DALGETY BAY
RADIUM CONTAMINATION

August 2012

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SCOTTISH ENVIRONMENT PROTECTION AGENCY

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1. Summary

This report is a technical report which details the potential doses which may result from inadvertent ingestion of radioactive sources at Dalgety Bay.

Radioactive items have been detected on the foreshore at Dalgety Bay since at least 1990. The contamination is believed to be associated with historic activities of the now MoD at Dalgety Bay. Since 1990 then many surveys have been undertaken on the beach to determine the potential numbers of items present and the possible implications for public health. In 2006, SEPA conducted a limited monitoring and recovery survey at Dalgety Bay to determine whether the contamination posed a realistic risk that should be further quantified. Assessment of the 2006 results showed a possibility of significant exposures to members of the public (Dale et al. 2008) which warranted consideration of interventions to protect the public and resulted in the erection of signs at a number of locations. In 2008, SEPA again conducted a further monitoring and recovery survey, combined with comprehensive laboratory analysis of a selection of recovered items. The assessment report (SEPA 2009) resulted in a change to the signage and the Ministry of Defence (MoD)[1] beginning a monitoring and recovery programme, agreed with SEPA, which was completed in 2010. The 2009 report also confirmed that of the approximately 3 km of coastline at Dalgety Bay a section of about 800m was the primary area of concern (for radioactive contamination) with the focus of that being around the slipways.

Following the 2009 assessment the MoD's programme of work in 2009/2010, to monitor for and recover point sources of radium-226, initially recovered 128 items. The removal of these sources gave some level of protection to users of the beach area during the programme of work. The report on that work confirmed SEPA's view that the beach was repopulated by radioactive sources within a few months and it was estimated that around 100 sources could re-populate the beach each year (Defence Estates, 2010).

In 2011, SEPA began an investigation into the headland area at Dalgety Bay to determine whether it was a potential cache of sources. Identification of such caches may allow remediation to be undertaken to minimise re-population of the beach with radioactive sources. This programme of work began in September 2011 and was only possible because the MoD agreed to receive any waste arising from the SEPA investigation.

During the headland investigation work the MoD deployed its contractor to undertake a further monitoring and recovery exercise of the affected area, using more sensitive equipment than SEPA possessed, which resulted in the removal of further items. However, during the headland work, SEPA's attention was drawn to the intertidal area recently[2] surveyed by the MoD contractor and a further three sources were recovered which the MoD contactor had apparently not detected. Further monitoring of the area by SEPA resulted in the recovery of over 400 additional sources, some of which were

[1] Defence Estates Agency (DE) manages the military estate, including accommodation for Service personnel and their families, on behalf of the Ministry of Defence (MOD). On 1 April 2011, Defence Estates Agency merged with other MoD departments to become the Defence Infrastructure Organisation (DIO)

[2] Following the MoD contactor monitoring, the area was re-monitored by SEPA before a tidal inundation of the area.

extremely radioactive and which required specialist transport arrangements to be made for their removal from the beach.

The SEPA surveys in 2011 resulted in the restriction of public access to an area of Dalgety Bay as the sources recovered from that area represented an unacceptable hazard to the public. As it is not known whether further such sources could be deposited in the area, the area remains restricted.

Probability of encounter

The number of sources recovered by SEPA and the MoD contractor in 2011 indicate that the probability of a member of the public encountering such a source in the area as a whole was significantly higher than SEPA had previously assessed. In 2012 following a further survey by the MoD contractor SEPA again found that significant numbers of sources had gone undetected by the contractor. Thus, at present, assessment of the probability of encountering a source is subject to great uncertainty.

This assessment is an update of our September 2011 report and has been produced primarily to provide information on the potential doses which could result if a point source were to be ingested and to allow SEPA to consider whether some areas of Dalgety Bay harbour radioactive sources which could deliver doses to users of the area in excess of those specified in the guidance issued to SEPA on Radioactive Contaminated Land (RCL). It is currently not possible to provide a robust risk assessment for Dalgety Bay as to do so would require considerably more information on e.g. public habits, detection efficiency and the characterisation (e.g. particle dimensions) of a much greater number of the sources recovered. Obtaining this information would be costly in terms of both time and resources. However, SEPA's 2006 report gives some initial estimates of the chance of encountering a particle in 2006 for the reportedly most frequently used area of the beach assessment of the risks from radioactive contamination at Dalgety Bay.

With regard to the hazard that the point sources could pose, two potential pathways have been considered, *viz*. skin contact and ingestion, both of which have previously been assumed to be *via* inadvertent exposures. However, in 2011 SEPA was informed of the potential for selection of items on the beach which could be radioactive e.g. dials, and that there have been instances of the deliberate collection of material from beaches as a souvenir. These pathways would significantly increase the potential for exposures to occur.

Skin Doses

The potential range of skin doses is dependent upon the activity of the source, time of exposure, distance and shielding between the source and skin, and skin area and thickness. Since SEPA's 2009 report, SEPA has undertaken a detailed assessment of the external dose rates of a range of Dalgety Bay particles recovered in 2008 which were reported upon in 2011 (http://www.sepa.org.uk/radioactive_substances/dalgety_bay.aspx). Consistent with the conclusions and recommendations of that report comparisons of dose rates have been made with those more recently recovered by SEPA. The high activity sources recovered by SEPA *viz*. 76 MBq, 13 MBq, 4.5 MBq and 3.6 MBq Ra-226 would clearly deliver skin burns if in contact with the skin for very short exposure times of a few seconds to a minute. However, initial results of work on some of the recently recovered sources of lesser activity indicate that there may have been a significant change in the hazard posed via this pathway and further work is needed to quantify this issue. In the interim we recommend that users of the beach should follow the advice on the signs to minimise the risk of exposure.

