Child	1.74022E-09	300
Infant	7.56983E-10	30

Calculated Data

	$P_{skin,wet, ann}$ (Annual)
Adult	3.2402E-06
Child	5.2207E-07
Infant	2.2709E-08

WET & DRY SAND
(Page 32, RPD-EA-9-2005)

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

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

Known Data

$D_{L,wet}$	0.005	$g\ cm^{-2}$
F_d	5.58659E-11	per g of sand
$D_{s,d\&w}$	2	

Specific Data

	S1	S2	S3	S4
Adult	1150	3500	1150	3500
Child	2170	1890	2170	1890
Infant	980	750	980	750

Calculated Probability of a fragment coming into direct contact with the skin (in dry and wet conditions)

	$P_{skin,dry\&wet}$
	P_{visit}
Adult	1.65251E-09
Child	1.77503E-09
Infant	7.72123E-10

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{skin,dry\&wet,ann} = 1 - P_{n\_skin,dry\&wet,vis}^{O_R}$$

$P_{skin,dry\&wet,ann}$ is the annual probability of skin contact with dry and wet sand
O_R is the annual occupancy rate
$P_{n\_skin,dry\&wet,vis}$ is the probability of not coming into contact with an item in dry and wet sand on a single visit, which is calculated as follows:

$$P_{n\_skin,dry\&wet,vis} = 1 - P_{skin,dry\&wet,vis}$$

$P_{skin,dry\&wet,vis}$ is the probability of coming into contact an item through dry and wet sand per visit

Specific Data

	$P_{skin,dry\&wet,vis}$ (Per Visit)	O_R (Annual, h)
Adult	1.65251E-09	2000
Child	1.77503E-09	300
Infant	7.72123E-10	30

Calculated Data

	$P_{skin,dry\&wet,ann}$ (Annual)
Adult	3.3050E-06
Child	5.3251E-07
Infant	2.3164E-08

5. A fragment under the fingernails

(Page 37, RPD-EA-9-2005)

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

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

Known Data

Fragment Density	Fd	5.58659E-11 per g of sand
Sand Density	Sd	1.79E+06 g/m^3

Specific Data

	$S_{n,volume}$ (m^3)	$S_{n,mass}$ (g)
Adult	2.40E-07	0.430
Child	8.60E-08	0.154
Infant	1.90E-08	0.034

Calculated Probability of a fragment being trapped under the fingernails

	P_{nail} Per Visit
Adult	2.4E-11
Child	8.6E-12
Infant	1.9E-12

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{nail,ann} = 1 - P_{n\_nail,vis}^{O_R}$$

$P_{nail,ann}$ is the annual probability of an item becoming lodged under a fingernail

O_R is the annual occupancy rate

$P_{n\_nail,vis}$ is the probability of not getting an item lodged under the fingernails which is calculated as follows:

$$P_{n\_nail,vis} = 1 - P_{nail,vis}$$

$P_{nail,vis}$ is the probability of getting an item lodged under the fingernails per visit

Specific Data

	$P_{nail,vis}$ (Per Visit)	O_R (Annual, h)
Adult	2.40000E-11	2000
Child	8.60000E-12	300
Infant	1.90000E-12	30

Calculated Data

	$P_{nail, ann}$ (Annual)
Adult	4.8000E-08
Child	2.5800E-09
Infant	5.7001E-11

6 A fragment on clothes

(Page 37-RPA-EA-9-2005)

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

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

<u>Known Data</u>

Fragment Density	F_d	5.58659E-11 per g of sand

Sand Loading on Clothes	L_d	0.0001	g cm^{-2}
Sand adherence change factor	f_s	2	-

Specific Data

	A_c (m^2)
Adult	1.9
Child	1.12
Infant	0.53

is the total body skin area

Calculation of Probability of fragments on clothes

	P_{cl} Per Visit
Adult	2.12291E-10
Child	1.2514E-10
Infant	5.92179E-11

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{cl,ann} = 1 - P_{n\_cl,vis}^{O_R}$$

$P_{cl,ann}$ is the annual probability of an item becoming lodged on clothing
O_R is the annual occupancy rate
$P_{n\_cl,vis}$ is the probability of not getting an item lodged on clothing which is calculated as follows:

$$P_{n\_cl,vis} = 1 - P_{cl,vis}$$

$P_{cl,vis}$ is the probability of getting an item lodged on clothing per visit

Specific Data

	$P_{cl,vis}$ (Per Visit)	O_R (Annual, h)
Adult	2.12291E-10	2000
Child	1.25140E-10	300
Infant	5.92179E-11	30

