Radiation Protection Division

RPD-EA-9-2005

Public Health Implications of Fragments of Irradiated Fuel

Module 3: The likelihood of encountering a fuel fragment on Sandside beach

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Contract Report

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ABSTRACT

Fragments of irradiated fuel the size of grains of sand have been found on Sandside Beach, which is adjacent to the Dounreay nuclear research facility in Caithness. Information on the number of fuel fragments found on the beach and the behaviour of individuals on the beach has been used to explore the likelihood of individuals coming into contact with such fragments. The results indicate that the probability of encountering a fuel fragment on Sandside beach is less than 1 in a million per year.

This work has been undertaken as part (Module 3) of a study commissioned by SEPA of the public health implications of these fragments of irradiated fuel. **This contract report presents the results of Module 3 of the study.**

This study was funded by the Scottish Environment Protection Agency under contract number 230/4065.

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Approval: June 2005
Publication: June 2005

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1 INTRODUCTION

Small fragments of irradiated nuclear reactor fuel have been found on Sandside beach, which is adjacent to the Dounreay nuclear research facility in Caithness. A study, funded by SEPA, to examine the public health implications of these fragments of irradiated fuel is currently underway. This **contract report** relates **only** to work carried out under **Module 3** of this study. A detailed description of all aspects of the study can be found in Wilkins et al (2005).

The purpose of the work carried out under Module 3 and reported herein was to estimate the likelihood of individuals coming into contact with fuel fragments on the beach.

In order to determine the appropriate probabilities, information from recent relevant habits surveys on the behaviour of individuals on Sandside beach was used. Information on the numbers of fuel fragments present on the beach was taken from the results of Module 2 of the study. It is worth noting that the publication of new habit data may supersede that detailed within this report but the methodology described will remain applicable.

This document defines the potential exposure pathways considered. These exposure pathways comprise primarily of direct contact pathways. The likelihood of being exposed by a fuel fragment distant from the body is not considered as potential doses from fuel fragments found at Sandside are dominated by contact beta doses from ^{137}Cs, ^{90}Sr and ^{90}Y. The document also incorporates the methodologies, assumptions and data used to determine the likelihood of encountering (ie, coming into contact with) a fuel fragment for a number of potentially exposed groups. The resulting probabilities of encountering a fuel fragment are also presented.

Both single value estimates of the probability of encountering a fuel fragment and distributions on these probabilities have been determined. The single value estimates relate to individuals with occupancies (or mollusc consumption rates) at the higher end of the overall range of occupancies (or mollusc consumption rates) for each of the potentially exposed groups considered. Best estimate values have been adopted for the other parameters used in the determination of the probabilities of encountering a fuel fragment for these 'high rate' sub-groups. However, it should be noted that, a conservative approach was used in deriving the "best estimate" number of fuel fragments per m^2 of sand in Module 2b to provide confidence that this value had not been underestimated.

Distributions on the probability of encountering a fuel fragment were determined using distributions on occupancies (or mollusc consumption rates) covering the whole range for each of the potentially exposed groups considered. Distributions on the other parameter values were also used. These relate to the uncertainties on the data used.

2 FUEL FRAGMENTS PER UNIT AREA OF SANDSIDE BEACH

In order to determine the likelihood of individuals coming into contact with fuel fragments from Sandside beach it is necessary to have information on the number of fuel fragments present per unit beach area.

Estimates of the number of fuel fragments present on Sandside beach per unit beach area were made in Module 2 of this study using information on the number of particles found during monitoring, the areas monitored and the detection efficiency of the detection system. In Module 2a such estimates were made on the basis of the detection characteristics of the Groundhog Mark I monitoring system and the number of detected fuel fragments (Walsh et al, 2003). The Groundhog Mark I system was in operation between July 1999 and June 2002. The Groundhog Evolution system underwent field trials in November 2002 and become operational at the beginning of 2003. In Module 2b estimates of fuel fragments per unit area were made using information on the detection efficiency of the Groundhog Evolution monitoring system and fuel fragments found using it between November 2002 and April 2004 (Smith and Bedwell, 2005).

It was decided in this study to use the estimated numbers of fuel fragments per unit area from Module 2b, as these relate to the most recent monitoring undertaken. The total estimated numbers of fuel fragments per m^2 are very similar in both cases although there are differences for the different activity bands. The estimated ranges from Module 2b do, however, encompass the values from Module 2a. The impact on the results of using the Module 2a values is discussed in Section 7.

The estimated number of fuel fragments present per unit beach area from Module 2b are presented in Table 1. Both best estimate values and distributions are given. The distributions were estimated using information on uncertainties in the system as discussed in Smith and Bedwell (2005).

Table 1 Estimated number of fuel fragments present per unit area of Sandside beach (per m^2 to a depth of 0.2 m), best estimate and distribution (lognormal)

Parameter	Particle ^{137}Cs activity range and ^{137}Cs activity assumed				Total
	Range ≤ 20 kBq	Range > 20kBq < 50kBq	Range ≥ 50 kBq < 100 kBq	Range ≥ 100 kBq	
	15 kBq	35 kBq	75 kBq	200 kBq	
Best estimate	2.16 10^{-5}	5.52 10^{-6}	4.26 10^{-6}	7.31 10^{-7}	3.21 10^{-5}
Distribution 0.1th percentile	1.89 10^{-6}	1.70 10^{-6}	1.89 10^{-6}	3.77 10^{-7}	5.85 10^{-6}
Distribution 97.5th percentile	4.32 10^{-5}	1.10 10^{-5}	6.38 10^{-6}	1.10 10^{-6}	6.17 10^{-5}

The values in Table 1 are averages over the monitored areas and monitoring period considered. They were derived using information from the areas of the beach that are monitored. However, for this part of the study they were considered to be representative of the whole beach, even those areas such as the rocky regions at each end of the beach that are not monitored. There are no compelling reasons to assume that the number of fuel fragments per unit mass of sand in these regions would be significantly different from that in the monitored area, but it should be noted that the application of these values to these unmonitored areas introduces an additional level of uncertainty into the analysis.

It should also be recognised that the distributions in Table 1 are representative of averaged numbers of fuel fragments present per unit area and therefore are strictly applicable to the derivation of likelihoods of encountering fuel fragments on the beach where the behaviour that brings individuals to the beach occurs regularly throughout the year (eg, daily dog walking). However, they are also used here to determine ranges on the likelihood of individuals coming into contact with a fuel fragment on a single visit to the beach, but under these circumstances the actual range would be wider. The derived ranges on per visit probabilities must therefore be seen as representative of an average rather than a reflection of the actual range.

As the implications of encountering a fuel fragment depend upon the activity of the fuel fragment the probabilities of encountering fuel fragments have been determined for fuel fragments in all four activity ranges indicated in Table 1 together with the overall total.

In order to determine the likelihood of encountering fuel fragments it was necessary to convert from fuel fragments per m^2 of sand (to a depth of 0.2 m), to fuel fragments per gramme of sand. This was undertaken using the following formula,

$$Fg = Fa / (d \times Ds)$$

where,

Fg = number of fuel fragments per gramme of sand, g^{-1}

Ds = density of sand, g m^{-3}, see below

Fa = number of fuel fragments per m^2 of sand, from Table 1

d = depth in sand to which above applies, 0.2 m

The bulk density of sand on Sandside beach is 1.7 10^6 g m^{-3} (RWE Nukem, 2002). A range on the bulk sand density has not been considered in the probabilistic analysis as this would be small and therefore not a significant contributor to the overall uncertainty on the number of fuel fragments per gramme.

3 POTENTIALLY EXPOSED GROUPS ON SANDSIDE BEACH

3.1 Beach activities in the Dounreay area

The most recent habits survey in the Dounreay area was carried out in 2003 (Tipple et al, 2004). The survey covered the sea and coastline within a 20 km radius of the UKAEA marine discharge pipeline outlet, including Sandside beach. The field work component of the survey took place between 11^{th}–24^{th} July 2003, during which time Sandside beach was visited every day by at least one of the survey team.

During the survey period the following activities were observed on Sandside beach: walking, dog walking, beachcombing, angling, swimming, snorkelling, sunbathing and surfing. The majority of the people using the beach were local rather than tourists. Other activities that were not observed at Sandside beach but were seen at other beaches in the survey area included: mollusc collecting, bait digging, horse riding, windsurfing, shore diving, and children playing. No-one under the age of 8 was seen on Sandside beach during the survey period.

The two previous habits surveys carried out in the area in 1993 (Thurston and Huggins, 1995) and 1999 (Tipple et al, 2001), identified similar sets of activities being undertaken on beaches in the Dounreay area, including: walking, dog walking, angling, bait digging, surfing, windsurfing and mollusc collecting. The 1993 survey also identified an individual canoeing in the area but no evidence of such activity was found to occur in later surveys.

3.2 Potentially exposed groups

On the basis of the information on the type of activities undertaken on beaches in the area, several potentially exposed groups of people have been identified. In defining these groups it was necessary to consider those activities that would bring individuals into contact with sand and also to scope the range of probabilities. Five such groups were identified:

3.2.1 Adult bait diggers

No bait digging was observed on Sandside beach during the 2003 survey. However, this activity was observed at other local beaches during the survey and it is therefore likely that it also occurred at Sandside. The bait digging undertaken was not occupational but primarily anglers digging for their own bait. Bait digging brings individuals into direct contact with significant quantities of sand and it was therefore judged important to consider this group explicitly.

3.2.2 Adult leisure

The most common activity undertaken on Sandside beach, evident in all of the surveys, was walking (including dog walking). It was therefore considered important to include a group representing the adult leisure users of the beach. The activities considered to be undertaken by this group were walking, beachcombing, sun bathing, playing, and paddling or swimming.

3.2.3 Child leisure

It was considered important to include an exposed group representing children using the beach. Although few were seen on Sandside beach during the 2003 survey they were observed on other beaches in the Dounreay area. The activities considered to be undertaken by this group were the same as the adult leisure group. A nominal age of 10 years was assumed for this group.

3.2.4 Infant leisure

It was also considered important to include an exposed group representing infants using the beach. A nominal age of 1 to 2 years was considered for this group. No children under the age of 5 were seen on any of the beaches during the 2003 survey. However, it was likely that infants did sometimes visit the beach although clearly not for as much time as adults or children. In this study the activities considered to be undertaken by this group included: walking, playing, digging, and paddling.

3.2.5 Mollusc consumers

Collection of winkles occurred from Sandside beach. It was therefore considered important to include a group to represent the consumers of such shellfish.

3.3 Occupancies and mollusc consumption rates

Information from the 2003 habits survey and, where necessary, earlier surveys and other information sources, was used to estimate annual beach occupancies for each of the above groups. Both a single value and a distribution were derived for each group. The single value related to typical individuals at the higher end of the range and is termed here the "high rate sub-group" value. The distribution considered the full range on the occupancies in the group, not simply the range on the high rate sub-group and thus allowed the range of probabilities of encountering fuel fragments to be evaluated. A detailed description of the derivation of these values is given in Appendix A.

In addition to annual probabilities it was considered important to estimate the likelihood of someone encountering a fuel fragment on a single visit to the beach. The assumptions made regarding visit durations are presented in Appendix A.

Information from the 2003 habits survey, earlier surveys and other information sources, was also used to determine annual mollusc consumption rates, both 'high rate sub-group' values and distributions. A detailed description of the derivation of these values is given in Appendix A.

4 EXPOSURE PATHWAYS ON SANDSIDE BEACH

There are a number of ways through which an individual could come into direct contact with a fuel fragment on the beach. The different potential exposure pathways are considered below.

Inhalation
It is possible that individuals could inhale a fuel fragment that was resuspended in the air.

Ingestion of a fuel fragment
It is possible that an individual could ingest a fuel fragment. The ingestion exposure pathways considered in this study are:

a inadvertent ingestion of sand, for example, with food;
b deliberate consumption of sand by infants (mouthing); and
c consumption of seafood gathered on Sandside Bay.

Deliberate ingestion of sand, known as pica, by adults and older children has not been considered as this is a rare medical condition.

Skin contact
It is possible that a fuel fragment could come into direct contact with the skin. It is also possible that a fuel fragment could get trapped under a nail.

All of the above exposure pathways relate to ways in which an individual could come into direct contact with a fuel fragment. In addition, it was also judged important to consider the possibility of sand becoming trapped in people's shoes or clothes. Although not in direct contact, fuel fragments may be trapped for some time and therefore the potential for prolonged exposure exists.

All of the above exposure pathways, except consumption of a fuel fragment in seafood, were considered for each of the exposed groups identified. The consumption of a fuel fragment in seafood is considered to apply only to the mollusc consumer group.

It is possible that an individual could be exposed as a result of a fuel fragment entering a wound. This is extremely unlikely and therefore has not been considered further here.

5 SAND REMOVED FROM SANDSIDE BEACH

Fuel fragments could also be encountered by individuals in contact with sand removed from the beach, for example, for use in sandpits or golf course bunkers or as a soil conditioner. There was some anecdotal evidence for this from local habits surveys. Generally, the likelihood of encountering a fuel fragment following the purposeful transfer of sand was expected to be significantly lower than from direct use of the beach. However, in order to get some indication of the level of probability involved, the likelihood of an infant encountering a fuel fragment in a sandpit filled with sand from Sandside beach has also been considered in this study.

6 METHODOLOGY

The methodologies and data used to determine the likelihood of encountering fuel fragments, for each of the exposure pathways identified above, for each of the potentially exposed groups, are presented in Appendices A, B and C.

Single value estimates of the probability of encountering a fuel fragment and distributions on these probabilities have both been determined. The single value estimates relate to individuals with occupancies (or mollusc consumption rates) at the higher end of the overall range of occupancies (or mollusc consumption rates) for each of the potentially exposed groups considered. For these 'high-rate' sub-groups best estimate values were adopted for the other parameters used in the determination of the probabilities of encountering a fuel fragment. As noted in the Introduction, the best estimate values for the number of fuel fragments per m^2 of sand were derived cautiously in Module 2b.

Distributions on the probability of encountering a fuel fragment were determined using distributions on occupancies (or mollusc consumption rates) covering the whole range for each of the potentially exposed groups considered. Distributions on the other parameter values were also used. These related to the uncertainties on the data used. The probability distributions applied were either triangular or lognormal. A lognormal distribution was deemed appropriate for positively skewed variables (variables with a distribution in which most of the values occur at the lower end of the range) with less well defined upper and lower bounds, as a result of potential outliers, describing the extremes of the distribution. Furthermore, the lower bound must be greater than 0. A triangular distribution was deemed appropriate where the maximum and minimum values describing the range were relatively clear cut.

The calculations were undertaken using an Excel spreadsheet with the Crystal Ball add-on used to determine distributions. Crystal Ball uses Monte Carlo simulation to calculate a range of possible outcomes and the likelihood of achieving them. Crystal Ball generates a value for each individual input variable. The value generated is bounded by parameters describing the distribution on the input variable, typically the distribution shape (eg, normal, lognormal) and shape parameters (eg, standard deviation or percentiles). Crystal Ball then uses these values to determine a single value for the endpoint probability of encountering a fuel fragment. This process is repeated to generate a distribution on the probability, from which, using a statistical approach, mean, median and percentile values can be derived.

7 RESULTS AND CONCLUSIONS

High rate sub-groups

The probabilities of encountering a fuel fragment for the 'high rate' sub-groups of each potentially exposed group are presented in Table 2.

These results indicate that for all potentially exposed groups, except the mollusc consumers, the most important exposure pathway resulting in direct physical contact with a fuel fragment was direct contact with skin. The highest annual probability for this exposure pathway was 3.7 10^{-7} y^{-1} (1 in 2.7 million per year), for the bait digger. The highest probability per beach visit for this exposure pathway was 1.7 10^{-8} y^{-1} (1 in 59 million), again for the bait digger. The probabilities for the other direct contact exposure pathways were at least ten times lower.

Table 2 Probabilities of encountering a fuel fragment on Sandside Beach for the 'high rate' sub-group of each potentially exposed group

Exposure pathway		Adult Bait Digger	Adult Winkle consumer	Child Winkle consumer	Adult Leisure	Child Leisure	Infant Leisure
Direct contact on skin	Annual	$3.7\ 10^{-7}$	-	-	$1.9\ 10^{-7}$	$9.4\ 10^{-8}$	$8.4\ 10^{-9}$
	Per Beach Visit	$1.7\ 10^{-8}$	-	-	$1.1\ 10^{-9}$	$1.4\ 10^{-9}$	$6.2\ 10^{-10}$
Under a fingernail	Annual	$9.8\ 10^{-10}$	-	-	$1.4\ 10^{-8}$	$1.4\ 10^{-9}$	$4.9\ 10^{-11}$
	Per Beach Visit	$4.6\ 10^{-11}$	-	-	$4.6\ 10^{-11}$	$1.6\ 10^{-11}$	$3.6\ 10^{-12}$
Inhalation	Annual	$3.4\ 10^{-12}$	-	-	$1.7\ 10^{-11}$	$7.0\ 10^{-13}$	$4.0\ 10^{-14}$
	Per Beach Visit	$1.6\ 10^{-13}$	-	-	$5.7\ 10^{-14}$	$8.2\ 10^{-15}$	$2.9\ 10^{-15}$
Inadvertent Ingestion	Annual	$1.8\ 10^{-11}$	-	-	$1.3\ 10^{-10}$	$7.2\ 10^{-11}$	$5.8\ 10^{-11}$
	Per Beach Visit	$8.5\ 10^{-13}$	-	-	$4.3\ 10^{-13}$	$8.3\ 10^{-13}$	$4.3\ 10^{-12}$
Ingestion of winkles	Annual	-	$8.2\ 10^{-9}$	$5.8\ 10^{-9}$	-	-	-
*On clothing**	*Annual*	*$3.9\ 10^{-9}$*	-	-	*$5.4\ 10^{-8}$*	*$9.0\ 10^{-9}$*	*$6.8\ 10^{-10}$*
	Per Beach Visit	*$1.8\ 10^{-10}$*	-	-	*$1.8\ 10^{-10}$*	*$1.1\ 10^{-10}$*	*$5.0\ 10^{-11}$*
*In shoes**	*Annual*	*$2.0\ 10^{-8}$*	-	-	*$2.8\ 10^{-7}$*	*$8.2\ 10^{-8}$*	*$1.3\ 10^{-8}$*
	Per Beach Visit	*$9.5\ 10^{-10}$*	-	-	*$9.5\ 10^{-10}$*	*$9.5\ 10^{-10}$*	*$9.5\ 10^{-10}$*
Total*	Annual	$3.9\ 10^{-7}$	$8.2\ 10^{-9}$	$5.8\ 10^{-9}$	**$5.4\ 10^{-7}$**	$1.9\ 10^{-7}$	$2.2\ 10^{-8}$
	Per beach visit	**$1.8\ 10^{-8}$**	-	-	$2.3\ 10^{-9}$	$2.5\ 10^{-9}$	$1.6\ 10^{-9}$

Notes

*The other exposure pathways relate to direct physical contact with a fuel fragment. These exposure pathways do not imply direct physical contact but are simply used to determine the probability of a fuel fragment getting trapped on clothes or in shoes. The probability of direct physical contact with a fuel fragment following initial trapping on clothing or in shoes is expected to be significantly lower than the values given here. However, in the absence of data on this, the probabilities for these exposure pathways have been conservatively added to the probabilities for the direct exposure pathways to give the total.