Calculated Data

	$P_{cl, ann}$ (Annual)
Adult	4.2458E-07
Child	3.7542E-08
Infant	1.7765E-09

7 A fragment in a shoe

(Page 38, RPD-EA-9-2005)

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

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

<u>**Known Data**</u>

Fragment Density	F_d	5.58659E-11	per g of sand
Trapped Sand in Shoe (per visit)	S_s	10	g

Specific data

NB: there is no age specific data for Ss

Calculation of Probability of fragments in shoe

	P_{shoe} Per Visit
Adult	5.58659E-10
Child	5.58659E-10
Infant	5.58659E-10

Calculation of Annual Probability

To calculate the annual probability the following formula is used

$$P_{shoe,ann} = 1 - P_{n\_shoe,vis}^{O_R}$$

$P_{shoe,ann}$ is the annual probability of an item becoming lodged in a shoe
O_R is the annual occupancy rate
$P_{n\_shoe,vis}$ is the probability of not getting an item lodged in a shoe which is calculated as follows:

$$P_{n\_shoe,vis} = 1 - P_{shoe,vis}$$

$P_{shoe,vis}$ is the probability of getting an item lodged in a shoe per visit

Specific Data

	$P_{shoe,vis}$ (Per Visit)	O_R (Annual, h)
Adult	5.58659E-10	2000
Child	5.58659E-10	300
Infant	5.58659E-10	30

Calculated Data

	$P_{shoe, ann}$ (Annual)
Adult	1.1173E-06
Child	1.6760E-07
Infant	1.6760E-08

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Survey Results and Data Input

a) *Enter the number of particles* 1 **particles**

b) *Enter the survey area* 10 **m^2**

c) *Enter the occupancy rates*

	Occupancy Rates (h/visit or h/yr)	
	Single Visit	**Annual**
Adult	1	2,000
Child	1	300
Infant	1	30

d) *Enter the density of material* 1.79E+06 **g/m^3**

Results

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of an item	per visit	2.57E-10	3.58E-11	1.23E-11
		per year	5.14E-07	1.07E-08	3.69E-10
2	Inadvertent Ingestion	per visit	2.79E-09	5.59E-09	2.79E-08
		per year	5.59E-06	1.68E-06	8.38E-07
3	Direct Skin Contact				
	dry sand	per visit	3.24E-07	3.48E-07	1.51E-07
		per year	6.4783E-04	1.0441E-04	4.5419E-06
	wet sand	per visit	1.62011E-05	1.74022E-05	7.56983E-06
		per year	3.1883E-02	5.2071E-03	2.2707E-04
	dry and wet sand	per visit	1.65251E-05	1.77503E-05	7.72123E-06
		per year	3.2510E-02	5.3110E-03	2.3161E-04
4	Fragment under fingernails	per visit	0.00000024	0.000000086	0.000000019
		per year	4.7988E-04	2.5800E-05	5.7000E-07
5	Fragment on clothes	per visit	2.12291E-06	1.2514E-06	5.92179E-07
		per year	4.2368E-03	3.7535E-04	1.7765E-05
6	Fragment in a shoe	per visit	5.58659E-06	5.58659E-06	5.58659E-06
		per year	1.1111E-02	1.6746E-03	1.6758E-04
	Total probability	per visit	2.45E-05	2.47E-05	1.39E-05
		per year	4.83E-02	7.39E-03	4.18E-04

In terms of Chance

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of a fragment	per visit	3,891,304,348	27,968,750,000	81,363,636,364
		per year	1,945,653	93,229,199	2,712,121,398
2	Inadvertent Ingestion	per visit	358,000,000	179,000,000	35,800,000
		per year	179,001	596,667	1,193,334
4	Direct Skin Contact				
	dry sand	per visit	3,086,207	2,873,194	6,605,166
		per year	1,544	9,578	220,173
	wet sand	per visit	61,724	57,464	132,103
		per year	31	192	4,404
	dry and wet sand	per visit	60,514	56,337	129,513
		per year	31	188	4,318
5	Fragment under fingernails	per visit	4,166,667	11,627,907	52,631,579
		per year	2,084	38,760	1,754,386
6	Fragment on clothes	per visit	471,053	799,107	1,688,679
		per year	236	2,664	56,290
7	Fragment in a shoe	per visit	179,000	179,000	179,000
		per year	90	597	5,967
	Total chance	per visit	40,854	40,519	71,700
		per year	21	135	2,390