Estimated probabilities of a fuel fragment getting trapped on clothing or in shoes are also presented in Table 2. These probabilities were comparable with those for direct skin contact. The estimated probability of a fuel fragment becoming trapped in a shoe was in fact greater than the probability of direct skin contact for the adult and infant 'leisure' potentially exposed groups, but by only about 50%. It must be remembered, however, that the probability of direct physical contact with the skin following initial trapping of a fuel fragment on clothes or in shoes would generally be significantly lower. However, in the absence of information on the probability of direct contact following initial trapping on clothes or in shoes the probabilities of a fuel fragment becoming trapped in this way have been summed with those for the direct contact exposure pathways to give the total probability of encountering a fuel fragment. The result was therefore a conservative estimate of the probability of direct physical contact with a fuel fragment.

The total annual probability of encountering a fuel fragment was highest for the high rate sub-group of the adult leisure exposed group at 5.4 10^{-7} y^{-1} (1 in 1.9 million per year). The highest probability per beach visit was 1.8 10^{-8} y^{-1} (1 in 56 million) for the bait digger.

More detailed results are provided in Appendix D.

Probabilistic analysis
The mean, median and 97.5th and 2.5th percentiles of the estimated distributions on the annual probabilities of encountering a fuel fragment for each exposed group are presented in Table 3. The equivalent values relating to beach visits are given in Table 4.

In addition to the exposed groups considered in Table 2, Table 3 includes infant winkle consumers. Typically, infants do not consume winkles and therefore a best estimate of zero was assumed. However, for the purposes of this study it was assumed that a small percentage of infants did consume winkles. A range on the infant ingestion rate of winkles was therefore assumed, hence accounting for the inclusion of infant winkle consumers within the probabilistic calculations.

The estimated annual probabilities for the ‘high-rate’ sub-groups (Table 2) were higher than the medians of the distributions in Table 3 for all exposure pathways and potentially exposed groups. This was to be expected because the ‘high rate’ sub-groups had occupancies (or mollusc consumption rates) at the higher end of the ranges for each group and were estimated using best estimate values for other parameters.

The estimated annual probabilities for the ‘high rate’ sub-groups (Table 2) were also higher than the means of the distributions in Table 3 in the vast majority of cases. However, in a few isolated cases the means were higher, but never by more than a factor of 2. This was a result of the high ‘tails’ on the distributions used for some parameters.

The estimated annual probabilities for the ‘high rate’ sub-groups (Table 2) were lower than the 97.5th percentiles of the distributions in Table 3 for all exposure pathways and potentially exposed groups by factors between 1.2 and 10. The highest 97.5th percentile was 1.5 10^{-6} y^{-1} (1 in 0.7 million per year) for direct skin contact for the adult leisure exposed group. Thus even at such high percentiles of the distributions probabilities remained in the region of 1 in a million a year or less.

An analysis of single beach visit probabilities in Table 4 revealed similar conclusions with a highest 97.5th percentile value of 4.0 10^{-8} (1 in 25 million per beach visit) for direct skin contact for the bait digger exposed group.

Table 3 Mean, median, 97.5th and 2.5th percentile annual probabilities of encountering a fuel fragment on Sandside Beach for each potentially exposed group (probabilistic analysis)

Exposure pathway		Adult Bait Digger	Adult Winkle consumer	Child Winkle consumer	Infant Winkle consumer	Adult Leisure	Child Leisure	Infant Leisure
Direct contact on skin	Mean	$1.7\ 10^{-7}$	-	-	-	$2.7\ 10^{-7}$	$7.3\ 10^{-8}$	$1.6\ 10^{-8}$
	Median	$1.1\ 10^{-7}$	-	-	-	$1.2\ 10^{-7}$	$2.5\ 10^{-8}$	$8.0\ 10^{-9}$
	97.5th %ile	$6.8\ 10^{-7}$	-	-	-	$1.5\ 10^{-6}$	$4.5\ 10^{-7}$	$8.3\ 10^{-8}$
	2.5th %ile	$1.7\ 10^{-8}$	-	-	-	$8.8\ 10^{-9}$	$1.2\ 10^{-9}$	$4.9\ 10^{-10}$
Under a fingernail	Mean	$5.0\ 10^{-10}$	-	-	-	$2.9\ 10^{-9}$	$2.2\ 10^{-10}$	$2.6\ 10^{-11}$
	Median	$5.0\ 10^{-11}$	-	-	-	$2.2\ 10^{-10}$	$2.3\ 10^{-11}$	$5.3\ 10^{-12}$
	97.5th %ile	$3.5\ 10^{-9}$	-	-	-	$1.7\ 10^{-8}$	$1.6\ 10^{-9}$	$1.7\ 10^{-10}$
	2.5th %ile	$6.8\ 10^{-13}$	-	-	-	$2.8\ 10^{-12}$	$3.3\ 10^{-13}$	$1.7\ 10^{-13}$
Inhalation	Mean	$2.3\ 10^{-12}$	-	-	-	$1.0\ 10^{-11}$	$3.8\ 10^{-13}$	$4.9\ 10^{-14}$
	Median	$4.9\ 10^{-13}$	-	-	-	$2.0\ 10^{-12}$	$1.0\ 10^{-13}$	$1.7\ 10^{-14}$
	97.5th %ile	$1.5\ 10^{-11}$	-	-	-	$7.1\ 10^{-11}$	$2.5\ 10^{-12}$	$3.0\ 10^{-13}$
	2.5th %ile	$1.4\ 10^{-14}$	-	-	-	$5.5\ 10^{-14}$	$3.9\ 10^{-15}$	$1.0\ 10^{-15}$
Inadvertent Ingestion	Mean	$8.1\ 10^{-12}$	-	-	-	$4.6\ 10^{-11}$	$2.0\ 10^{-11}$	$3.7\ 10^{-11}$
	Median	$4.9\ 10^{-12}$	-	-	-	$2.1\ 10^{-11}$	$6.8\ 10^{-12}$	$1.7\ 10^{-11}$
	97.5th %ile	$4.0\ 10^{-11}$	-	-	-	$2.4\ 10^{-10}$	$1.2\ 10^{-10}$	$1.9\ 10^{-10}$
	2.5th %ile	$3.6\ 10^{-13}$	-	-	-	$1.9\ 10^{-12}$	$3.9\ 10^{-13}$	$1.5\ 10^{-12}$
Ingestion of winkles	Mean	-	$9.3\ 10^{-9}$	$4.8\ 10^{-9}$	$1.8\ 10^{-9}$	-	-	-
	Median	-	$6.9\ 10^{-9}$	$3.9\ 10^{-9}$	$1.2\ 10^{-9}$	-	-	-
	97.5th %ile	-	$3.2\ 10^{-8}$	$1.4\ 10^{-8}$	$7.0\ 10^{-9}$	-	-	-
	2.5th %ile	-	$1.5\ 10^{-9}$	$1.1\ 10^{-9}$	$4.9\ 10^{-11}$	-	-	-
*On clothing**	*Mean*	$7.5\ 10^{-9}$	-	-	-	$4.0\ 10^{-8}$	$5.6\ 10^{-9}$	$1.1\ 10^{-9}$
	Median	$3.7\ 10^{-9}$	-	-	-	$1.8\ 10^{-8}$	$2.0\ 10^{-9}$	$5.5\ 10^{-10}$
	97.5th %ile	$3.7\ 10^{-8}$	-	-	-	$2.1\ 10^{-7}$	$3.2\ 10^{-8}$	$5.5\ 10^{-9}$
	2.5th %ile	$2.3\ 10^{-10}$	-	-	-	$1.1\ 10^{-9}$	$8.2\ 10^{-11}$	$3.6\ 10^{-11}$
*In shoes**	*Mean*	$2.7\ 10^{-8}$	-	-	-	$1.5\ 10^{-7}$	$3.4\ 10^{-8}$	$1.4\ 10^{-8}$
	Median	$1.4\ 10^{-8}$	-	-	-	$7.0\ 10^{-8}$	$1.3\ 10^{-8}$	$7.6\ 10^{-9}$
	97.5th %ile	$1.3\ 10^{-7}$	-	-	-	$7.7\ 10^{-7}$	$2.0\ 10^{-7}$	$6.8\ 10^{-8}$
	2.5th %ile	$1.3\ 10^{-9}$	-	-	-	$5.7\ 10^{-9}$	$6.7\ 10^{-10}$	$7.0\ 10^{-10}$

Notes

*The other exposure pathways relate to direct physical contact with a fuel fragment. These exposure pathways do not imply direct physical contact but are simply used to determine the probability of a fuel fragment getting trapped on clothes or in shoes. The probability of direct physical contact with a fuel fragment following initial trapping on clothing or in shoes is expected to be significantly lower than the values given here.

Table 4 Mean, median, 97.5th and 2.5th percentile probabilities of encountering a fuel fragment on Sandside Beach per beach visit for each potentially exposed group (probabilistic analysis)

Exposure pathway		Adult Bait Digger	Adult Leisure	Child Leisure	Infant Leisure
Direct contact on skin	Mean	1.1 10^{-8}	4.8 10^{-9}	3.6 10^{-9}	1.7 10^{-9}
	Median	7.9 10^{-9}	3.2 10^{-9}	2.5 10^{-9}	1.2 10^{-9}
	97.5th %ile	4.0 10^{-8}	1.9 10^{-8}	1.3 10^{-8}	6.1 10^{-9}
	2.5th %ile	1.4 10^{-9}	3.0 10^{-10}	2.4 10^{-10}	1.1 10^{-10}
Under a fingernail	Mean	2.6 10^{-11}	2.9 10^{-11}	9.7 10^{-12}	2.4 10^{-12}
	Median	3.4 10^{-12}	3.2 10^{-12}	1.7 10^{-12}	7.0 10^{-13}
	97.5th %ile	1.9 10^{-10}	1.9 10^{-10}	6.4 10^{-11}	1.5 10^{-11}
	2.5th %ile	6.5 10^{-14}	6.3 10^{-14}	4.5 10^{-14}	3.3 10^{-14}
Inhalation	Mean	1.4 10^{-13}	1.3 10^{-13}	1.9 10^{-14}	5.2 10^{-15}
	Median	3.4 10^{-14}	2.8 10^{-14}	7.5 10^{-15}	2.2 10^{-15}
	97.5th %ile	9.1 10^{-13}	8.8 10^{-13}	1.1 10^{-13}	2.9 10^{-14}
	2.5th %ile	1.2 10^{-15}	9.4 10^{-16}	5.0 10^{-16}	1.6 10^{-16}
Inadvertent Ingestion	Mean	5.1 10^{-13}	5.9 10^{-13}	1.0 10^{-12}	3.9 10^{-12}
	Median	2.7 10^{-13}	3.0 10^{-13}	5.4 10^{-13}	2.2 10^{-12}
	97.5th %ile	2.4 10^{-12}	2.9 10^{-12}	4.8 10^{-12}	1.8 10^{-11}
	2.5th %ile	3.0 10^{-14}	3.3 10^{-14}	5.9 10^{-14}	2.6 10^{-13}
*On clothing**	*Mean*	*3.8 10^{-10}*	*3.8 10^{-10}*	*2.2 10^{-10}*	*1.1 10^{-10}*
	Median	*2.7 10^{-10}*	*2.7 10^{-10}*	*1.6 10^{-10}*	*7.4 10^{-11}*
	97.5th %ile	*1.4 10^{-9}*	*1.4 10^{-9}*	*8.1 10^{-10}*	*3.9 10^{-10}*
	2.5th %ile	*2.6 10^{-11}*	*2.6 10^{-11}*	*1.6 10^{-11}*	*7.1 10^{-12}*
*In shoes**	*Mean*	*1.4 10^{-9}*	*1.4 10^{-9}*	*1.4 10^{-9}*	*1.4 10^{-9}*
	Median	*1.0 10^{-9}*	*9.9 10^{-10}*	*1.0 10^{-9}*	*9.8 10^{-10}*
	97.5th %ile	*4.7 10^{-9}*	*4.7 10^{-9}*	*4.6 10^{-9}*	*4.6 10^{-9}*
	2.5th %ile	*1.7 10^{-10}*	*1.6 10^{-10}*	*1.6 10^{-10}*	*1.5 10^{-10}*

Notes

*The other exposure pathways relate to direct physical contact with a fuel fragment. These exposure pathways do not imply direct physical contact but are simply used to determine the probability of a fuel fragment getting trapped on clothes or in shoes. The probability of direct physical contact with a fuel fragment following initial trapping on clothing or in shoes is expected to be significantly lower than the values given here.

Activity ranges

As the implications of encountering a fuel fragment depend upon the activity of the fuel fragment, the probabilities of encountering fuel fragments have been determined for fuel fragments in all four of the activity ranges indicated in Table 1. The resultant annual probabilities of encountering a fuel fragment on Sandside Beach for the 'high rate' sub-group of each potentially exposed group for the different activity ranges are presented in Table 5. These results indicated that the total estimated probabilities of encountering a fuel fragment were dominated by the lower activity fuel fragments. However, it should be noted that the estimated numbers of fuel fragments present in the lower activity bands are much more uncertain than those in the higher bands because of the low detection probabilities for low activity fuel fragments. For more discussion of this issue, see Smith and Bedwell (2005).

The highest estimated probability of encountering a fuel fragment with ^{137}Cs activity > 100 kBq was 1.2 10^{-8} y^{-1} (1 in 83 million per year) for the 'high rate' sub-group of the adult leisure exposed group, compared to the probability for the same group of encountering any fuel fragment of 5.4 10^{-7} y^{-1} (1 in 1.8 million per year). An individual in this group was estimated to be 30 times more likely to encounter a particle of less than 20 kBq ^{137}Cs than a particle greater than 100 kBq ^{137}Cs.

As was mentioned in Section 2, the above probabilities of encountering a fuel fragment were derived using estimates of the numbers of fuel fragments per unit area derived using information on fuel fragments found using the Groundhog Evolution monitoring system rather than the Groundhog Mark I system. The total estimated numbers of fuel fragments per unit area were very similar in both cases and thus the resulting probabilities would be similar. However, there were differences for the different activity bands. In particular, the number of fuel fragments with ^{137}Cs activities in the range > 100 kBq found using Groundhog Mark I was a factor of 2.5 higher and thus the probabilities of encountering a fuel fragment would have been higher by this factor if the information from Groundhog Mark I had been used in this study. This difference gives some indication of the variation in probabilities over time.

More results of the analysis in terms of activity ranges are presented in Appendix D.

Sandpit

The likelihood of encountering a fuel fragment in sand removed from the beach has also been considered in this study. To scope the possible probabilities the scenario of a child playing in a sandpit filled with sand from Sandside beach was considered. Although there was anecdotal evidence that sand is removed from the beach for various purposes no cases of sand from the beach being used in sandpits have been reported. The probability of a fuel fragment being present in a sandpit filled using sand from Sandside beach has been estimated to be 1 in 66,000. The probability of an infant encountering a fuel fragment in a sandpit was estimated to be 1 in 1.5 million per year. The direct skin contact exposure pathway dominates this probability. These are relatively high probabilities in comparison with those in Table 2. However, conservative assumptions were made in the analysis and as there was no indication of a sandpit having been filled with sand from the beach this probability can be considered hypothetical.

Table 5 Annual probabilities of encountering a fuel fragment on Sandside Beach for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual probability of encountering a fuel fragment on Sandside Beach (y^{-1})
< 20 kBq	Adult Bait Digger	$2.6\ 10^{-7}$
	Adult Leisure	$3.6\ 10^{-7}$
	Adult Winkle Consumer	$5.5\ 10^{-9}$
	Child Leisure	$1.2\ 10^{-7}$
	Child Winkle Consumer	$3.9\ 10^{-9}$
	Infant Leisure	$1.5\ 10^{-8}$
20 kBq - 50 kBq	Adult Bait Digger	$6.7\ 10^{-8}$
	Adult Leisure	$9.3\ 10^{-8}$
	Adult Winkle Consumer	$1.4\ 10^{-9}$
	Child Leisure	$3.2\ 10^{-8}$
	Child Winkle Consumer	$9.9\ 10^{-10}$
	Infant Leisure	$3.8\ 10^{-9}$
50 kBq - 100 kBq	Adult Bait Digger	$5.2\ 10^{-8}$
	Adult Leisure	$7.2\ 10^{-8}$
	Adult Winkle Consumer	$1.1\ 10^{-9}$
	Child Leisure	$2.4\ 10^{-8}$
	Child Winkle Consumer	$7.6\ 10^{-10}$
	Infant Leisure	$2.9\ 10^{-9}$
> 100 kBq	Adult Bait Digger	$8.9\ 10^{-9}$
	Adult Leisure	$1.2\ 10^{-8}$
	Adult Winkle Consumer	$1.9\ 10^{-10}$
	Child Leisure	$4.2\ 10^{-9}$
	Child Winkle Consumer	$1.3\ 10^{-10}$
	Infant Leisure	$5.0\ 10^{-10}$
Total	Adult Bait Digger	$3.9\ 10^{-7}$
	Adult Leisure	$5.4\ 10^{-7}$
	Adult Winkle Consumer	$8.2\ 10^{-9}$
	Child Leisure	$1.9\ 10^{-7}$
	Child Winkle Consumer	$5.8\ 10^{-9}$
	Infant Leisure	$2.2\ 10^{-8}$

8 REFERENCES

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APPENDIX A OCCUPANCIES AND MOLLUSC CONSUMPTION RATES

Three habits surveys have been undertaken in the Dounreay area in 1993, 1999 and, most recently, 2003. These surveys cover Sandside beach and other beaches in the area.

In deriving beach occupancy values for the main groups using Sandside beach the aim has been to use, wherever possible, the most recent information available for Sandside beach itself, rather than other beaches in the area. However, for some groups it has been necessary to consider information from other beaches and earlier surveys. The overall data hierarchy was as follows:

a Information for Sandside beach from 2003 survey (Tipple et al, 2004)

b Information from other beaches from 2003 survey (Tipple et al, 2004)

c Information from earlier surveys (Thurston and Huggins, 1995) and (Tipple et al, 2001)

The potentially exposed groups considered in the study were identified in the main text. The detailed derivation of occupancy rates for each group and winkle consumption rates is presented below.

Both a single value and a distribution on occupancy have been derived for each group. The single value relates to typical individuals at the higher end of the range for each group and is termed here the "high rate sub-group" value. Such values have generally been determined by taking the arithmetic mean of the maximum value and all observed occupancy rates within a factor of 3 of the maximum value – the so called 'cut-off' method. This approach owes much to the ICRP approach to defining critical groups (ICRP, 1991) and is widely implemented in the derivation of occupancies and mollusc consumption rates for use in this study. The distributions on the occupancies for each exposed group were developed by considering the full range for each group (not simply those at the higher end), and thus allow the range of probabilities of encountering a fuel fragment for individuals within the group to be estimated.

A1 Bait diggers

No bait digging was observed on Sandside beach during the 2003 survey, however, it was observed at other local beaches during the survey and it can therefore be considered likely to occur at Sandside. The bait digging observed was primarily anglers digging for their own bait and not occupational bait digging. For this reason angling and bait digging were often considered collectively in the habits survey and hence in the derivation of occupancy rates for this group.

Table A1 below includes all occupancies above 100 h y^{-1} provided in the 2003 habits survey that were deemed applicable to the group defined as adult bait diggers. The values in brackets are the occupancy rates applicable to a specific substrate. Note that the 'Observation No.' in Table A1 (and all subsequent tables) is the observation number of the individual surveyed, as defined in the habits survey. The inclusion of this information made it easier to relate this data back to the habits survey.

Using the "cut off" method, a high rate occupancy of 324 h y^{-1} was derived. This high rate group incorporates data from two individuals, observation numbers 12 and 103, giving a total range of 179-468 h y^{-1}.

Table A1 Adult angler and bait digger occupancy rates (h y^{-1}) from 2003 survey (Tipple et al, 2004)

Observation No.	Activity	Occupancy	Substrate
12 – adult	Angling & bait digging	468	Sand
103 – adult	Angling, bait digging & dog walking	179	Sand (155) Rock (24)
136 – adult	Angling	130	Rock
294 – adult	Angling	120	Rock
295 – adult	Angling	120	Rock
72 – adult	Angling & bait digging	118	Sand
149 – 15 year old	Angling & bait digging	117	Sand
150 – 15 year old	Angling & bait digging	117	Sand

This value for the 'high rate' sub-group was in reasonable agreement with the 1999 habits survey, which indicated a value of 288 h y^{-1} (range of 182-400 hy^{-1}). The 1993 habits survey suggested a significantly higher value of 468 h y^{-1} (range of 350-930 h y^{-1}). However, the data from the 1993 habits survey was highly skewed to account for an individual who was observed to have an unusually high occupancy rate, 930 h y^{-1}. To put this into context, the next highest observation observed was 360 h y^{-1}.

On the basis of the above data a high rate occupancy of 324 h y^{-1} for angling plus bait digging, derived from the 2003 survey data, was considered appropriate for this study.

The 2003 habits survey also identified occupancy rates applicable to angling and bait digging as low as 39 hours per year. Using this information the distribution on the occupancy for this group used in this study is a lognormal distribution with 2.5th percentile 39 h y^{-1} and 97.5th percentile 470 h y^{-1}.

The above data relate to time spent both angling and bait digging. However, this study was concerned primarily with the time spent bait digging as this offered the greatest opportunity for contact with sand. It was therefore necessary to estimate the fraction of the total time spent bait digging. In all cases angling occupied a higher fraction of the overall time, but in the 2003 survey no information on the actual fraction of time was given. The data for the 1999 survey usefully indicated the fraction of the total time spent handling sediment (ie, bait digging), ranging from 7% to 21%, with an average of 13%. Therefore a factor of 0.13 has been applied to the total occupancy rate for angling and bait digging to give a time spent bait digging.

A2 Adult leisure

The highest occupancy rates applicable to the adult leisure exposed group in the vicinity of Dounreay from the 2003 habits survey are presented in Table A2.

Table A2 Adult leisure occupancy rates (h y^{-1}) from 2003 survey (Tipple et al, 2004)

Observation No	If location = Sandside Beach, then "Y"	Activity	Occupancy	Substrate
222 – adult	Y	Dog walking	410	Sand
228 – adult	Y	Dog walking	410	Sand
59 – adult	Y	Dog walking	350	Sand
146 – adult	N	Dog walking	350	Sand
147 – adult	N	Dog walking	350	Sand
191 – adult	N	Dog walking	350	Sand
192 – adult	N	Dog walking	350	Sand
175 – adult	N	Dog walking	300	Sand
93 – adult	N	Walking	250	Sand
97 – adult	N	Walking	250	Sand
275 – adult	N	Walking	240	Sand
173 – adult	N	Dog walking	225	Sand
96 – adult	N	Walking & angling usually barefooted	198	Sand
157 – adult	N	Dog walking	182	Sand
254 – adult	Y	Dog walking	156	Sand
255 – adult	Y	Dog walking	156	Sand
185 – adult	N	Dog walking	150	Sand

Table A2 includes all observations that are greater than one third of the maximum occupancy rate for this group. High rate occupancies have been calculated for two different groups, all individuals in the Dounreay area and individuals surveyed at Sandside only. These are given in Table A3 below.

Table A3 Adult leisure high rate occupancies (h y^{-1})

High Rate Group	High Rate Occupancy		
	Mean	Range	Description
Sandside Beach Only	296	Max = 410 Min = 156	Derived from 5 individuals; Observation Numbers: 222, 228, 59, 254 & 255.
Dounreay Area	275	Max = 410 Min = 150	Derived from all 17 individuals.

The "Sandside beach only" data were used to define the adult leisure high rate occupancy for this study. A rounded value of 300 h y^{-1} was assumed. This decision was based on the desire to utilise data specific to Sandside beach wherever possible. However, if all the Dounreay area data were used the difference would be small. This value was somewhat lower than those described in the 1993 and 1999 surveys applicable to the entire Dounreay area, of 399 h y^{-1} and 412 h y^{-1}, respectively, (maximum value in each case of 548 h y^{-1}). However, the limited observations specific to Sandside beach in these surveys resulted in a preference for the 2003 habits survey data set.

The following additional occupancies and the associated activities applicable to Sandside beach and the Dounreay area were used to determine the distribution on occupancies for the group as a whole:

i) Dog walking and beachcombing (1 adult) was noted at Sandside beach – 122 h y^{-1}.

ii) Sun bathing occurred in the Dounreay area. Maximum occupancy rates identified were for 4 adults each spending 32 h y^{-1}. One adult was observed at Sandside who used the beach, and another beach in the Dounreay area, for a number of activities (sunbathing, beachcombing, shore diving, and walking) for a total of 23 h y^{-1}.

iii) Numerous other dog walkers and walkers were identified as spending time on Sandside beach but at lower occupancies than those provided in Table A3. The lowest occupancy observed on Sandside beach was 24 h y^{-1}.

Based on the above data, the distribution on the occupancy for the adult leisure group used in this study was a lognormal distribution with 2.5th percentile 24 h y^{-1} and 97.5th percentile 410 h y^{-1}.

A3 Child leisure

The 2003 habits survey identifies a range of child occupancies applicable to beaches in the Dounreay area. The highest occupancies for children are listed in Table A4.

Table A4 Child (10 year old) leisure occupancy rates (h y^{-1}) for the Dounreay area from 2003 habits survey (Tipple et al, 2004)

Observation No.	Activity	Occupancy	Substrate
202	Walking	123	Sand
289	Dog Walking	104	Sand
238	Dog Walking	104	Sand & stones
144	Walking	100	Sand
145	Walking	100	Sand
58	Dog Walking	66	Sand (33) Rock (33)
153	Walking	65	Sand
154	Walking	65	Sand
260	Walking	52	Sand
273	Walking	48	Sand

The "cut off" method implies a high rate occupancy of 83 h y^{-1} (based on all 10 observations in Table A4) for a 10 year old child.

A minimum occupancy rate of 2 h y^{-1} was identified in the 2003 survey applicable to a 10 year old child walking on beaches in the Dounreay area. Using this information and the above observations the distribution on the occupancy for the child leisure group used in this study was a lognormal distribution with 2.5th percentile 2 h y^{-1} and 97.5th percentile 125 h y^{-1}.

A4 Infant leisure

None of the habits surveys detailed occupancies of infants using Sandside beach or any other beach in the area. Although this could reflect the fact that infants did not use the beaches, this seemed unlikely. It was considered more likely that infants would only be present on the beach occasionally.

Occupancies relating to 5 year old children were presented in the 2003 survey report, applicable to the Dounreay area. These are presented in Table A5.

Table A5 Child (5 year old) leisure occupancy rates (h y^{-1}) from 2003 habits survey (Tipple et al, 2004)

Observation No.	Activity	Occupancy	Substrate
274	Walking	48	Sand
305	Playing on beach	15	Sand
324	Walking	12	Sand
182	Playing on beach	4	Sand
183	Playing on beach	4	Sand
184	Playing on beach	4	Sand
189	Walking	2	Sand

The above information has been used to estimate appropriate occupancy rates for infants (1 to 2 years old) on Sandside beach. It was considered that all data, except observation 274, would be equally applicable to an infant. Observation 274 implied that an infant walked on the beach for approximately 1 hour per week, every week for a year, which was deemed unrealistic. However all other observations fitted the more expected pattern of sporadic visits of an infant to the beach. Using the "cut-off" method results in a high rate infant occupancy of 13.5 h y^{-1} (based on observation numbers 305 and 324).

There were limited data on which to develop a distribution on occupancies for this group. To scope the possible occupancies for this group a lognormal distribution was developed assuming a 2.5th percentile of 2 h y^{-1} and a 97.5th percentile of 30 h y^{-1} (a generic critical group beach occupancy (Smith and Jones, 2003)). It should be recognised that because of the lack of basic data the uncertainties in the values for this population group were greater than those for the others.

A5 Summary of annual occupancies

A summary of the annual occupancies used in this study is provided in Table A6.

Table A6 Annual occupancies used in this study

Age Group	Occupancy rates (h y^{-1})	
	High rate	Distribution[a]
Adult Bait Diggers	**330**[b]	**470-39**[b]
Adult Leisure	**300**	**410-24**
Child Leisure	**85**	**125-2**
Infant Leisure	**13.5**	**30-2**

Notes

a The distributions are lognormal in all cases. The upper and lower bounds given represent the 97.5th and 2.5th percentiles respectively

b These values apply jointly to angling and bait digging. To apply to bait digging only, a scaling factor of 0.13 is applied.

A6 Beach visit durations

In order to determine the probability of encountering a fuel fragment on a single visit to the beach information on the duration of a beach visit was required. The assumptions used in this study are presented in Table A7. In the absence of specific information these were estimated on the basis of the likely habits of each group.

The adult leisure group was dominated by dog walkers with an annual high rate occupancy of 300 h y^{-1}. It was considered that this was likely to be made up of daily visits for a large fraction of the year. This implies visits of approximately 1 hour per day. Best estimate single beach visit duration's of one hour were also assumed for children and infants.

Anecdotal evidence suggests that progressively younger children become progressively less tolerant to beach conditions in inclement weather. Accordingly, it is assumed that progressively younger children visit the beach less. It is thought that this variability in number of beach visits with age matches the variability in the annual occupancy with age (Table A6), implying a best estimate beach visit duration of one hour for both a child and an infant. Furthermore, a duration of one hour is thought to be typical of an infant or child's attention span for walking and playing (the beach activities undertaken by children and infants, as detailed in Table A4 and Table A5).

It is thought that bait diggers would be the most tolerant exposed group of inclement weather conditions. Furthermore, it is recognised that bait digging requires a greater effort to perform the activity with regard to protective clothing worn and tools and equipment used and as a result warrants a longer single beach visit duration. However, no individual was observed to be making a living from bait digging at Sandside beach and accounting for the arduous nature of the activity, a full days bait digging is deemed unrealistic. Hence a best estimate of two hours was assumed.

Table A7 Assumed duration of visits to beach

Exposed group	Duration of beach visit (h)	
	Best estimate	Lognormal Distribution[a]
Infant	1	97.5th percentile - 2 2.5th percentile - 0.5
Child	1	97.5th percentile - 3 2.5th percentile - 0.5
Adult (leisure)	1	97.5th percentile - 4 2.5th percentile - 0.5
Adult (bait digger)	2	97.5th percentile - 3 2.5th percentile - 0.5

A7 Mollusc consumption rates

A7.1 2003 Habits Survey

Although not observed at Sandside during the 2003 fieldwork period, the team was informed that commercial winkle collection regularly took place amongst the rocks on the west side of Sandside Bay. The fact that the survey witnessed no gathering of winkles was not surprising as the main collection period is September–January when the price paid for winkles is higher (Thurston and Huggins, 1995), whilst the survey was carried out in July.

It is worth noting that the commercial collection of winkles is recognised to occur in Sandside Bay but the produce is exported abroad and not used for local consumption.

The 2003 habits survey did not reveal any person consuming winkles from Sandside beach. However, 6 adults were identified who consume molluscs from the Dounreay area; 4 at 0.2 kg y^{-1}, 1 at 0.3 kg y^{-1} and 1 at 0.7 kg y^{-1}. It should be noted that the 0.7 kg y^{-1} value applies to the consumption of mussels. The remaining 5 values apply to the consumption of winkles. On the basis of the above data the survey team derived high rate mollusc consumption rates for adults, which are presented in Table A8.

Table A8 Summary of adult mollusc consumption rates (kg y^{-1}) in the Dounreay area from the 2003 habits survey report (Tipple et al, 2004)

Food Group	No. of observations	No. of higher rate consumers	Observed max critical consumption rate	Observed lower critical consumption rate	Observed critical group mean consumption rate	Observed 97.5 %ile consumption rate
Molluscs	6	2	0.7	0.3	0.5	0.6

Table A8 refers to "critical" consumption rates. This is the consumption rate of the "critical group". The derivation of the critical group and the "high rate sub-group" referenced throughout this document is identical, it is only the naming convention which differs. The term "critical group" was used throughout the 2003 habit survey for ease of presentation. However, as recognised in the habit survey, this term is misleading because the critical group can only be established when doses are determined taking into account all pathways. For this reason, this study uses the term, the 'high rate' sub-group. The derivation of the high rate sub-group is detailed at the beginning of Appendix A.

The observed maximum critical consumption rate, observed lower critical consumption rate, observed critical group mean consumption rate and observed 97.5th percentile consumption rate (see Table A8) presented in the 2003 habits survey report were all derived from the 2003 habits survey data. The critical group was defined as the two highest adult consumers. The observed critical group mean consumption rate was the arithmetic mean of the two critical group consumption rates. By contrast the 97.5th percentile consumption rate was derived using all observations (6 values in this case).

No children or infants were identified as mollusc consumers. However, the 2003 habits survey derived consumption rates for these groups by scaling the adult consumption rates. This was achieved using the ratios detailed in Table A9. For 10 and 15 year old children these ratios were determined using generic national 97.5th percentile consumption rates determined by the then Ministry for Agriculture Fisheries and Food (MAFF, 1998) and the Food Standards Agency (Byrom et al, 1995 and FSA, 2002) for adults, 15 year olds and 10 year olds. No MAFF data were available for 6 to 12 month old infants. The habits survey report did not detail how the infant ratio was derived but it is evident that a factor of 0.525 was used.

Table A9 Ratios used in 2003 habits survey report for determining consumption rates for children (Tipple et al, 2004)

Food Group	Ratio child/adult		
	6-12 months old	10 year old	15 year old
Molluscs	0.525	0.7	0.6

A7.2 1999 and 1993 Habits Surveys

Consumption rates of mollusc consumers from these surveys are provided in Table A10 below.

Table A10 Summary of consumption rates (kg y^{-1}) in the Dounreay area ((Tipple et al. 2001) and Thurston and Huggins, 1995)

Habits Survey	Age	No. of observations	No. of higher rate consumers	Consumption rates			
				Maximum critical group	Lower critical group	Mean critical group	97.5th rate
(Tipple et al. 2001)	Adult	13	6	2.7	1.4	2.2	2.7
(Tipple et al. 2001)*	Child	1 (2)	1 (2)	0.4 (0.4)	0.4 (0.4)	0.4 (0.4)	n/a
Thurston and Huggins, 1995	Adult	9	8	0.65	0.22	0.4	n/a

Note:

* The values in brackets are for a 15 year old child. The default child values apply to a 10 year old child.