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Survey Results and Data Input

a) *Enter the number of particles* — 1 **particles**

b) *Enter the survey area* — 250 **m^2**

c) *Enter the occupancy rates*

	Occupancy Rates (h/visit or h/yr)	
	Single Visit	**Annual**
Adult	1	2,000
Child	1	300
Infant	1	30

d) *Enter the density of material* — 1.79E+06 **g/m^3**

Results

	Exposure Pathway		Adult	Child	Infant
1	Inhalation of an item	per visit	1.03E-11	1.43E-12	4.92E-13
		per year	2.06E-08	4.29E-10	1.47E-11
2	Inadvertent Ingestion	per visit	1.12E-10	2.23E-10	1.12E-09
		per year	2.23E-07	6.70E-08	3.35E-08
3	Direct Skin Contact				
	dry sand	per visit	1.30E-08	1.39E-08	6.06E-09
		per year	2.5921E-05	4.1765E-06	1.8168E-07
	wet sand	per visit	6.48045E-07	6.96089E-07	3.02793E-07
		per year	1.2953E-03	2.0881E-04	9.0838E-06
	dry and wet sand	per visit	6.61006E-07	7.10011E-07	3.08849E-07
		per year	1.3211E-03	2.1298E-04	9.2654E-06
4	Fragment under fingernails	per visit	9.6E-09	3.44E-09	7.6E-10
		per year	1.9200E-05	1.0320E-06	2.2800E-08
5	Fragment on clothes	per visit	8.49162E-08	5.00559E-08	2.36872E-08
		per year	1.6982E-04	1.5017E-05	7.1061E-07
6	Fragment in a shoe	per visit	2.23464E-07	2.23464E-07	2.23464E-07
		per year	4.4683E-04	6.7037E-05	6.7039E-06
	Total probability	per visit	9.79E-07	9.87E-07	5.58E-07
		per year	1.96E-03	2.96E-04	1.67E-05

In terms of Chance

	Exposure Pathway		Adult	Child	Infant
1	Inhalation of a fragment	per visit	97,282,608,696	699,218,750,000	2,034,090,909,091
		per year	48,641,289	2,330,693,799	67,804,872,439
2	Inadvertent Ingestion	per visit	8,950,000,000	4,475,000,000	895,000,000
		per year	4,475,000	14,916,667	29,833,333
4	Direct Skin Contact				
	dry sand	per visit	77,155,172	71,829,856	165,129,151
		per year	38,578	239,433	5,504,306
	wet sand	per visit	1,543,103	1,436,597	3,302,583
		per year	772	4,789	110,087
	dry and wet sand	per visit	1,512,847	1,408,429	3,237,826
		per year	757	4,695	107,928
5	Fragment under fingernails	per visit	104,166,667	290,697,674	1,315,789,474
		per year	52,084	968,993	43,859,652
6	Fragment on clothes	per visit	11,776,316	19,977,679	42,216,981
		per year	5,889	66,593	1,407,233
7	Fragment in a shoe	per visit	4,475,000	4,475,000	4,475,000
		per year	2,238	14,917	149,167
	Total chance	per visit	1,021,338	1,012,970	1,792,507
		per year	511	3,377	59,750

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Survey Results and Data Input

a)	*Enter the number of particles*		1	**particles**
b)	*Enter the survey area*		280,000	**m^2**
c)	*Enter the occupancy rates*		**Occupancy Rates (h/visit or h/yr)**	
			Single Visit	**Annual**
		Adult	1	1,000
		Child	1	300
		Infant	1	30
d)	*Enter the density of material*		1.79E+06	**g/m^3**