The adult consumption rates derived from the 1993 survey data and reported in the survey report incorporated consumption rate data from four children. Age related weighting factors were applied to child consumption rates in an effort to compensate for the child's difference in anatomy and physiology. The weighting factors were calculated using age related dose per unit intake data compiled from recent NRPB and ICRP publications and monitoring data (see Thurston et al, 1995 for details). The four children varied in age from 16 to 3.

Both habits surveys assumed that molluscs comprise 100% of winkles. Tipple et al (2001) noted that children under the age of 10 were not known to eat molluscs.

A7.3 Mollusc consumption rates used in this study

The mollusc consumption rates used in this study were derived from the data described in Sections A7.1 and A7.2. It should be noted, however, that the data related to individuals consuming molluscs collected within the Dounreay area rather than specifically from Sandside beach. The assumption made in this study that all of these molluscs come from Sandside beach is therefore conservative.

Adult

A typical higher rate ingestion rate of 0.5 kg y^{-1} was assumed for adults, based primarily on the results of the 2003 survey. This was consistent with the 1993 survey results but lower than that for the 1999 survey.

A lognormal distribution on consumption rates for this group has been assumed with a 2.5th percentile of 0.3 kg y^{-1} and a 99.9th percentile of 2.7 kg y^{-1}. The 2.5th percentile value was the lower limit from the 2003 survey data. The upper percentile was the maximum value from the 1999 survey data. It was felt that the value of 0.7 kg y^{-1} from the 2003 habits survey, did not cover the full range of potential values. The upper bound, 2.7 kg y^{-1}, was effectively a cut-off value, ie, no ingestion rate would exceed this value. The lower bound is consistent with both of the earlier surveys.

Children (10 year old)

Although the 2003 habits survey failed to identify any child mollusc consumers, earlier surveys did identify some young consumers. For this study, consumption rates for children were derived by scaling the adult consumption rates outlined in the 2003 habits survey report. Based on this approach a high rate child ingestion rate for winkles of 0.35 kg y^{-1} was used in this study.

A lognormal distribution on consumption rates for this group has been assumed, again derived by scaling from the adult rates, with a 2.5th percentile of 0.2 kg y^{-1} and a 97.5th percentile of 0.5 kg y^{-1}. These values are in broad agreement with the child ingestion rate data within the 1999 survey.

Infants (<1 year old)

No infant mollusc consumers were identified in any of the habits surveys of the Dounreay area. This finding was consistent with the results of other surveys (Smith and Jones, 2003). On this basis it was assumed that no consumption occurred.

However, to explore the possible consequences of infants consuming molluscs a simple triangular distribution with a range of 0.0 - 0.37 kg y^{-1} has been used. The upper value was derived from the adult rates using the scaling factor adopted in the 2003 survey report.

Summary

Based on the evidence above it is apparent that winkles are the primary mollusc consumed by the local population. Therefore it has been assumed that all mollusc consumption rates are applicable specifically to winkles. The ingestion rates of winkles used in this study are summarised in Table A11.

Table A11 Ingestion rates for winkles used in this study

Age Group	Ingestion rate of winkles (kg y^{-1})		
	High rate	Distribution	Shape of Distribution
Adult	0.5	0.3 - 2.7 [a]	Lognormal
Child	0.35	0.2 - 0.5 [b]	Lognormal
Infant	0.0	0.0 - 0.37	Triangular

Notes

[a] The upper and lower bounds described by the distribution represent the 99.9th (cut-off value) and 2.5th percentiles respectively.

[b] The upper and lower bounds described by the distribution represent the 97.5th and 2.5th percentiles respectively.

A8 Winkle characteristics

In order to determine the probability of inadvertently ingesting a fuel fragment in a winkle information on the characteristics of these animals was needed. The relevant data used in this study are presented in Table A12 and includes the typical mass of sediment in the digestive tract and the total mass of a winkle. Note that it has been assumed that the number of fuel fragments per gramme of sand in the digestive tract of a winkle is the same as on a beach (as derived in Section 2). All the data were taken from Wilkins et al (1998).

Table A12 Characteristics of winkles (Wilkins et al, 1998)

Parameter	Best estimate	Distribution
Sediment in digestive tract (g)	0.24	Triangular Min 0.2 Mean 0.24 Max 0.6
Mass (kg)	0.006	Triangular Min 0.005 Mean 0.006 Max 0.015
Edible fraction	0.23	Triangular Min 0.22 Mean 0.23 Max 0.25

A9 References

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APPENDIX B METHODOLOGY FOR DETERMINING LIKELIHOOD OF ENCOUNTERING FUEL FRAGMENTS

The methodologies used to determine the probabilities of encountering a fuel fragment for each potential exposure pathway are described below. Discussion of the values adopted and underlying assumptions is provided in Appendix C.

B1 Inhalation of a fuel fragment

The probabilities of inhaling a fuel fragment, both per visit and annually, were given by the following equations,

$P_{inh,v}$ = Fd x Sl x Br x Dv

$P_{inh,a}$ = Fd x Sl x Br x Oa

where,

$P_{inh,v}$ = probability of inhaling a fuel fragment per visit

$P_{inh,a}$ = annual probability of inhaling a fuel fragment, y^{-1}

Fd = number of fuel fragments per g of sand, g^{-1}, see Section 2

Sl = sand loading in air, g m^{-3}, see Table C2

Dv = duration of beach visit, h, see Table A7

Oa = number of hours spent on beach annually, h y^{-1}, see Table A6

Br = breathing rate, m^3 h^{-1}, see Table C4

B2 Inadvertent ingestion of a fuel fragment with sand

The probabilities of inadvertently ingesting a fuel fragment in sand, both per visit and annually, were given by the following equations,

$P_{ings,v}$ = Fd x SIr x Dv

$P_{ings,a}$ = Fd x SIr x Oa

where,

$P_{ings,v}$ = probability of ingesting a fuel fragment in sand per visit

$P_{ings,a}$ = annual probability of ingesting a fuel fragment in sand, y^{-1}

SIr = rate of inadvertent ingestion of sand, g h^{-1}, see Table C9

B3 Ingesting a fuel fragment in winkles

The only seafood routinely gathered from the rocky areas at the edge of Sandside beach are winkles. Winkles feed mainly on microalgae residing on rocks. As a result of this grazing habit, the gut of winkles contains substantial amounts of sediment (Wilkins et al, 1998).

The probability of ingesting a fuel fragment incorporated into winkles gathered from the rocky areas at the edge of the beach was determined using the following approach.

The number of fuel fragments in each winkle was given by the following equation,

Fw = Fd x Sw x Fa

where,

Fw = number of fuel fragments in an individual winkle

Sw = typical mass of sand/sediment in gut of winkle, g, see Table A12

Fa = fraction of sediment intake from the contaminated area

It was assumed in this assessment that the numbers of fuel fragments per unit mass applies to all the sand/sediment that the winkle is exposed to, ie, it was assumed that the entire sediment intake by winkles is from Sandside beach. However, the parameter Fa is retained in the equation in case future assessments adopt a different assumption.

Seafood intake rates are given in terms of kg per year. For use in this study, these were converted to the number of individual winkles consumed per person per year using the following equation,

Cw = Wir / (Mw x Ef)

where,

Cw = number of winkles ingested per person per year, y^{-1}

WIr = intake rate of winkles, kg y^{-1}, see Table A11

Mw = mass of individual winkle, kg, see Table A12

Ef = edible fraction of species expressed as a fraction of the whole mass of the animal, see Table A12

The annual probability of an individual consuming a fuel fragment in winkles was then determined as follows,

$P_{ingw,a}$ = Fw x Cw

where,

$P_{ingw,a}$ = annual probability of a winkle consumer ingesting a fuel fragment, y^{-1}

It was assumed that the entire gastrointestinal tract was consumed, as this is the general case.

B4 A fuel fragment in direct contact with skin

This section considers the likelihood of encountering a fuel fragment in sand adhering to the skin, except skin under fingernails or in shoes or on clothes, which are covered in following sections. The methodology adopted for the adult, child and infant 'leisure' exposed groups differs from that assumed for bait diggers due to the different activities undertaken.

B4.1 Adult, child and infant 'leisure' exposed group

Dermal loading of sand is very dependent upon whether sand is wet or dry and thus contact with each requires separate consideration. Dermal loading is also generally higher on hands (and feet if exposed) than on other parts of the body.

Contact with dry sand only

Under these circumstances the probability of encountering a fuel fragment during a particular visit to the beach was given by the following equation,

$P_{skin,ds,v}$ = (Safh,ds x DLds,fh + SArm,ds x DLds,rm) x Fd x DSef

where,

$P_{skin,ds,v}$ = the probability of encountering a fuel fragment on skin in dry sand, per beach visit

Safh,ds = area of skin on hands and feet that was exposed to dry sand, cm^2

SArm,ds = area of skin on other parts of the body that was exposed to dry sand, cm^2

DLds,fh = dermal loading of dry sand on hands and feet, g cm^{-2}, see Table C10

DLds,rm = dermal loading of dry sand on skin on other parts of the body, g cm^{-2}, see Table C10

DSef = factor to account for the re-adherence of sand on skin during the visit, see Table C13

It was further assumed, see Table C10, that,

DLds,rm = 0.5 x DLds,fh

Thus,

$P_{skin,ds,v}$ = (Safh,ds + 0.5 x SArm,ds) x DLds,fh x Fd x DSef

Using this assumption essentially implied that when undertaking probabilistic calculations the parameters DLds,fh and DLds,rm were directly correlated.

Contact with wet sand only

Under these circumstances the probability of encountering a fuel fragment during a particular visit to the beach was given by the following equation,

$P_{skin,ws,v}$ = (Safh,ws x DLws,fh + SArm,ws x DLws,rm) x Fd x WSef

where,

$P_{skin,ws,v}$	=	the probability of encountering a fuel fragment on skin in wet sand, per beach visit
Safh,ws	=	area of skin on hands and feet that was exposed to wet sand, cm^2
SArm,ws	=	area of skin on other parts of the body that was exposed to wet sand, cm^2
DLws,fh	=	dermal loading of wet sand on hands and feet, g cm^{-2}, see Table C11
DLws,rm	=	dermal loading of wet sand on skin on other parts of the body, g cm^{-2}, see Table C11
WSef	=	factor to account for the re-adherence of sand during the visit, see Table C13

It was further assumed, see Table C11, that,

DLws,rm = 0.5 x DLws,fh

Thus,

$P_{skin,ws,v}$ = (Safh,ws + 0.5 x SArm,ws) x DLws,fh x Fd x WSef

Using this assumption essentially implied that when undertaking probabilistic calculations the parameters DLws,fh and DLws,rm were directly correlated.

Contact with both dry and wet sand

Under these circumstances the probability of encountering a fuel fragment during a particular visit to the beach was given by the following equation,

$P_{skin,s,v} = P_{skin,ds,v} + P_{skin,ws,v}$

where,

$P_{skin,s,v}$	=	the probability of encountering a fuel fragment on skin in sand (dry or wet), per beach visit.

It follows that,

$P_{skin,s,v}$ = (Safh,ds x DLds,fh + SArm,ds x DLds,rm) x Fd x DSef + (Safh,ws x DLws,fh + SArm,ws x DLws,rm) x Fd x Wsef

Using the above assumptions regarding the ratio between sand loadings on the hands and other parts of the body,

$P_{skin,s,v}$ = (SAfh,ds + 0.5 x SArm,ds) x DLds,fh x Fd x DSef + (Safh,ws + 0.5 x SArm,ws) x DLws,fh x Fd x WSef

Clearly any area of skin cannot be simultaneously exposed to both dry and wet sand and thus the values of exposed skin areas used in the above calculations reflected this constraint. Whilst the above equation was adequate for the determination of probabilities using single values for each parameter, when undertaking probabilistic calculations using distributions on the parameter values some simplification was undertaken to allow for this constraint on the values the areas could take.

The approach taken for the probabilistic calculations was to use an effective area approach. The underlying assumption was of a direct correlation between the dermal loadings of dry and wet sand on skin, ie, from Tables C10 and C11,

DLds,fh = DLws,fh / 50

It was also further assumed that DSef and WSef were equivalent, ie both equal to Sef, Table C13.

On this basis,

$P_{skin,s,v}$ = [(SAfh,ds + 0.5 x SArm,ds)/50 + (Safh,ws + 0.5 x SArm,ws)] x DLws,fh x Fd x Sef

Where the term,

[(SAfh,ds + 0.5 x SArm,ds)/50 + (Safh,ws + 0.5 x SArm,ws)] was the effective area exposed to wet sand.

The distribution on the effective area exposed to wet sand was assumed to be triangular in shape. The minimum, peak and maximum values of the distribution were determined using the assumptions regarding the parts of the body exposed to dry and wet sand in Tables B1 and B2 and information on the skin areas of different parts of the body (see Table C12). Note that for ‘cold’ conditions it was assumed that all exposure was to wet sand and so that for these conditions it was not necessary to use an effective area approach.

Exposed skin areas

The activities undertaken on the beach and the clothing worn, and thus the amount of skin exposed, depend to a significant extent on the weather. In order to give some indication of the range on the likelihood of encountering a fuel fragment in sand on a visit to the beach, probabilities were determined for each exposed group for trips to the beach in 'cold' and 'warm' conditions. Cold conditions reflected time spent on the beach in winter and most of spring and autumn, when the weather was cool and individuals were generally warmly dressed against the elements and their activities generally limited to walking on the beach or playing ball games, for example. Warm conditions reflected days when the weather was warm enough for sunbathing, perhaps swimming and for infants to dig and play in wet sand.

The assumptions made about clothing and activities for each exposed group, for both cold and warm conditions, and the consequent parts of the body exposed are presented in Tables B1 and B2. These were combined with information on skin areas of different parts of the body (Table C12) to give the areas of skin exposed.

It should be noted that the distributions on exposed skin areas were based solely on consideration of the range of clothing worn. Ranges in skin areas resulting from the variation in body size and shape for each age group were not considered. In essence the resulting probabilities thus relate to 'typical' individuals in the different age groups. It should also be noted that dermal loading of sand on the face was ignored. The face would only be exposed to dry sand and dermal loadings on the face were expected to be significantly lower than on other parts of the body.

Table B1 Activities, clothing and exposed skin areas during beach visits under 'cold' conditions

Adult leisure

General Activities

Dog walking, walking, beachcombing, ball games

Clothing and skin exposure

Best estimate – Fully clothed except perhaps for hands. Hands may be exposed to wet sand when, for example, beachcombing or throwing sticks for dogs. Palms of both hands exposed to wet sand.

Distribution

Shape **–** Triangular

Minimum – Fully clothed wearing gloves. No skin exposed.

Peak – as best estimate

Maximum – Both hands exposed to wet sand

Child leisure

General Activities

Dog walking, walking, beachcombing, ball games

Clothing and skin exposure

Best estimate – Fully clothed except perhaps for hands. Hands may be exposed to wet sand when, for example, beachcombing or throwing sticks for dogs. Palms of both hands exposed to wet sand

Distribution

Shape **–** Triangular

Minimum – Fully clothed wearing gloves. No skin exposed.

Peak – as best estimate

Maximum – Both hands exposed to wet sand

Infant leisure

General Activities

Walking, beachcombing

Fully clothed. Gloves may occasionally be removed. Visit will be short so dermal loading expected to be low

Clothing and skin exposure

Best estimate – Fully clothed. Gloves may occasionally be removed. Visit will be short so dermal loading expected to be low. 25% of palm of one hand exposed to wet sand

Distribution

Shape – Triangular

Minimum – Fully clothed wearing gloves. No skin exposed.

Peak – as best estimate

Maximum – Palm of one hand exposed to wet sand

Table B2 Activities, clothing and exposed skin areas during beach visits under 'warm' conditions

Adult leisure

General Activities

Dog walking, walking, beachcombing, ball games, sunbathing, swimming, playing with children (including digging in wet sand)

Clothing and skin exposure

Best estimate – wearing light summer clothing (eg t-shirt and shorts) with lower arms and legs exposed. Lower arms and lower legs exposed to dry sand (m^2) and palms of both hands and soles of feet to wet sand

Distribution

Shape **–** Triangular

Minimum – wearing light summer clothing but legs covered (eg t-shirt and trousers) walking on beach. Lower arms and hands exposed to dry sand no exposure to wet sand

Peak – as best estimate

Maximum – wearing minimal clothing (eg swimming costume) and lying on wet sand or perhaps digging in wet sand with children. 25% of total body area exposed to wet sand

Child leisure

General Activities

Dog walking, walking, beachcombing, ball games, sunbathing, swimming, playing including digging in wet sand, exploring rock pools

Clothing and skin exposure

Best estimate – wearing light summer clothing (eg t-shirt and shorts) with lower arms and legs exposed. Lower arms and lower legs exposed to dry sand and both hands and feet to wet sand

Distribution

Shape – Triangular

Minimum – wearing light summer clothing but legs covered (eg t-shirt and trousers) walking on beach. Lower arms and hands exposed to dry sand no exposure to wet sand

Peak – as best estimate

Maximum – wearing minimal clothing (eg swimming costume) and lying on wet sand or perhaps digging in wet sand. 25% of total body area exposed to wet sand

Infant leisure

General Activities

Walking, beachcombing, ball games, playing including digging in wet sand

Clothing and skin exposure

Best estimate – wearing light summer clothing (eg t-shirt and shorts) with lower arms and legs exposed walking or beachcombing. Lower arms and lower legs exposed to dry sand and both hands and feet to wet sand

Distribution

Shape – Triangular

Minimum – wearing light summer clothing but legs covered (eg t-shirt and trousers) walking on beach. Lower arms and hands exposed to dry sand no exposure to wet sand

Peak – as best estimate

Maximum – wearing minimal clothing (eg swimming costume) and lying on wet sand or perhaps digging in wet sand. 25% of total body area exposed to wet sand

Annual probabilities of contact with a fuel fragment in sand on skin

To determine the annual probability of contact with a fuel fragment from the probabilities per beach visit, it was necessary to consider both the total number of beach visits per year and when they occurred.

The annual probability of coming into contact with a fuel fragment on skin was given by,

$P_{skin,s,a}$ = (FVwc x $P_{skin,s,v,wc}$ + FVcc x $P_{skin,s,v,cc}$) x Nv

where,

$P_{skin,s,a}$	=	the annual probability of encountering a fuel fragment on skin in sand (dry or wet), y^{-1}
$P_{skin,s,v,wc}$	=	the probability of encountering a fuel fragment on skin in sand (dry or wet), per beach visit in warm conditions
$P_{skin,s,v,cc}$	=	the probability of encountering a fuel fragment on skin in sand (dry or wet), per beach visit in cold conditions
FVwc	=	fraction of visits in warm conditions, see Table C14
FVcc	=	fraction of visits in cold conditions, is equal to 1 - FVwc
Nv	=	total number of beach visits per year, y^{-1}

Nv is given by the following equation,

Nv = Oa / Dv

B4.2 Bait diggers

The methodology used to determine the probability of contacting a fuel fragment in sand for a bait digger is that described in Wilkins et al (1998). This is outlined below:

The probability of encountering a fuel fragment in sand on skin during a particular visit to the beach for a bait digger was given by the following equation,

$P_{skin,v}$ = Fd x Gs x Nt x Dv x Gf

where,

$P_{skin,v}$	=	the probability of encountering a fuel fragment on skin in sand, per beach visit
Gs	=	the amount of sediment adhering to each contact item, g
Nt	=	the number of items handled per hour
Gf	=	fraction of sediment on the contact item that is likely to be contacted

In respect to the above, the items contacted are the bait that is being dug up.

The best estimate values and ranges for Gs, Nt and Gf were taken from Wilkins et al (1998) and are summarised in Table C15.

B5 A fuel fragment under fingernails

The probability of being exposed to a fuel fragment trapped under nails on a visit to the beach was given by the following equation,

$P_{nails,v}$ = Fd x Sn

where,

$P_{nails,v}$	=	the probability of contacting a fuel fragment in sand trapped under nails per beach visit
Sn	=	amount of sand trapped under nails per visit to the beach, g, see Table C16

The annual probability of contacting a fuel fragment in sand trapped under nails was given by the following equation,

$P_{nails,a}$ = $P_{nails,v}$ x Nv

B6 A fuel fragment on clothes

There is no information in the literature on the quantities of sand that may adhere to clothing. A number of simplified assumptions were therefore used to determine the probability of a fuel fragment adhering to clothing during a visit to the beach. The probability of a fuel fragment adhering to clothing on a visit to the beach was given by the following equation,

$P_{cl,v}$ = Fd x Sacl x Ld X Clef

where,

$P_{cl,v}$	=	the probability of a fuel fragment adhering to clothing on a visit to the beach
Sacl	=	the area of clothing that is exposed to sand, cm^2
Ld	=	the loading of sand on clothing, g cm^{-2}
Clef	=	factor to account for the change of sand adhering

In the absence of any specific data, it was assumed that the loading of sand on clothing would be the same as that for dry sand on skin other than hands or feet (see Table C10). This is likely to be an overestimate as most clothing materials, eg, cotton, will provide a less adherent surface than skin, although some such as wide weave knitted garments may be more likely to trap sand grains. In the absence of any specific data Clef was assumed to be equivalent to Sef (see Table C13).

The area of clothing for the single value calculations was assumed to be the same as the total skin area of the body for each exposed group (see Table C12). Although clearly the whole of the body would not be covered, ie, head and hands uncovered, the area of clothing is larger than the skin area covered, so use of the total skin area would account for this to some extent. For the distribution, a triangular distribution was assumed with the peak and max as the single value and the minimum as zero, representing a small amount of clothing with a very low adherence potential.

B7 A fuel fragment in a shoe

The probability of a fuel fragment being trapped in an individual's shoe on a visit to the beach was given by the following equation,

$P_{shoe,v}$ = Fd x Ss

where,

$P_{shoe,v}$	=	the probability of a fuel fragment being trapped in shoes per beach visit
Ss	=	amount of sand trapped in shoes per visit to the beach, g, see Table C17

The annual probability of a fuel fragment being trapped in an individual's shoe was given by the following equation,

$P_{shoes,a}$ = Nv x $P_{shoes,v}$

B8 Exposure following purposeful removal of sand

As indicated in Section 5 of the main text, the only exposure scenario considered following purposeful removal of sand from the beach is that of an infant potentially exposed following the use of sand from Sandside beach in the sandpit. The infant could be exposed via skin contact or potentially inhalation or ingestion. The probabilities of each were determined as described below.

It should be stressed that the estimated probability of a fuel fragment being in a sandpit filled using sand from Sandside beach was low. It was determined using the following equation,

$P_{sandpit}$ = Fd x Sp

where,

$P_{sandpit}$	=	the probability of a sand pit containing a fuel fragment
Sp	=	the quantity of sand in a typical sandpit, g, see Table C18

Direct skin contact whilst playing in a sandpit

The probability of direct skin contact with a fuel fragment whilst playing in a sandpit is given by the following equation,

$P_{sandpit,skin} = P_{sandpit} \times Fsc$

where,

$P_{sandpit,skin}$ = the annual probability of skin contact with a fuel fragment if a fuel fragment is present in the sandpit, y^{-1}

Fsc = the fraction of sand in a sandpit that comes into contact with the skin per year, 0.044, see discussion below

It was considered highly unrealistic to assume that an infant would come into contact with all the sand in a sandpit over the course of a year. The amount of sand that an infant would typically come into contact with was expressed as a fraction of the total amount of sandpit sand. It was assumed that an infant would incur 25% coverage of sand over their hands, feet, lower legs and lower arms each time they used the sandpit, implying an area of 350 cm^2 (see Table C12). To account for the change of sand on skin while in a sandpit a factor of 2 was assumed (analogous to the sand on skin pathway). Assuming the coverage was one sand grain thick resulted in a mass of sand on skin of 0.14 kg, which was applicable to a single sandpit session. It was assumed that an infant plays in a sandpit for 1 hour per session and 50 sessions per year, thus an estimated mass of 7 kg of sand per year comes into direct contact with the skin of an infant playing in a sandpit. As a result a factor of 7/160 (or approximately 0.044) was used in the calculations of annual probability of direct skin contact with a fuel fragment whilst playing in a sandpit.

Inhalation of a fuel fragment in a sandpit

If there was a fuel fragment in the sandpit then the probability of inhaling it during a year was given by the following equation,

$P_{sandpit,inh} = Sl \times Br \times Oa / Sp$

where,

$P_{sandpit,inh}$ = annual probability of inhaling a fuel fragment from a sandpit if a fuel fragment is present in the sand pit, y^{-1}

Sl = sand loading in air above sandpit, g m^{-3}, see Table C18

Oa = number of hours a year spent in sandpit, h y^{-1}, see Table C18

Br = breathing rate, m^3 h^{-1}, see Table C18

Ingestion of a fuel fragment

If there was a fuel fragment in the sandpit then the probability of ingesting a fuel fragment by the inadvertent ingestion of sand whilst in a sandpit, for example with food, was given by the following,

$P_{sandpit,inh}$ = SIr x Oa / Sp

where,

$P_{sandpit,inh}$	=	annual probability of ingesting a fuel fragment from a sandpit if a fuel fragment is present in the sandpit, y^{-1}
SIr	=	rate of inadvertent ingestion of sand by infant, g h^{-1}, see Table C18

B9 References

Wilkins BT, Fry FA, Burgess PH, Fayers CA, Haywood SM, Bexon AP and Tournette C (1998). *Radiological Implication of the Presence of Fragments of Irradiated Fuel in the Sub-tidal Zone at Dounreay*. Chilton, NRPB-M1005.

APPENDIX C OTHER DATA

In this Appendix other data used in the derivation of the likelihoods of individuals coming into contact with fuel fragments are defined. This includes the following information:

a sand loadings in air;
b inhalation rates;
c inadvertent ingestion rates for sand;
d dermal loading of sand on skin;
e skin areas;
f the quantities of sand trapped under nails;
g the quantities of sand trapped in shoes; and
h the amount of sand in sand pits.

C1 Inhalation of a fuel fragment

C1.1 Sand loadings in air

It is widely recognized that sand, when disturbed by the action of wind, can, under certain conditions, be lifted off the residing surface (eg, a beach) and become airborne. Horikawa (1988) explained that on beaches where a strong seasonal wind blows, sand transport by wind is an important mechanism when considering the beach material budget. If the wind speed reaches a critical value, sand grains on a loose sand surface begin to move. Winds of the same or higher speed have the potential to elevate the sand grains. The bulk of sand movement takes place close to the ground and the moving sand particles do not rise to a high elevation. Furthermore, the relatively large mass of the sand grains means that levels of suspension are quite small. However it is recognized that sand can be blown to heights of 1-2 metres.

Wind speeds required for the suspension of sand repeatedly occur in northern Scotland. Thus it is reasonable to assume that suspended grains of sand achieve a height of an average adult on a “frequent” basis. However, it is important to consider individuals’ habits under such circumstances. Persons frequenting Sandside beach for seasonal leisure activities, eg, sunbathing or playing are less likely to visit the beach under inclement weather than those who have a commitment to a hobby, eg, angling or assigned to a routine activity, eg, dog walking.

The potential for inhalation of sand on Sandside beach necessitates the consideration of an individual inhaling a fuel fragment. Values of sand loading in air are used in determining the probability of encountering a fuel fragment via such a pathway.

A literature survey identified only one study giving values of sand loadings in air above beaches (Haslam et al, 1994). This provided the results of a number of measurements of atmospheric dust loadings above a range of beach types in Cumbria. On the basis of the experimental data an atmospheric dust loading for Cumbrian beaches of 10^{-4} g m^{-3} was used in that study. To put this into context other information on dust and soil loadings is presented in Table C1.

Table C1 Dust and soil loadings appropriate for a range of activities

Dust loading (kg m^{-3})	Scenario
10^{-5}	Dusty Environment (ploughing etc). Generally short exposure duration.
10^{-6}	Enhanced outdoor ambient dust levels (digging in domestic gardens, site excavation). Short or long durations, occasionally representing an "average" over dusty environment & outdoor ambient levels. Urban locations. Enhanced workplace levels.
10^{-7}	Outdoor ambient dust levels, also used in some studies for general ambient exposure levels (indoor & outdoor).
10^{-8}	Indoor ambient dust levels.

The sand loadings for Sandside beach used in this study reflect the tendency for individuals, notably children and infants, to spend less time at the beach under windier conditions. It was also recognized that the loadings of sand in air would generally be lower than for soil and dust because of the higher grain size. A sand loading for children and infants of 10^{-7} kg m^{-3} was assumed, with an associated range of 10^{-6} kg m^{-3} to 10^{-8} kg m^{-3} (also suitable for use when considering an infant playing in a sand pit). This best estimate value is identical to that used in Haslam et al (1994). It was thought that adult dog walkers and bait diggers would tolerate higher loadings and would be more likely to use the beach throughout the year under a wide range of weather conditions. Thus a best estimate sand loading, applicable to adults, of 5 10^{-7} kg m^{-3} was derived, with an associated range of 5 10^{-6} kg m^{-3} to 10^{-8} kg m^{-3}. The best estimate value is a factor of 5 higher than the recommended value for Cumbrian beaches in Haslam et al (1994). This is intended to reflect the possibly windier conditions in the north of Scotland. The shape of the distribution was lognormal in all cases.

Table C2 Sand loading in air

Exposed group	Sand loading (g m^{-3})	
	Best estimate	Distribution[a]
Infant	1 10^{-4}	1 10^{-3} – 1 10^{-5}
Child	1 10^{-4}	1 10^{-3} – 1 10^{-5}
Adult (leisure)	5 10^{-4}	1 10^{-3} – 1 10^{-5}
Adult (bait digger)	5 10^{-4}	1 10^{-3} – 1 10^{-5}

Notes

A lognormal distributions, values presented are the 97.5th and 2.5th percentiles.

C1.2 Inhalation rates

Inhalation rates whilst individuals are outdoors were required for this study. Tables 16A and 16B in ICRP Publication 66 (ICRP, 1994) give recommended inhalation rates for individuals whilst outdoors. These are presented in Table C3.

Table C3 Inhalation rates for individuals outdoors (ICRP, 1994)

Age group	Inhalation rate $m^3\ h^{-1}$	Assumptions
1 year old infant	0.31	1/3 sitting + 2/3 light exercise
5 year old child	0.49	1/3 sitting + 2/3 light exercise
10 year old child	0.87	1/3 sitting + 2/3 light exercise
15 year old child (male)	0.89	2/3 light exercise + 1/3 heavy exercise
Adult (sedentary male worker)	1.21	½ sitting + 3/8 light exercise + 1/8 heavy exercise
Adult (outdoor worker)	1.69	7/8 light exercise + 1/8 heavy exercise

The work of Beals et al (1994) indicated that distributions on inhalation rates are approximately lognormal. The results indicated that it would be reasonable to assume that the standard deviation of the lognormal distribution is approximately 15% of the mean. On this basis the following best estimate inhalation rates and distributions were used in this study.

Table C4 Breathing rates

Age group	Breathing rates ($m^3\ h^{-1}$)	
	Best estimate	Lognormal Distribution
Infant	0.31	Mean 0.31, SD 0.05
Child	0.87	Mean 0.87, SD 0.13
Adult (leisure)	1.21	Mean 1.21, SD 0.18
Adult (bait digger)	1.69	Mean 1.69, SD 0.25

Note that the likelihood of inhaling a fuel fragment is calculated for particles residing in any part of the respiratory tract, the mouth inclusive. Therefore no consideration of particle size was made when determining the likelihood of inhaling a fuel fragment.

C2 Ingestion of a fuel fragment with sand

C2.1 Review of soil ingestion data

Review by Simon (1998)

In 1998 a review of the literature covering both inadvertent ingestion of soil and geophagia was produced by Simon (1998). This was a thorough review of the literature in this area. It indicated that the most reliable estimates of inadvertent soil intake were from studies that had inferred their findings from the quantity of soil trace elements measured in faeces, and, in this context, he listed the following 6 papers: Binder et al (1986), Linsalata and Eisenbud (1986), Clausing et al (1987), Calabrese et al

(1989), Davis et al (1990) and van Wijnen et al (1990). Simon noted that - "there is a paucity of studies which have been specifically designed to determine soil ingestion rates …. Only four rigorously conducted empirical studies to quantify soil ingestion are noted in the English literature", these are listed as Binder et al (1986); Calabrese et al (1989); van Wijnen et al (1990) and Davis et al (1990). Simon noted that the findings of these studies provide ingestion rates that are expected to be suitable for typical US or European populations.

A summary of the data from these four studies (and two papers analysing data from two of these studies) is provided in the following table, the text for which was taken from Table 3 in Simon (1998).

Simon noted that the majority of the available data is for children, with very little data for adults. He does state, however, that - "There appears to be a general consensus that among adults in western society who do not routinely contact the soil by occupation or hobby, intake of soil is very low – probably in the order of a few milligrams to a few tens of milligrams per day".

Simon briefly discussed the use of variability ranges and uncertainties on soil ingestion rates in dose assessments, but concluded that – "Despite the rather adequate body of literature that documents the occurrence of soil ingestion, at present there is not sufficient information to adequately assess the true variability within any single group or uncertainty of mean intake values". A few publications were noted that have attempted to model the variability of intakes within a population, for example, Thompson and Burmaster (1991), see Table C5 for their predicted distribution. Finley et al (1994) fitted the intake data from Stanek and Calabrese (1995) to a population distribution. For children they gave the 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th} percentiles as 0, 0, 0, 16, 45, 67 and 110 mg d^{-1}.

Simon (1998) also provided a compilation of possible uncertainty distributions on inadvertent intake rates based on his judgement after reviewing the literature cited in the paper. He noted that - "the central estimates are consistent with the consensus of numerous authors that 100 mg d^{-1} represents a reasonable value of intake for children" and that the ranges - "may be assumed to represent a subjective 95% .. confidence interval for a representative individual". Simon's suggested distributions relevant to this study are given in Table C6.

Table C5 Review of soil ingestion rates (data taken from Table 3 in Simon (1998))

Author(s)	Study description	Ingestion rate estimate
Binder et al (1986)	59 children in Montana (urban area) were studied in summer using fecal analysis for soil trace elements	181 mg d^{-1} (Al) 184 mg d^{-1} (Si) 1834 mg d^{-1} (Ti)
Calabrese et al (1989)	65 children, 1-4 years of age in greater Amherst, MA area (urban), fecal analysis for soil trace elements during 8 day period, one soil pica child identified	9 to 40 mg d^{-1} for non-pica, 5 to 8 g d^{-1} for pica
Davis et al (1990)	104 school children randomly selected, 2–7 years of age in SE Washington State (urban and rural areas) fecal analysis for soil trace elements	39 mg d^{-1} (Al) 82 mg d^{-1} (Si) 245 mg d^{-1} (Ti)
Van Wijnen et al (1990)	Two different groups in summer in the Netherlands were studied and compared to hospitalised children, using fecal analysis for titanium: Day care groups: Camping groups	0 to 90 mg d^{-1} (geometric mean) 30 to 200 mg d^{-1}
Thompson and Burmaster (1991)	Reanalysed data of Binder et al (1986) using actual stool weights, fitted parametric (lognormal) distributions	59 mg d^{-1} (geometric mean) 91 mg d^{-1} (arithmetic mean) 126 mg d^{-1} (standard deviation)
Stanek and Calabrese (1995)	Revision of estimates presented in Calabrese et al (1989)	Range of median daily soil ingestion of 64 subjects over 365 days: 1 – 103 mg d^{-1} Range of average daily soil ingestion of 63 subjects over 365 days: 1 – 2268 mg d^{-1} Median of the daily average soil ingestion for 64 subjects: 75 mg d^{-1} Range of upper 95% soil ingestion estimates: 1 – 5263 mg d^{-1} Median upper 95% soil ingestion estimate of 64 subjects over 365 days: 252 mg d^{-1}

Table C6 Suggested values of soil ingestion model parameters for inadvertent ingestion, from Simon (1998).