Results

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of an item	per visit	9.18E-15	1.28E-15	4.39E-16
		per year	9.21E-12	4.00E-13	1.33E-14
2	Inadvertent Ingestion	per visit	9.98E-14	2.00E-13	9.98E-13
		per year	9.98E-11	5.99E-11	2.99E-11
3	Direct Skin Contact				
	dry sand	per visit	1.16E-11	1.24E-11	5.41E-12
		per year	1.1572E-08	3.7291E-09	1.6221E-10
	wet sand	per visit	5.78611E-10	6.21508E-10	2.70351E-10
		per year	5.7861E-07	1.8645E-07	8.1105E-09
	dry and wet sand	per visit	5.90184E-10	6.33939E-10	2.75758E-10
		per year	5.9018E-07	1.9018E-07	8.2727E-09
4	Fragment under fingernails	per visit	8.57143E-12	3.07143E-12	6.78571E-13
		per year	8.5715E-09	9.2143E-10	2.0357E-11
5	Fragment on clothes	per visit	7.5818E-11	4.46927E-11	2.11492E-11
		per year	7.5818E-08	1.3408E-08	6.3448E-10
6	Fragment in a shoe	per visit	1.99521E-10	1.99521E-10	1.99521E-10
		per year	1.9952E-07	5.9856E-08	5.9856E-09
	Total probability	per visit	8.74E-10	8.81E-10	4.98E-10
		per year	8.74E-07	2.64E-07	1.49E-08

In terms of Chance

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of a fragment	per visit	108,956,521,739,130	783,125,000,000,000	2,278,181,818,181,820
		per year	108,520,472,949	2,501,999,792,984	75,059,993,789,508
2	Inadvertent Ingestion	per visit	10,024,000,000,000	5,012,000,000,000	1,002,400,000,000
		per year	10,019,131,540	16,707,845,028	33,411,971,418
4	Direct Skin Contact				
	dry sand	per visit	86,413,793,103	80,449,438,202	184,944,649,446
		per year	86,414,084	268,164,785	6,164,838,716
	wet sand	per visit	1,728,275,862	1,608,988,764	3,698,892,989
		per year	1,728,276	5,363,296	123,296,420
	dry and wet sand	per visit	1,694,388,100	1,577,439,965	3,626,365,675
		per year	1,694,389	5,258,134	120,878,850
5	Fragment under fingernails	per visit	116,666,666,667	325,581,395,349	1,473,684,210,526
		per year	116,666,009	1,085,270,107	49,123,032,585
6	Fragment on clothes	per visit	13,189,473,684	22,375,000,000	47,283,018,868
		per year	13,189,477	74,583,406	1,576,104,229
7	Fragment in a shoe	per visit	5,012,000,000	5,012,000,000	5,012,000,000
		per year	5,012,000	16,706,665	167,066,643
	Total chance	per visit	1,143,898,924	1,134,526,914	2,007,608,082
		per year	1,143,899	3,781,756	66,920,265

NOV. 07	SCOTTISH ENVIRONMENT PROTECTION AGENCY
	ASSESSMENT TOOL FOR DETERMINING THE PROBABILITY OF ENCOUNTERING A RADIOACTIVE FRAGMENT ON BEACHES

Survey Results and Data Input

a) *Enter the number of particles* — 1 particles

b) *Enter the survey area* — 67,000 m^2

c) *Enter the occupancy rates*

	Occupancy Rates (h/visit or h/yr)	
	Single Visit	**Annual**
Adult	1	270
Child	1	300
Infant	1	30

d) *Enter the density of material* — 1.79E+06 g/m^3

Results

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of an item	per visit	3.84E-14	5.34E-15	1.83E-15
		per year	1.03E-11	1.60E-12	5.66E-14
2	Inadvertent Ingestion	per visit	4.17E-13	8.34E-13	4.17E-12
		per year	1.13E-10	2.50E-10	1.25E-10
3	Direct Skin Contact				
	dry sand	per visit	4.84E-11	5.19E-11	2.26E-11
		per year	1.3058E-08	1.5584E-08	6.7789E-10
	wet sand	per visit	2.41808E-09	2.59735E-09	1.12983E-09
		per year	6.5288E-07	7.7920E-07	3.3895E-08
	dry and wet sand	per visit	2.46644E-09	2.6493E-09	1.15242E-09
		per year	6.6594E-07	7.9479E-07	3.4573E-08
4	Fragment under fingernails	per visit	3.58209E-11	1.28358E-11	2.83582E-12
		per year	9.6716E-09	3.8508E-09	8.5075E-11
5	Fragment on clothes	per visit	3.16851E-10	1.86776E-10	8.83849E-11
		per year	8.5550E-08	5.6033E-08	2.6515E-09
6	Fragment in a shoe	per visit	8.3382E-10	8.3382E-10	8.3382E-10
		per year	2.2513E-07	2.5015E-07	2.5015E-08
	Total probability	per visit	3.65E-09	3.68E-09	2.08E-09
		per year	9.86E-07	1.11E-06	6.24E-08

In terms of Chance

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of a fragment	per visit	26,071,739,130,435	187,390,625,000,000	545,136,363,636,364
		per year	96,695,644,173	625,499,948,246	17,661,175,009,296
2	Inadvertent Ingestion	per visit	2,398,600,000,000	1,199,300,000,000	239,860,000,000
		per year	8,884,153,726	3,997,869,177	7,995,312,504
4	Direct Skin Contact				
	dry sand	per visit	20,677,586,207	19,250,401,284	44,254,612,546
		per year	76,583,664	64,167,963	1,475,155,997
	wet sand	per visit	413,551,724	385,008,026	885,092,251
		per year	1,531,674	1,283,361	29,503,077
	dry and wet sand	per visit	405,442,867	377,458,849	867,737,501
		per year	1,501,641	1,258,197	28,924,583
5	Fragment under fingernails	per visit	27,916,666,667	77,906,976,744	352,631,578,947
		per year	103,395,044	259,689,465	11,754,295,704
6	Fragment on clothes	per visit	3,156,052,632	5,354,017,857	11,314,150,943
		per year	11,689,082	17,846,729	377,138,519
7	Fragment in a shoe	per visit	1,199,300,000	1,199,300,000	1,199,300,000
		per year	4,441,853	3,997,667	39,976,669
	Total chance	per visit	273,718,671	271,476,083	480,391,934
		per year	1,013,773	904,921	16,013,064

NOV. 07	SCOTTISH ENVIRONMENT PROTECTION AGENCY	SEPA Scottish Environment Protection Agency
	ASSESSMENT TOOL FOR DETERMINING THE PROBABILITY OF ENCOUNTERING A RADIOACTIVE FRAGMENT ON BEACHES	

Survey Results and Data Input

a)	*Enter the number of particles*		1	**particles**
b)	*Enter the survey area*		48,000	**m^2**
c)	*Enter the occupancy rates*		**Occupancy Rates (h/visit or h/yr)**	
			Single Visit	**Annual**
		Adult	1	180
		Child	1	300
		Infant	1	30
d)	*Enter the density of material*		1.79E+06	**g/m^3**

Results

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of an item	per visit	5.35E-14	7.45E-15	2.56E-15
		per year	9.63E-12	2.23E-12	7.66E-14
2	Inadvertent Ingestion	per visit	5.82E-13	1.16E-12	5.82E-12
		per year	1.05E-10	3.49E-10	1.75E-10
3	Direct Skin Contact				
	dry sand	per visit	6.75E-11	7.25E-11	3.15E-11
		per year	1.2151E-08	2.1753E-08	9.4623E-10
	wet sand	per visit	3.37523E-09	3.62547E-09	1.57705E-09
		per year	6.0754E-07	1.0876E-06	4.7311E-08
	dry and wet sand	per visit	3.44274E-09	3.69797E-09	1.60859E-09
		per year	6.1969E-07	1.1094E-06	4.8258E-08
4	Fragment under fingernails	per visit	5E-11	1.79167E-11	3.95833E-12
		per year	9.0000E-09	5.3750E-09	1.1875E-10
5	Fragment on clothes	per visit	4.42272E-10	2.60708E-10	1.23371E-10
		per year	7.9609E-08	7.8212E-08	3.7011E-09
6	Fragment in a shoe	per visit	1.16387E-09	1.16387E-09	1.16387E-09
		per year	2.0950E-07	3.4916E-07	3.4916E-08
	Total probability	per visit	5.10E-09	5.14E-09	2.91E-09
		per year	9.18E-07	1.54E-06	8.72E-08