Lifestyle	Distributions on ingestion rates (g d^{-1})	
	Adult	Child
Rural lifestyles – heavily vegetated, forest and fields	LN(0.1, 3.2)	LN(0.1, 4.2)
Rural lifestyles – sparsely vegetated	LN(0.2, 3.2)	LN(0.2, 4.2)
Suburban lifestyles – including lawns, parks, recreational areas, some gardens	LN(0.1, 3.2)	LN(0.1, 4.2)

Notes:

LN(geometric mean, geometric standard deviation)

Child approximately 1-6 years

Review of literature produced following Simon (1998)

A literature review of papers on soil ingestion produced since 1985 was undertaken. The majority of the papers identified had been considered by Simon or related to studies that had been considered by Simon. Those covering studies not considered by Simon or published since are discussed briefly below.

Stanek et al (1997) reported the results of a study on adult ingestion rates. This gave a median of 1 mg d^{-1}, average 10 mg d^{-1}, standard deviation 94 mg d^{-1}, 75^{th} percentile 49 mg d^{-1} and 95^{th} percentile 331 mg d^{-1}.

Calabrese et al (1997) provided an analysis of 64 children residing on a contaminated site in Montana. This gave median < 1 mg d^{-1} and 95^{th} percentile of 160 mg d^{-1}. However, it was noted that the method has a residual negative error suggesting estimates are below the actual values. The magnitude could not be quantified but it was stated that it was likely not to affect the mean by more than 40 mg d^{-1}. The impact on the upper end was less clear.

Stanek (2000) provided daily estimates for 64 children (age 1–4 years). This gave a mean of 31 mg d^{-1}, median 17 mg d^{-1}, 95^{th} percentile over 7 days 133 mg d^{-1}, 30 days 112 mg d^{-1}, 90 days 108 mg d^{-1} and 365 days 106 mg d^{-1}. It was stated that these provide basic distributions that could serve as a starting point for Monte Carlo risk assessments.

EPA recommendations

Using the results of studies carried out up until 1997 the US EPA (1999) recommended for children the use of 100 mg d^{-1} as a mean value and 400 mg d^{-1} as an upper estimate of the mean. A value of 50 mg d^{-1} was recommended for adults.

Assumptions used in the CLEA contaminated land model

In modelling soil ingestion by children from birth to six years the Contaminated Land Exposure Assessment (CLEA) model (DEFRA and EA, 2002) treats the daily ingestion rate as a lognormal distribution with a specified range that uses the EPA recommendations as a basis. The distribution has an approximate mean rate of 100 mg d^{-1} and a 97.5^{th} percentile rate of about 400 mg d^{-1} (50^{th} percentile – 64 mg d^{-1} and 95^{th} percentile - 303 mg d^{-1}). It was noted that no tracer studies have been undertaken on older children and only two on adults. The soil ingestion rates for older children and adults in the CLEA model were treated deterministically (ie, single point value). For older children the value has been set at 100 mg d^{-1} and for adults at 50 mg d^{-1}.

C2.2 Recommended inadvertent ingestion rates of sand for this study

For this study inadvertent ingestion rates of sand on beaches were required for various age groups. None of the papers mentioned above specifically relate to sand, although some of the children in the study by van Wijnen et al (1990) were camping by a beach. It was considered, however, that inadvertent ingestion rates for sand would be similar to those for soil and thus sand ingestion rates could be determined by considering the data on soil ingestion rates.

Infants (<3 years) - Daily ingestion rates

On the basis of the data summarised in the above sections, drawing in particular on the results for children in camp sites from van Wijnen et al (1990), the EPA guidance (based on experimental data up to 1997), and the approach taken in CLEA, it seemed reasonable for children below the age of 6 or 7 to adopt the distribution on daily intakes used in CLEA. This was defined as follows: mean 100 mg d^{-1}, 50^{th} percentile 64 mg d^{-1}, 95^{th} percentile 303 mg d^{-1} and 97.5^{th} percentile 400 mg d^{-1}. The distribution is given in Table C7.

Infants (<3 years) - Hourly ingestion rates

All the experimental studies reviewed focussed on the daily ingestion rate. As the exposures considered in this study are short term and episodic inadvertent ingestion rates were required in terms of mg h^{-1}. It was therefore necessary to derive a distribution on hourly rates from the distribution on daily intakes mentioned above.

The average hourly intake rate for any given exposure is given by the following:

HI = DI / ED

where,

HI = hourly intake, mg h^{-1}

DI = daily intake, mg d^{-1}

ED = exposure duration, h d^{-1}

The daily intake clearly depends both on the amount of time spent outdoors that day and the activities undertaken whilst outside. It is likely that younger children in this age range (ie, under around 3 years old) would have a higher average hourly ingestion rate but would be outside for less time than the upper end of the age range. Thus the daily intakes for both may be similar, but the actual hourly rates would be higher for the younger children. Unfortunately, the data available do not make hourly rates simple to derive as none of the studies give detailed information on the time spent with access to soil.

One study investigating the outdoor play behaviour of children (under 18 years old) (Wong et al, 2000) indicated that the median reported play frequency was 7 days per week in warm weather and 3 days per week in cold weather. The median play duration was 3 hours per day in warm weather (5^{th} percentile – 1 hour per day, 50^{th} percentile – 3 hours per day, and 95^{th} percentile - 8 hours per day) and 1 hour per day in cold weather (5^{th} percentile – 1 hour per day, 50^{th} percentile – 1 hour per day, and 95^{th} percentile - 4 hours per day). These exposure durations were based on information for children below the age of 18, no breakdown by age was given. Considering the results from this study and other factors such as sleep requirements and the types of activities undertaken in the experimental studies discussed above, it was considered that a typical daily exposure duration for the very young children (< 3 years) in the studies reviewed would be around 2 hours in a day.

Assuming a daily exposure of 2 hours and the distribution on daily intake rates given above a distribution on the hourly intake rate was derived. This is presented in Table C7. However, assuming a single exposure duration is rather simplistic. A distribution on hourly intake rate was therefore also derived assuming a distribution on daily exposure duration. A lognormal distribution was assumed with 50^{th} percentile - 2 hours and 95^{th} percentile - 6 hours. The distribution on hourly intake rate using this distribution was determined using a Crystal Ball spreadsheet. For the correlation between daily exposure duration and daily intake rates a correlation factor of 0.5 was used*. The resulting distribution is presented in Table C7. This is very similar to that generated using a defined 2 hourly exposure duration but is a slightly 'narrower' distribution. Clearly the distribution on exposure durations is highly uncertain. Other possible distributions were therefore also examined, including a triangular distribution with min - 1 h d^{-1}, most likely - 2 h d^{-1} and max - 5 h d^{-1} and another lognormal distribution with 0.1^{th} percentile 1 h d^{-1} and 99.9^{th} percentile of 6 h d^{-1}. Various correlation values were also considered. In all cases the 50^{th} percentile was in the region of 30 mg h^{-1}, the mean around 40 mg h^{-1}, and the 97.5^{th} percentile ranged from 110 to 190 mg h^{-1}.

On the basis of this analysis and consideration of the basic data reviewed it was decided that for this study the following distribution on hourly intake rate be used for infants (< 3 years): 50^{th} percentile 30 mg h^{-1} and 97.5^{th} percentile 175 mg h^{-1} (mean - 45 mg h^{-1}).

* Assuming no correlation generated a mean hourly intake of 60 mg h^{-1} and a 97.5^{th} percentile of 306 mg h^{-1}, which seemed inconsistent with the distribution on daily intake rate. Using a correlation of 0.75 reduced the mean to around 40 mg h^{-1} and the 97.5^{th} percentile to 115 mg h^{-1}.

Table C7 Distributions on soil intake rates for infants (<3 years)

Distribution parameters	Daily intake rate mg d^{-1}	Hourly intake rate mg h^{-1} (assuming daily exposure of 2 hours)	Hourly intake rate mg h^{-1} (assuming distribution on daily exposure – see text)
Mean	100	50	47
50th percentile	64	32	32
95th percentile	303	151	134
97.5th percentile	400	200	176

Young children (5 years)

Following on from the above analysis for infants, it was assumed that a 5 year old involved in the experimental studies would typically spend about twice the time exposed as an infant. On this basis and following the above approach, the following distribution on hourly intake rate was derived for young children (around 5 years): 50th percentile 15 mg h^{-1} and 97.5th percentile 87.5 mg h^{-1} (mean 22.5 mg h^{-1}).

Adults and older children (>15 years)

Developing a range for older children and adults was more difficult given the lack of basic data. For adults the formula proposed by Sedman and Mahmood (1984) for modelling the change in consumption rate with age suggests dividing the rates for young children by a factor of 10. The adult distribution derived in this manner is given in Table C8. This distribution is generally consistent with the conclusion of Simon (1998) that – "there appears to be a general consensus that among adults in western society who do not routinely contact the soil by occupation or hobby, intake of soil is very low – probably on the order of a few milligrams to a few tens of milligrams per day*"*. Although adults on a beach come into contact with sand and thus potentially may be considered to have a higher intake, the size of sand grains is such that they are relatively easily detected in food and on hands and therefore there is less likelihood of inadvertent ingestion.

Only one of the studies reviewed related to adult intake rates (Stanek et al, 1997), giving: median 1 mg d^{-1}, average 10 mg d^{-1}, standard deviation 94 mg d^{-1}, 75th percentile 49 mg d^{-1} and 95th percentile 331 mg d^{-1}. Whilst the median and average values are broadly consistent with those proposed here the high percentiles are almost at the level of young children which did not seem generally appropriate.

On this basis the following distribution on hourly sand intake rate was used for adults and older children (> 15 years): 50th percentile 3 mg h^{-1} and 97.5th percentile 17.5 mg h^{-1} (mean – 4.5 mg h^{-1}).

Table C8 Soil intake rates for adults and older children (>15 years)

Parameter	Sand intake rates	
	Child (1-2 years) mg h^{-1}	Adult mg h^{-1}
Mean	45	4.5
50th percentile	30	3.0
97.5th percentile	175	17.5

Children (10 years)

In the absence of specific data for this age group a distribution on hourly intake rate between that for younger children and adults was used: 50th percentile 6 mg h^{-1} and 97.5th percentile 35 mg h^{-1} (mean – 9 mg h^{-1}).

Summary

The distributions on hourly intake of sand used in this study are presented in Table C9. The best estimate values used are those presented in Smith and Jones (2003).

Table C9 Inadvertent ingestion rates for sand

Age group	Inadvertent ingestion rate of sand (g h^{-1})	
	Best estimate	Lognormal Distribution
Infant	5.0 10^{-2}	Mean - 4.5 10^{-2} 50th percentile - 3.0 10^{-2} 97.5th percentile - 1.75 10^{-1}
Child	1.0 10^{-2}	Mean - 9.0 10^{-3} 50th percentile - 6.0 10^{-3} 97.5th percentile - 3.5 10^{-2}
Adult (leisure)	5.0 10^{-3}	Mean - 4.5 10^{-3} 50th percentile - 3.0 10^{-3} 97.5th percentile - 1.75 10^{-2}
Adult (bait digger)	5.0 10^{-3}	Mean - 4.5 10^{-3} 50th percentile - 3.0 10^{-3} 97.5th percentile - 1.75 10^{-2}

C2.3 Inadvertent ingestion and mouthing

In the past, many studies explicitly considered only inadvertent ingestion, regarding any form of deliberate soil eating as too rare a condition to warrant inclusion in an environmental exposure assessment. However, there is a growing awareness that relatively short-term deliberate ingestion (exploratory mouthing) is widespread among young children and that such behaviour may be regarded as a 'normal' temporary phenomenon among some young children. It was therefore considered desirable to include it within the sand ingestion rates used in the study. However, there was insufficient evidence to model ingestion by exploratory mouthing and inadvertent ingestion separately. It was also clear that the experimental studies referred to above include some element of this behaviour. It was therefore considered that the recommended ingestion rates reflect both inadvertent ingestion and exploratory mouthing for infants and young children.

C3 Adherence of a fuel fragment to skin

C3.1 Literature review of soil adherence to skin

A literature survey was undertaken to identify any relevant literature relating to the loading of sand on skin and clothing. The literature survey found no specific references to sand, and no references to the adherence of soil on clothes. It did, however, identify a small number of papers on dermal soil loading.

It is clear from the literature that the amount of soil that comes into contact with the skin depends upon a number of factors, including:

a The exposed skin area;
b The type of activity involved;
c The duration of initial contact; and
d The texture and wetness of the soil.

The US EPA (US EPA, 1992) suggested that an average value for soil loading may be 0.2 mg of soil per cm^2 of skin and that a reasonable worst case might be 1 mg cm^{-2}. In the CLEA contaminated land exposure assessment model (Defra and EA, 2002) a soil loading of 1 mg cm^{-2}, ie, EPA reasonable worst case, is assumed.

In Sedman (1989) data from a few studies were averaged to produce a skin soil loading of 0.5 mg cm^{-2}, for children aged 1 to 3, with lower values for older children and adults. The purpose of the suggested values is for the derivation of action levels.

A number of the papers reviewed presented detailed measurements of dermal soil loadings for a number of activities. Of particular interest in this context is Holmes et al (1999). This paper also contains the data presented in Kissel et al (1996), which was an earlier publication by the same project team. In this paper pre and post activity soil loadings from hands, forearms, lower legs, faces and feet were reported for volunteers engaged in various occupational and recreational activities. This data provides a useful perspective on the types of behaviour likely to lead to soil contact falling within general classes of activity (eg, background, low, moderate, or high contact). A number of conclusions were drawn from the experimental data including the following:

a Post-activity loadings are typically higher than pre-activity levels, demonstrating that exposure is episodic;
b Hand loadings are dependent upon the class of activity;
c Hand loadings generally provide conservative estimates of loadings on nonhand body parts within activity classes; and
d Hand loadings do not provide conservative estimates of nonhand loadings across activity classes.

In all, measurements from 200 individuals were made. It was suggested on the basis of the data that it might be useful to distinguish background, low, moderate and high contact categories using the following ranges of soil loading on the hands:

Background	< 0.01 mg cm^{-2}
Low contact activity	0.01 – 0.1 mg cm^{-2}
Moderate contact activity	0.1 – 1.0 mg cm^{-2}
High contact activity	>1.0 mg cm^{-2}

Groups having hand loadings falling within the moderate contact category included irrigation system installers, gardeners, archeologists, construction workers, farmers, water utility crews, heavy equipment operators, and reed gatherers. The EPA default range (0.2–1.0 mg cm^{-2}) largely overlaps what are defined as moderate contact activities.

Only one type of activity produced geometric mean hand loadings above 1.0 mg cm^{-2} (ie, high contact activity). These were children transported to a muddy river bank to play. Their mean hand loadings were above 10 mg cm^{-2}.

The results support the view that hand loadings usually provide conservative estimates of nonhand loadings within activities. The only caveat is that loadings on bare feet are likely to be roughly equivalent to loadings on hands. Loadings on faces, forearms and lower legs were found to be roughly 20 to 60% of hand loadings.

Finley et al (1994) reviewed the literature on soil adherence and proposed the use of a standard probability density function (PDF) of soil adherence. This standard PDF is lognormally distributed; the arithmetic mean and standard deviation are 0.52 ± 0.9 mg of soil per cm^2 of skin. They considered that their review indicated that soil adherence under environmental conditions would be minimally influenced by age, sex, soil type, or particle size and thus their proposed PDF should be considered applicable to all settings. The 50th and 95th percentile values of the PDF (0.25 and 1.7 mg of soil per cm^2 of skin, respectively) are very similar to the EPA estimates of average and upper bound soil adherence (0.2 and 1.0 mg of soil per cm^2 of skin).

The effect of particle size on dermal loading of soil

The experimental data reported above is based on soils rather than sand. Soils in general consist of particles smaller in size than sand. It was considered important therefore to explore the relationship between particle size and dermal adherence to provide an input to the derivation of appropriate dermal adherence values to use in this study.

The annual report on beach monitoring published in September 2001 provides a distribution on the sizes of sand particles at Sandside and Dounreay beaches. The range for Sandside beach is approximately 0.1 mm to 2 mm, with the majority around 0.3 mm.

Sheppard and Evenden (1994) examined the impact on adhesion of particle size. They studied the dermal adhesion properties of 11 different soils including a number of sandy soils. They found that adhering skin surfaces preferentially selected particles with diameters smaller than 0.1 mm. For soils that originally had few particles smaller than 0.1 mm, the particle size distribution of the adhering soil was markedly different from that of the original soil. They found that dry particles above 50 μm did not adhere to dry skin. However, this effect was less marked when the soil moisture was higher.

An earlier study (Que Hee et al, 1985) looked at the adherence of house dust and hand dust. They considered the impact of particle size on adherence. The results are difficult to interpret but seem to indicate that adherence does not change significantly with particle size.

Driver et al (1989) (as reported in Finley et al 1994) found a two fold adherence difference between unsieved and very fine (150 μm) soil particles.

The US EPA concluded in 1992 (EPA, 1992) that while particle size may influence adherence, there were insufficient data to develop quantitative relationships between particle size and skin adherence.

C3.2 Recommended dermal loading of sand on skin for use in this study

In the absence of any specific data on the loading of sand on skin it was necessary to use the above information on the adherence of soil to skin to estimate sand adherence. From the information above on the effects of particle size, and, importantly, general practical experience, it is assumed that dry sand will adhere to skin less well than soil. This is because soil contains particles smaller in size than sand, and smaller particles more readily adhere to skin. On the basis of this assumption and the data in Section 2, particularly that from Holmes et al (1999), it was decided that for activities involving contact with dry sand a best estimate assumption of dermal loading on hands and, if applicable, feet of 0.1 mg cm^{-2} should be used. This is slightly below the EPA average value of 0.2 mg cm^{-2}, to reflect the lower adherence properties of sand, and is the lower point of the moderate contact range as defined by Holmes (1999). For probabilistic calculations a triangular distribution was adopted covering the Holmes (1999) low and moderate contact activity ranges, ie, 0.01 mg cm^{-2} to 1.0 mg cm^{-2}, with the peak at 0.1 mg cm^{-2}. The dermal loading on skin other than on hands and feet was assumed to be a factor of 0.5 lower than that on hands and feet on the basis of a conservative assessment of the results in Holmes et al (1999). The assumptions for dermal loading of dry sand are summarised in Table C10.

Table C10 Dermal loading of dry sand on skin

Parameter	Best estimate	Distribution
Dermal loading of sand on hands and feet	0.1 mg cm^{-2}	Triangular distribution min 0.01 mg cm^{-2} peak 0.1 mg cm^{-2} max 1.0 mg cm^{-2}
Dermal loading of sand on other parts of the body	50% of loading on hands and feet	

It was assumed that dermal loading of wet sand would be greater than that of dry sand. When on a beach it is not unusual, following paddling etc, to have feet completely covered in a fine layer of wet sand. Sand of grain sizes corresponding to that of Sandside beach forming a monolayer on the skin, would correspond to a skin loading of approximately 10 mg cm^{-2}. Dermal loadings of soil at this relatively high level were only encountered by Holmes et al (1999) on children playing in mud by a river. These children had dermal loadings of soil on hands of between approximately 30 and 60 mg cm^{-2}. On the basis of the above data, for activities involving contact with wet sand, such as bait digging, winkle picking, paddling and digging in the sand close to the sea, a best estimate assumption of dermal loading on hands and, if applicable, feet of 5 mg cm^{-2} was used. For probabilistic calculations a triangular distribution covering the range 0.5 mg cm^{-2} to 50 mg cm^{-2}, with the peak at 5 mg cm^{-2} was used. The dermal loading on skin other than hands and feet was, as above, assumed to be a factor of 0.5 lower than that on hands and feet. The assumptions for dermal loading of wet sand are summarised in Table C11.

Table C11 Dermal loading of wet sand on skin

Parameter	Best estimate	Distribution
Dermal loading of sand on hands and feet	5 mg cm^{-2}	Triangular distribution min 0.5 mg cm^{-2} peak 5 mg cm^{-2} max 50 mg cm^{-2}
Dermal loading of sand on other parts of the body	50% of loading on hands and feet	

C3.3 Skin areas

The skin areas for various parts of the body were required in order to determine the quantities of sand that may adhere to skin.

Distributions on skin areas were not required because the overall probabilities being determined related to individuals with 'standard' physical characteristics. Therefore only best estimate values were required. The areas of the body identified as key for this assessment (following consideration primarily of habits and clothing) were: palms of hand and outstretched fingers, whole hands, lower arms, lower legs, soles of feet, total feet and total body area. The skin areas used are presented in Table

C12. The total body areas are those from ICRP Publication 32 (ICRP, 2002). The areas of individual body parts were determined by multiplying these total skin areas by the mean ratios of area of body part to total skin area published in EPA (1997). The only exceptions are for the soles of the feet and palms and outstretched fingers, which are assumed to be 50% of the areas of the feet and hands, respectively.

Table C12 Skin areas used in this study

Age Group	Surface Areas (m^2)						
	Lower Arms	Lower Legs	Hands	Palms & outstretched fingers	Feet	Soles of feet	Total Body
Adult	0.11	0.24	0.099	0.050	0.13	0.065	1.90
Child (10 y)	0.059	0.13	0.059	0.030	0.085	0.043	1.12
Infant (2 y)	0.026	0.049	0.028	0.014	0.037	0.019	0.53

C3.4 Additional factors affecting the adherence of a fuel fragment to skin

Values for a number of additional parameters were required in order to determine the probability of direct skin contact with a fuel fragment. These are presented in the following tables.

The values of dermal loading identified in Appendix B4.1 (DLws,fh, DLws,rm DLds,fh, and DLds,rm) relate to the dermal loading at the end of a beach trip. However, during the visit it is likely that some of the sand on the skin will fall off and be replaced by other sand. Thus the total quantity of sand to which the skin is exposed is greater than that implied simply by the use of the above dermal loadings. Use of a factor to account for the re-adherence of sand during the visit, Sef, allows account to be taken of the change of sand present on the skin during the visit. The value of Sef is clearly dependent upon a number of factors including whether the sand is wet or dry and the activities being undertaken. However, no data are available to allow quantification. Clearly the minimum value of Sef is 1. For this study a best estimate value of 2 was used. The distribution used was triangular with, respectively, minimum 1.0, peak 2.0, and maximum 5.0.

Table C13 Factor to account for the re-adherence of sand during a single visit

Parameter	Best estimate	Lognormal Distribution
Factor to account for the re-adherence of sand during the visit	2	0.1^{th} percentile - 1 97.5^{th} percentile - 5

The activities undertaken on the beach and the clothing worn, and thus the amount of skin exposed, depend to a significant extent on the weather. In order to give some indication of the range on the likelihood of encountering a fuel fragment in sand on a visit to the beach, probabilities were determined for each exposed group for trips to the beach in 'cold' and 'warm' conditions. Cold conditions reflected time spent on the beach in winter and most of spring and autumn, when the weather was cool and individuals were generally warmly dressed against the elements and their activities generally limited to walking on the beach or playing ball games, for example. Warm conditions reflected days when the weather was warm enough for sunbathing, perhaps swimming and for infants to dig and play in wet sand.

Infants are assumed to typically spend 100% of their time on the beach in warm conditions, with a distribution of 0.75-1, on the basis that adults are unlikely to expose an infant to physically demanding and potentially hazardous conditions while at a relatively vulnerable age. At the other end of the scale adult bait diggers are likely to brave almost any conditions to undertake their activity, and therefore are assumed to frequent the beach equally throughout the year. However it has been assumed that "cold" conditions occur throughout most of autumn and spring as well as winter, therefore resulting in a best estimate of 0.25. The range of 0.25-0.5 accounts for the marginal favouritism of adult bait diggers of "warm" conditions. Identical best estimate and range values are used to describe the fraction of visits in warm conditions of the adult leisure age group, as their primary activity, dog walking, is also assumed to take place equally throughout the year, again with the distribution accounting for the preference of warmer conditions. Child fractions of visits in warm conditions were placed between infant and adult bearing in mind that their tolerance of cold conditions is likely to reside between these respective groups.

Table C14 Fraction of beach visits in warm conditions

Age group	Fraction	
	Best estimate	Triangular Distribution
Infant	1	Max 1 Min 0.75
Child	0.75	Max 1 Min 0.5
Adult (leisure)	0.25	Max 0.5 Min 0.25
Adult (bait digger)	0.25	Max 0.5 Min 0.25

The best estimate values and ranges for Gs, Nt and Gf were taken from Wilkins et al (1998) and are summarised in Table C15.

Table C15 Parameters used to describe the probability of contacting a fuel fragment in sand for a bait digger (Wilkins et al, 1998)

Parameter	Best estimate	Distribution (all triangular)
Sediment on each item (Gs)	30 g	Minimum 10 g Most likely 30 g Maximum 50 g
Number of items handled (Nt)	60 h^{-1}	Minimum 30 h^{-1} Most likely 60 h^{-1} Maximum 100 h^{-1}
Fraction of sediment contacted (Gf)	0.05	Minimum 0.01 Most likely 0.05 Maximum 0.1

C4 A fuel fragment under a fingernail

No information was found on the length of the dead, white tip of the nail under which sand may become trapped. Therefore the derivation of quantities of sand which may become trapped under nails was based on a number of assumptions. Nails were considered as rectangular plates. The fingernails of an adult are typically 9-14 mm in breadth and 10-13 mm in length (ICRP, 2002). A breadth of 12 mm was assumed to be typical. The length of the dead, white tip of the nail, extending away from the finger is variable depending on the individual concerned. The full range will extend from 0 mm to in excess of 10 mm. However, the maximum length of nail under which sand could get trapped is assumed to be 4 mm, as only the part of the nail forming a "wedge" with the adjacent skin will trap sand. A typical length of 2 mm was assumed. A maximum gap of 2 mm and a typical gap of 1 mm was assumed between the skin and the nail. Thus the maximum volume of sand which could potentially be trapped under an adult fingernail was assumed to be 112 mm^3 and a typical volume of sand which could potentially be trapped under an adult fingernail was assumed to be 24 mm^3.

No data are available on typical nail sizes for children or infants. It was therefore assumed that the distance between the nail and the skin would not differ from that for the adult but that the breadth and length of the nail would be smaller by a factor equal to the ratio of the hand area of the age considered and the adult value. Using this approach the maximum volume of sand which could potentially be trapped under a child's (10 year old) fingernail was assumed to be 40 mm^3 with a typical volume of 8.6 mm^3. The maximum volume of sand which could potentially be trapped under an infant's (2 year old) fingernail was assumed to be 8.8 mm^3, with a typical volume of 1.9 mm^3. These assumptions are summarised in Table C16.

Table C16 Typical and maximum volumes of sand trapped under fingernails[a]

Age Group	Typical volume of sand mm^3 (m^3)[b]	Maximum volume of sand mm^3 (m^3)[b]
Adult	240 (2.4 10^{-7})	1120 (1.1 10^{-6})
10 year old child	86 (8.6 10^{-8})	400 (4.0 10^{-7})
2 year old infant	19 (1.9 10^{-8})	88 (8.8 10^{-8})

Notes

a Minimum mass of sand trapped under fingernails is assumed to be 0.0001 g (for all age groups) ie, as low as Crystal Ball would allow, and this is assumed to be the 0.1th percentile of the lognormal distribution.

b The 97.5th percentile of the lognormal distribution.

C5 A fuel fragment in a shoe

In order to estimate the probability of a fuel fragment becoming trapped in a shoe it was necessary to make assumptions regarding the amount of sand that would potentially become trapped in shoes.

A web based search revealed amounts of sand in shoes ranged between 8 and 50 grammes. On the basis of this data and personal experience a best estimate mass of sand trapped in a single shoe per beach visit of 10 grammes was assumed. Table C17 details the best estimate and distribution on the mass of sand trapped in shoes per beach visit assumed in this study. In the absence of detailed age and activity specific information the values described in Table C17 were applied to all exposed groups considered.

Table C17 Mass of sand trapped in shoes per visit to the beach

Parameter	Best estimate	Distribution (triangular)
Amount of sand (Ss)	10 g	Minimum 1 g Most likely 10 g Maximum 50 g

C6 Exposure following purposeful removal of sand

To estimate the probability of a fuel fragment being present in a sandpit filled using sand from Sandside beach it was necessary to collate information on the quantities of sand in a sandpit.

A web based search of well-known retail outlets, notably Argos and Toys 'r' us, revealed typical masses of sand required to fill a sandpit or, otherwise, the dimensions of a sandpit. If not already provided, masses of sandpit sand were inferred from the volume assuming half of the sandpit is filled with sand and a sand density of 2000 kg m^{-3}. Masses of sandpit sand ranging from 110 kg to 220 kg were estimated. On the basis of this data a mid-point and best estimate value of 160 kg was assumed. A larger range than that calculated was assumed, accounting for the potential variability in the fraction of the sandpit filled with sand. The best estimate and distribution on the mass of sand in a sandpit are detailed in Table C18.

It is customary that infants only play in sandpits in warm weather. Such conditions in the vicinity of Sandside beach are assumed to only occur in summer, typically associated with the months of June, July and August (a 13 week period). It is assumed that an infant would typically play in a sandpit for 4 hours per week, with a range of 2 to 8 hours per week. Scaling the weekly occupancy by a total duration of 13 weeks implies a best estimate and distribution of infant occupancy in a sand pit of 50 h y^{-1} and 25-100 h y^{-1} respectively, as highlighted in Table C18.

Note that the values displayed in Table C18 for sand loading in air, infant breathing rate and infant sand ingestion rate are analogous to the values applicable to a Sandside beach scenario. The derivation of these values can be found in Appendices C1.1, C1.2 and C2.2 respectively.

Table C18 Sandpit exposure parameters

Parameter	Best estimate	Distribution
Mass of sand in a sandpit	160 kg	Triangular Minimum – 80 kg Peak – 160 kg Maximum – 240 kg
Sand loading in air above sandpit [a]	1 10^{-4} g m^{-3}	Lognormal 97.5^{th} percentile - 1 10^{-3} g m^{-3} 2.5^{th} percentile – 1 10^{-5} g m^{-3}
Infant occupancy in sandpit [a]	50 h y^{-1}	Lognormal 2.5^{th} percentile – 25 h y^{-1} 97.5^{th} percentile – 100 h y^{-1}
Infant breathing rate	0.31 m^3 h^{-1}	Lognormal Mean 0.31 m^3 h^{-1} SD 0.05
Infant sand ingestion rate	5.0 10^{-2} g h^{-1}	Mean - 4.5 10^{-2} g h^{-1} 50^{th} percentile - 3.0 10^{-2} g h^{-1} 97.5^{th} percentile - 1.75 10^{-1} g h^{-1}

C7 References

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APPENDIX D RESULTS

Note that for all tables described within this document the column header denoted as the particle activity range refers to the activity levels of ^{137}Cs by which the particles are conventionally characterised. It does not refer to the total particle activity ie the contributions from ^{90}Sr and ^{90}Y are not included.

Table D1 Annual probabilities of inhaling a fuel fragment on Sandside beach for the 'high rate' subgroup of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual Probability of inhaling a fuel fragment (y^{-1})
< 20 kBq	Adult (bait digger)	$2.31\ 10^{-12}$
	Adult (leisure)	$1.15\ 10^{-11}$
	Child (leisure)	$4.70\ 10^{-13}$
	Infant (leisure)	$2.66\ 10^{-14}$
20 kBq - 50 kBq	Adult (bait digger)	$5.89\ 10^{-13}$
	Adult (leisure)	$2.94\ 10^{-12}$
	Child (leisure)	$1.20\ 10^{-13}$
	Infant (leisure)	$6.78\ 10^{-15}$
50 kBq - 100 kBq	Adult (bait digger)	$4.54\ 10^{-13}$
	Adult (leisure)	$2.27\ 10^{-12}$
	Child (leisure)	$9.24\ 10^{-14}$
	Infant (leisure)	$5.23\ 10^{-15}$
> 100 kBq	Adult (bait digger)	$7.81\ 10^{-14}$
	Adult (leisure)	$3.90\ 10^{-13}$
	Child (leisure)	$1.59\ 10^{-14}$
	Infant (leisure)	$9.00\ 10^{-16}$
Total	Adult (bait digger)	$3.44\ 10^{-12}$
	Adult (leisure)	$1.72\ 10^{-11}$
	Child (leisure)	$7.00\ 10^{-13}$
	Infant (leisure)	$3.96\ 10^{-14}$

Table D2 Probabilities of inhaling a fuel fragment on Sandside beach per beach visit for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of inhaling a fuel fragment per beach visit
< 20 kBq	Adult (bait digger)	$1.07\ 10^{-13}$
	Adult (leisure)	$3.84\ 10^{-14}$
	Child (leisure)	$5.52\ 10^{-15}$
	Infant (leisure)	$1.97\ 10^{-15}$
20 kBq - 50 kBq	Adult (bait digger)	$2.74\ 10^{-14}$
	Adult (leisure)	$9.80\ 10^{-15}$
	Child (leisure)	$1.41\ 10^{-15}$
	Infant (leisure)	$5.02\ 10^{-16}$
50 kBq - 100 kBq	Adult (bait digger)	$2.11\ 10^{-14}$
	Adult (leisure)	$7.56\ 10^{-15}$
	Child (leisure)	$1.09\ 10^{-15}$
	Infant (leisure)	$3.88\ 10^{-16}$
> 100 kBq	Adult (bait digger)	$3.63\ 10^{-15}$
	Adult (leisure)	$1.30\ 10^{-15}$
	Child (leisure)	$1.87\ 10^{-16}$
	Infant (leisure)	$6.67\ 10^{-17}$
Total	Adult (bait digger)	$1.60\ 10^{-13}$
	Adult (leisure)	$5.73\ 10^{-14}$
	Child (leisure)	$8.24\ 10^{-15}$
	Infant (leisure)	$2.94\ 10^{-15}$

Table D3 Annual probabilities of inadvertently ingesting a fuel fragment on Sandside beach for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual Probability of inadvertently ingesting a fuel fragment (y^{-1})
< 20 kBq	Adult (bait digger)	$1.23\ 10^{-11}$
	Adult (leisure)	$8.57\ 10^{-11}$
	Child (leisure)	$4.86\ 10^{-11}$
	Infant (leisure)	$3.86\ 10^{-11}$
20 kBq - 50 kBq	Adult (bait digger)	$3.13\ 10^{-12}$
	Adult (leisure)	$2.19\ 10^{-11}$
	Child (leisure)	$1.24\ 10^{-11}$
	Infant (leisure)	$9.84\ 10^{-12}$
50 kBq - 100 kBq	Adult (bait digger)	$2.42\ 10^{-12}$
	Adult (leisure)	$1.69\ 10^{-11}$
	Child (leisure)	$9.56\ 10^{-12}$
	Infant (leisure)	$7.59\ 10^{-12}$
> 100 kBq	Adult (bait digger)	$4.16\ 10^{-13}$
	Adult (leisure)	$2.90\ 10^{-12}$
	Child (leisure)	$1.64\ 10^{-12}$
	Infant (leisure)	$1.31\ 10^{-12}$
Total	Adult (bait digger)	$1.83\ 10^{-11}$
	Adult (leisure)	$1.28\ 10^{-10}$
	Child (leisure)	$7.24\ 10^{-11}$
	Infant (leisure)	$5.75\ 10^{-11}$