In terms of Chance

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of a fragment	per visit	18,678,260,869,565	134,250,000,000,000	390,545,454,545,455
		per year	103,817,418,796	448,119,365,908	13,053,911,963,393
2	Inadvertent Ingestion	per visit	1,718,400,000,000	859,200,000,000	171,840,000,000
		per year	9,545,974,029	2,864,065,393	5,728,021,504
4	Direct Skin Contact				
	dry sand	per visit	14,813,793,103	13,791,332,263	31,704,797,048
		per year	82,298,835	45,971,095	1,056,825,774
	wet sand	per visit	296,275,862	275,826,645	634,095,941
		per year	1,645,978	919,423	21,136,532
	dry and wet sand	per visit	290,466,531	270,418,280	621,662,687
		per year	1,613,703	901,395	20,722,090
5	Fragment under fingernails	per visit	20,000,000,000	55,813,953,488	252,631,578,947
		per year	111,111,102	186,046,496	8,421,170,032
6	Fragment on clothes	per visit	2,261,052,632	3,835,714,286	8,105,660,377
		per year	12,561,404	12,785,713	270,188,770
7	Fragment in a shoe	per visit	859,200,000	859,200,000	859,200,000
		per year	4,773,334	2,864,001	28,640,001
	Total chance	per visit	196,096,958	194,490,328	344,161,385
		per year	1,089,428	648,301	11,472,047

NOV. 07	SCOTTISH ENVIRONMENT PROTECTION AGENCY
	ASSESSMENT TOOL FOR DETERMINING THE PROBABILITY OF ENCOUNTERING A RADIOACTIVE FRAGMENT ON BEACHES

SEPA Scottish Environment Protection Agency

Survey Results and Data Input

a)	*Enter the number of particles*		1	**particles**
b)	*Enter the survey area*		90,000	**m^2**
c)	*Enter the occupancy rates*		**Occupancy Rates (h/visit or h/yr)**	
			Single Visit	**Annual**
		Adult	1	365
		Child	1	300
		Infant	1	30
d)	*Enter the density of material*		1.79E+06	**g/m^3**

Results

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of an item	per visit	2.86E-14	3.97E-15	1.37E-15
		per year	1.04E-11	1.20E-12	4.00E-14
2	Inadvertent Ingestion	per visit	3.10E-13	6.21E-13	3.10E-12
		per year	1.13E-10	1.86E-10	9.31E-11
3	Direct Skin Contact				
	dry sand	per visit	3.60E-11	3.87E-11	1.68E-11
		per year	1.3141E-08	1.1601E-08	5.0466E-10
	wet sand	per visit	1.80012E-09	1.93358E-09	8.41092E-10
		per year	6.5705E-07	5.8007E-07	2.5233E-08
	dry and wet sand	per visit	1.83613E-09	1.97225E-09	8.57914E-10
		per year	6.7019E-07	5.9168E-07	2.5737E-08
4	Fragment under fingernails	per visit	2.66667E-11	9.55556E-12	2.11111E-12
		per year	9.7333E-09	2.8667E-09	6.3333E-11
5	Fragment on clothes	per visit	2.35878E-10	1.39044E-10	6.57976E-11
		per year	8.6096E-08	4.1713E-08	1.9739E-09
6	Fragment in a shoe	per visit	6.20732E-10	6.20732E-10	6.20732E-10
		per year	2.2657E-07	1.8622E-07	1.8622E-08
	Total probability	per visit	2.72E-09	2.74E-09	1.55E-09
		per year	9.93E-07	8.23E-07	4.65E-08

In terms of Chance

	Exposure Pathway		**Adult**	**Child**	**Infant**
1	Inhalation of a fragment	per visit	35,021,739,130,435	251,718,750,000,000	732,272,727,272,727
		per year	96,020,460,047	833,999,930,995	25,019,997,929,836
2	Inadvertent Ingestion	per visit	3,222,000,000,000	1,611,000,000,000	322,200,000,000
		per year	8,825,914,961	5,370,058,579	10,740,117,158
4	Direct Skin Contact				
	dry sand	per visit	27,775,862,069	25,858,747,994	59,446,494,465
		per year	76,098,144	86,195,851	1,981,546,583
	wet sand	per visit	555,517,241	517,174,960	1,188,929,889
		per year	1,521,966	1,723,917	39,630,995
	dry and wet sand	per visit	544,624,746	507,034,274	1,165,617,539
		per year	1,492,123	1,690,115	38,853,920
5	Fragment under fingernails	per visit	37,500,000,000	104,651,162,791	473,684,210,526
		per year	102,739,718	348,836,370	15,789,638,452
6	Fragment on clothes	per visit	4,239,473,684	7,191,964,286	15,198,113,208
		per year	11,614,998	23,973,208	506,604,171
7	Fragment in a shoe	per visit	1,611,000,000	1,611,000,000	1,611,000,000
		per year	4,413,699	5,370,000	53,700,000
	Total chance	per visit	367,681,797	364,669,365	645,302,598
		per year	1,007,348	1,215,565	21,510,089