Table D4 Probabilities of inadvertently ingesting a fuel fragment on Sandside beach per beach visit for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of inadvertently ingesting a fuel fragment per beach visit
< 20 kBq	Adult (bait digger)	$5.72\ 10^{-13}$
	Adult (leisure)	$2.86\ 10^{-13}$
	Child (leisure)	$5.72\ 10^{-13}$
	Infant (leisure)	$2.86\ 10^{-12}$
20 kBq - 50 kBq	Adult (bait digger)	$1.46\ 10^{-13}$
	Adult (leisure)	$7.29\ 10^{-14}$
	Child (leisure)	$1.46\ 10^{-13}$
	Infant (leisure)	$7.29\ 10^{-13}$
50 kBq - 100 kBq	Adult (bait digger)	$1.13\ 10^{-13}$
	Adult (leisure)	$5.63\ 10^{-14}$
	Child (leisure)	$1.13\ 10^{-13}$
	Infant (leisure)	$5.63\ 10^{-13}$
> 100 kBq	Adult (bait digger)	$1.94\ 10^{-14}$
	Adult (leisure)	$9.68\ 10^{-15}$
	Child (leisure)	$1.94\ 10^{-14}$
	Infant (leisure)	$9.68\ 10^{-14}$
Total	Adult (bait digger)	$8.52\ 10^{-13}$
	Adult (leisure)	$4.26\ 10^{-13}$
	Child (leisure)	$8.52\ 10^{-13}$
	Infant (leisure)	$4.26\ 10^{-12}$

Table D5 Annual probabilities of ingesting a fuel fragment in winkles for the 'high rate' sub-group of winkle consumers for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual probability of ingesting a fuel fragment (y^{-1})
< 20 kBq	Adult (leisure)	$5.52\ 10^{-09}$
	Child (leisure)	$3.87\ 10^{-09}$
20 kBq - 50 kBq	Adult (leisure)	$1.41\ 10^{-09}$
	Child (leisure)	$9.86\ 10^{-10}$
50 kBq - 100 kBq	Adult (leisure)	$1.09\ 10^{-09}$
	Child (leisure)	$7.61\ 10^{-10}$
> 100 kBq	Adult (leisure)	$1.87\ 10^{-10}$
	Child (leisure)	$1.31\ 10^{-10}$
Total	Adult (leisure)	$8.23\ 10^{-09}$
	Child (leisure)	$5.76\ 10^{-09}$

Table D6 Annual probabilities of direct skin contact with a fuel fragment on Sandside beach for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual probability of contact with a fuel fragment in sand on skin (y^{-1})
< 20 kBq	Adult (bait digger)	$2.46\ 10^{-07}$
	Adult (leisure)	$1.28\ 10^{-07}$
	Child (leisure)	$6.31\ 10^{-08}$
	Infant (leisure)	$5.64\ 10^{-09}$
20 kBq - 50 kBq	Adult (bait digger)	$6.27\ 10^{-08}$
	Adult (leisure)	$3.26\ 10^{-08}$
	Child (leisure)	$1.61\ 10^{-08}$
	Infant (leisure)	$1.44\ 10^{-09}$
50 kBq - 100 kBq	Adult (bait digger)	$4.84\ 10^{-08}$
	Adult (leisure)	$2.52\ 10^{-08}$
	Child (leisure)	$1.24\ 10^{-08}$
	Infant (leisure)	$1.11\ 10^{-09}$
> 100 kBq	Adult (bait digger)	$8.32\ 10^{-09}$
	Adult (leisure)	$4.33\ 10^{-09}$
	Child (leisure)	$2.14\ 10^{-09}$
	Infant (leisure)	$1.91\ 10^{-10}$
Total	Adult (bait digger)	$3.66\ 10^{-07}$
	Adult (leisure)	$1.91\ 10^{-07}$
	Child (leisure)	$9.41\ 10^{-08}$
	Infant (leisure)	$8.41\ 10^{-09}$

Table D7 Probabilities of direct skin contact with a fuel fragment on Sandside beach for a beach visit under 'cold conditions' for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of contact with a fuel fragment per beach visit
< 20 kBq	Adult (bait digger)	$1.14\ 10^{-08}$
	Adult (leisure)	$3.18\ 10^{-10}$
	Child (leisure)	$1.91\ 10^{-10}$
	Infant (leisure)	$1.11\ 10^{-11}$
20 kBq - 50 kBq	Adult (bait digger)	$2.92\ 10^{-09}$
	Adult (leisure)	$8.10\ 10^{-11}$
	Child (leisure)	$4.86\ 10^{-11}$
	Infant (leisure)	$2.84\ 10^{-12}$
50 kBq - 100 kBq	Adult (bait digger)	$2.25\ 10^{-09}$
	Adult (leisure)	$6.25\ 10^{-11}$
	Child (leisure)	$3.75\ 10^{-11}$
	Infant (leisure)	$2.19\ 10^{-12}$
> 100 kBq	Adult (bait digger)	$3.87\ 10^{-10}$
	Adult (leisure)	$1.08\ 10^{-11}$
	Child (leisure)	$6.45\ 10^{-12}$
	Infant (leisure)	$3.76\ 10^{-13}$
Total	Adult (bait digger)	$1.70\ 10^{-08}$
	Adult (leisure)	$4.74\ 10^{-10}$
	Child (leisure)	$2.84\ 10^{-10}$
	Infant (leisure)	$1.66\ 10^{-11}$

Table D8 Probabilities of direct skin contact with a fuel fragment on Sandside beach for a beach visit under 'warm conditions' for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of contact with a fuel fragment per beach visit
< 20 kBq	Adult (bait digger)	$1.14\ 10^{-08}$
	Adult (leisure)	$7.52\ 10^{-10}$
	Child (leisure)	$9.26\ 10^{-10}$
	Infant (leisure)	$4.18\ 10^{-10}$
20 kBq - 50 kBq	Adult (bait digger)	$2.92\ 10^{-09}$
	Adult (leisure)	$1.92\ 10^{-10}$
	Child (leisure)	$2.36\ 10^{-10}$
	Infant (leisure)	$1.07\ 10^{-10}$
50 kBq - 100 kBq	Adult (bait digger)	$2.25\ 10^{-09}$
	Adult (leisure)	$1.48\ 10^{-10}$
	Child (leisure)	$1.82\ 10^{-10}$
	Infant (leisure)	$8.22\ 10^{-11}$
> 100 kBq	Adult (bait digger)	$3.87\ 10^{-10}$
	Adult (leisure)	$2.55\ 10^{-11}$
	Child (leisure)	$3.14\ 10^{-11}$
	Infant (leisure)	$1.41\ 10^{-11}$
Total	Adult (bait digger)	$1.70\ 10^{-08}$
	Adult (leisure)	$1.12\ 10^{-09}$
	Child (leisure)	$1.38\ 10^{-09}$
	Infant (leisure)	$6.23\ 10^{-10}$

Table D9 Annual probabilities of trapping a fuel fragment under a fingernail for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual probability of trapping a fuel fragment under a fingernail (y^{-1})
< 20 kBq	Adult (bait digger)	$6.55\ 10^{-10}$
	Adult (leisure)	$9.14\ 10^{-09}$
	Child (leisure)	$9.18\ 10^{-10}$
	Infant (leisure)	$3.26\ 10^{-11}$
20 kBq - 50 kBq	Adult (bait digger)	$1.67\ 10^{-10}$
	Adult (leisure)	$2.33\ 10^{-09}$
	Child (leisure)	$2.34\ 10^{-10}$
	Infant (leisure)	$8.31\ 10^{-12}$
50 kBq - 100 kBq	Adult (bait digger)	$1.29\ 10^{-10}$
	Adult (leisure)	$1.80\ 10^{-09}$
	Child (leisure)	$1.81\ 10^{-10}$
	Infant (leisure)	$6.41\ 10^{-12}$
> 100 kBq	Adult (bait digger)	$2.22\ 10^{-11}$
	Adult (leisure)	$3.10\ 10^{-10}$
	Child (leisure)	$3.11\ 10^{-11}$
	Infant (leisure)	$1.10\ 10^{-12}$
Total	Adult (bait digger)	$9.77\ 10^{-10}$
	Adult (leisure)	$1.36\ 10^{-08}$
	Child (leisure)	$1.37\ 10^{-09}$
	Infant (leisure)	$4.86\ 10^{-11}$

Table D10 Probabilities per beach visit of trapping a fuel fragment under a fingernail for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of trapping a fuel fragment under a fingernail per beach visit
< 20 kBq	Adult (bait digger)	$3.05\ 10^{-11}$
	Adult (leisure)	$3.05\ 10^{-11}$
	Child (leisure)	$1.08\ 10^{-11}$
	Infant (leisure)	$2.41\ 10^{-12}$
20 kBq - 50 kBq	Adult (bait digger)	$7.78\ 10^{-12}$
	Adult (leisure)	$7.78\ 10^{-12}$
	Child (leisure)	$2.75\ 10^{-12}$
	Infant (leisure)	$6.16\ 10^{-13}$
50 kBq - 100 kBq	Adult (bait digger)	$6.00\ 10^{-12}$
	Adult (leisure)	$6.00\ 10^{-12}$
	Child (leisure)	$2.13\ 10^{-12}$
	Infant (leisure)	$4.75\ 10^{-13}$
> 100 kBq	Adult (bait digger)	$1.03\ 10^{-12}$
	Adult (leisure)	$1.03\ 10^{-12}$
	Child (leisure)	$3.66\ 10^{-13}$
	Infant (leisure)	$8.17\ 10^{-14}$
Total	Adult (bait digger)	$4.55\ 10^{-11}$
	Adult (leisure)	$4.55\ 10^{-11}$
	Child (leisure)	$1.61\ 10^{-11}$
	Infant (leisure)	$3.60\ 10^{-12}$

Table D11 Annual probabilities of a fuel fragment adhering to clothing for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual Probability of a fuel fragment adhering to clothing (y^{-1})
< 20 kBq	Adult (bait digger)	$2.59\ 10^{-09}$
	Adult (leisure)	$3.62\ 10^{-08}$
	Child (leisure)	$6.05\ 10^{-09}$
	Infant (leisure)	$4.54\ 10^{-10}$
20 kBq - 50 kBq	Adult (bait digger)	$6.62\ 10^{-10}$
	Adult (leisure)	$9.23\ 10^{-09}$
	Child (leisure)	$1.54\ 10^{-09}$
	Infant (leisure)	$1.16\ 10^{-10}$
50 kBq - 100 kBq	Adult (bait digger)	$5.11\ 10^{-10}$
	Adult (leisure)	$7.13\ 10^{-09}$
	Child (leisure)	$1.19\ 10^{-09}$
	Infant (leisure)	$8.94\ 10^{-11}$
> 100 kBq	Adult (bait digger)	$8.78\ 10^{-11}$
	Adult (leisure)	$1.23\ 10^{-09}$
	Child (leisure)	$2.05\ 10^{-10}$
	Infant (leisure)	$1.54\ 10^{-11}$
Total	Adult (bait digger)	$3.87\ 10^{-09}$
	Adult (leisure)	$5.40\ 10^{-08}$
	Child (leisure)	$9.02\ 10^{-09}$
	Infant (leisure)	$6.78\ 10^{-10}$

Table D12 Probabilities per beach visit of a fuel fragment adhering to clothing for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of a fuel fragment adhering to clothing per beach visit
< 20 kBq	Adult (bait digger)	$1.21\ 10^{-10}$
	Adult (leisure)	$1.21\ 10^{-10}$
	Child (leisure)	$7.11\ 10^{-11}$
	Infant (leisure)	$3.37\ 10^{-11}$
20 kBq - 50 kBq	Adult (bait digger)	$3.08\ 10^{-11}$
	Adult (leisure)	$3.08\ 10^{-11}$
	Child (leisure)	$1.81\ 10^{-11}$
	Infant (leisure)	$8.59\ 10^{-12}$
50 kBq – 100 kBq	Adult (bait digger)	$2.38\ 10^{-11}$
	Adult (leisure)	$2.38\ 10^{-11}$
	Child (leisure)	$1.40\ 10^{-11}$
	Infant (leisure)	$6.63\ 10^{-12}$
> 100 kBq	Adult (bait digger)	$4.09\ 10^{-12}$
	Adult (leisure)	$4.09\ 10^{-12}$
	Child (leisure)	$2.41\ 10^{-12}$
	Infant (leisure)	$1.14\ 10^{-12}$
Total	Adult (bait digger)	$1.80\ 10^{-10}$
	Adult (leisure)	$1.80\ 10^{-10}$
	Child (leisure)	$1.06\ 10^{-10}$
	Infant (leisure)	$5.02\ 10^{-11}$

Table D13 Annual probabilities of a fuel fragment becoming trapped in a shoe for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Annual probability of encountering a fuel fragment in a shoe (y^{-1})
< 20 kBq	Adult (bait digger)	$1.37\ 10^{-08}$
	Adult (leisure)	$1.91\ 10^{-07}$
	Child (leisure)	$5.40\ 10^{-08}$
	Infant (leisure)	$8.57\ 10^{-09}$
20 kBq - 50 kBq	Adult (bait digger)	$3.48\ 10^{-09}$
	Adult (leisure)	$4.86\ 10^{-08}$
	Child (leisure)	$1.38\ 10^{-08}$
	Infant (leisure)	$2.19\ 10^{-09}$
50 kBq - 100 kBq	Adult (bait digger)	$2.69\ 10^{-09}$
	Adult (leisure)	$3.75\ 10^{-08}$
	Child (leisure)	$1.06\ 10^{-08}$
	Infant (leisure)	$1.69\ 10^{-09}$
> 100 kBq	Adult (bait digger)	$4.62\ 10^{-10}$
	Adult (leisure)	$6.45\ 10^{-09}$
	Child (leisure)	$1.83\ 10^{-09}$
	Infant (leisure)	$2.90\ 10^{-10}$
Total	Adult (bait digger)	$2.04\ 10^{-08}$
	Adult (leisure)	$2.84\ 10^{-07}$
	Child (leisure)	$8.05\ 10^{-08}$
	Infant (leisure)	$1.28\ 10^{-08}$

Table D14 Probabilities per beach visit of a fuel fragment becoming trapped in a shoe for the 'high rate' sub-group of each potentially exposed group for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Exposed Group	Probability of encountering a fuel fragment in a shoe per beach visit
< 20 kBq	Adult (bait digger)	$6.35\ 10^{-10}$
	Adult (leisure)	$6.35\ 10^{-10}$
	Child (leisure)	$6.35\ 10^{-10}$
	Infant (leisure)	$6.35\ 10^{-10}$
20 kBq - 50 kBq	Adult (bait digger)	$1.62\ 10^{-10}$
	Adult (leisure)	$1.62\ 10^{-10}$
	Child (leisure)	$1.62\ 10^{-10}$
	Infant (leisure)	$1.62\ 10^{-10}$
50 kBq - 100 kBq	Adult (bait digger)	$1.25\ 10^{-10}$
	Adult (leisure)	$1.25\ 10^{-10}$
	Child (leisure)	$1.25\ 10^{-10}$
	Infant (leisure)	$1.25\ 10^{-10}$
> 100 kBq	Adult (bait digger)	$2.15\ 10^{-11}$
	Adult (leisure)	$2.15\ 10^{-11}$
	Child (leisure)	$2.15\ 10^{-11}$
	Infant (leisure)	$2.15\ 10^{-11}$
Total	Adult (bait digger)	$9.47\ 10^{-10}$
	Adult (leisure)	$9.47\ 10^{-10}$
	Child (leisure)	$9.47\ 10^{-10}$
	Infant (leisure)	$9.47\ 10^{-10}$

Table D15 Probability of a sandpit filled using sand from Sandside beach containing a fuel fragment for different ^{137}Cs activity ranges

Particle activity range (^{137}Cs activity)	Probability of a sandpit containing a fuel fragment
< 20 kBq	$1.02\ 10^{-05}$
20 kBq - 50 kBq	$2.59\ 10^{-06}$
50 kBq - 100 kBq	$2.00\ 10^{-06}$
> 100 kBq	$3.44\ 10^{-07}$
Total	$1.52\ 10^{-05}$

Table D16 Annual probability of an infant encountering a fuel fragment in a sandpit filled using sand from Sandside beach for different ^{137}Cs activity ranges

Exposure Pathway	Particle activity range (^{137}Cs activity)	Annual probability of an infant encountering a fuel fragment in a sandpit (y^{-1})
Direct skin contact with a fuel fragment	< 20 kBq	$4.45\ 10^{-07}$
	20 kBq - 50 kBq	$1.13\ 10^{-07}$
	50 kBq - 100 kBq	$8.75\ 10^{-08}$
	> 100 kBq	$1.51\ 10^{-08}$
	Total	$6.63\ 10^{-07}$
Ingesting a fuel fragment	< 20 kBq	$1.59\ 10^{-10}$
	20 kBq - 50 kBq	$4.05\ 10^{-11}$
	50 kBq - 100 kBq	$3.13\ 10^{-11}$
	> 100 kBq	$5.38\ 10^{-12}$
	Total	$2.37\ 10^{-10}$
Inhaling a fuel fragment	< 20 kBq	$9.84\ 10^{-14}$
	20 kBq - 50 kBq	$2.51\ 10^{-14}$
	50 kBq - 100 kBq	$1.94\ 10^{-14}$
	> 100 kBq	$3.33\ 10^{-15}$
	Total	$1.47\ 10^{-13}$