Ingestion Doses

In relation to the risks from ingestion, following the work in our 2011 report a further solubility experiment was undertaken using a representative gut solution. In total 30 sources were tested to determine the range of solubility should such a source be ingested. The results of this study have shown that the solubility (up to 25%) was consistent with those reported previously in 2011. For those point sources subjected to this solubility work, the committed effective doses to a 3-month old infant (age range zero to one year old) could have been around 205 mSv and to a one year old 72 mSv (age range 1 to 2 years) which is consistent with the work in our 2011 report, that some of the physically smaller sources are more soluble and present a potentially greater hazard than previously assumed. Thus, significant doses could result to young children from the ingestion of some of the lower activity sources. The confirmation of this work may mean that further efforts are needed to mitigate the potential release of such sources into the environment.

Longevity

The radionuclides of concern at Dalgety Bay are radium-226 and its daughters. Radium-226 has a half-life of 1600 years thus radioactive decay is unlikely to have any significant effect on the total activity for centuries. Recent SEPA work appears to indicate that about 500 sources could re-populate the beach within short time scales which is inconsistent with the number of sources found on earlier surveys and indicates that there may have been a step change in the rate of contamination. The reason for such a change is unclear. However, anecdotal reports of significant erosion of made ground at Dalgety Bay are a potential cause. The evidence available to date therefore suggests that, without intervention, significant radiation hazards will remain at Dalgety Bay for many years to come. Although a programme of monitoring and removal will mitigate the potential for the public to encounter a source, it will not eliminate the hazard from sources re-populating the beach[3]. Thus, a management plan to determine the extent of the contamination and develop long term actions to mitigate the contamination is required.

[3] As the source is finite, a programme of monitoring and removal must reduce the source over time. It is important to note that the break down of physically large radioactive sources in the local environment may increase the radiological hazards due to the radioactivity not being homogenously distributed throughout a source and the physically smaller source being more easily ingested.

2. Scope and Purpose

This report was developed by SEPA in accordance with SEPA's duties under the Radioactive Contaminated Land (Scotland) Regulations 2007 (RCL Regulations) and the associated Statutory Guidance. The radioactively contaminated land regime allows, in situations of lasting exposure to radiation or where there is a significant possibility of such exposure, for remediation to occur, (under circumstances where intervention is likley to be justified). In 2009, SEPA provided a report which detailed that there was a possibility of significant harm at Dalgety Bay (to a 3 month old child, zero to 1 year old range). Following this work our 2011 report detailed that significant sources continued to populate the beach and in 2011 sources were recovered which posed an unacceptable hazards to be present on a public beach.

The principal criteria for significant harm and the significant possibility of significant harm are set out below. Two types of exposure situations can be envisaged – (a) where exposure conditions are almost certain to occur (such as general widespread contamination, i.e. homogeneous contamination), and (b) where they are uncertain to occur (such as localised hot spots, i.e. heterogeneous contamination). The SEPA 2009 report showed that it was unlikely that situation (a) existed and thus this report only considers situation (b) hot spots or heterogeneous contamination.

2.1. Criteria for Radioactive Contaminated Land

In 2007, Radioactive Contaminated Land Regulations were introduced which gave SEPA a statutory duty for land contaminated with radioactive substances. The associated statutory guidance provides SEPA with specific criteria where SEPA should regard significant harm as being caused to human beings when lasting exposure gives rise to an individual dose exceeding one or more of the following:

Homogeneous contamination

(a) An effective dose of 3 mSv per annum;
(b) An equivalent dose to the lens of the eye of 15 mSv per annum;
(c) An equivalent dose to the skin of 50 mSv per annum.

SEPA should regard significant harm as being caused to non-human species when lasting exposure gives rise to dose rates that exceed one or more of the following:

(a) 40 $\mu Gy\ hr^{-1}$ to terrestrial biota or plants;
(b) 400 $\mu Gy\ hr^{-1}$ to aquatic biota or plants.

In assessing doses to non-human species SEPA will take account of the most up-to-date methodology.

Heterogeneous contamination

In cases of lasting exposure when radiation exposure is not certain to occur the probability of radiation dose being received needs to be taken into account. In the following paragraphs "potential annual equivalent dose" and "potential annual effective dose" are doses that are not certain to occur.

Where:
(a) the potential total effective dose is less than 3 mSv; and
(b) the potential equivalent dose to the lens of the eye is less than 15 mSv; and
(c) the potential equivalent dose is less than 50 mSv

SEPA should not regard the possibility of significant harm as significant, irrespective of the probability of radiation dose being received.

Where:

(d) the potential total effective dose is greater than 100 mSv; or
(e) contact with contamination would result in a dose to the skin greater than 10 Gy in 1 hour;

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

If the conditions in (a) to (e) are not met, the probability of radiation dose being received needs to be taken into account. SEPA shall regard the possibility of significant harm as significant where:

(a) the potential total effective dose multiplied by the probability of exposure is greater than 3 mSv; or
(b) the potential equivalent dose to the lens of the eye multiplied by the probability of exposure is greater than 15 mSv; or
(c) the potential equivalent dose to the skin multiplied by the probability of exposure is greater than 50 mSv.

In order to provide the data necessary to allow SEPA to make an informed judgement on whether areas of Dalgety Bay should be considered as Radioactive Contaminated Land as defined in the Statutory Guidance, information was needed on:

1. The doses likely to occur;
2. Where radiation exposure is not certain to occur, the probability of such an occurrence;
3. The doses of lasting exposure when radiation exposure is not certain to occur.

2.2. Designation as Radioactive Contaminated Land

Irrespective of whether the information in this or other reports suggests that any of the various criteria are exceeded, SEPA must also consider whether sufficient management arrangements are in place prior to determining whether land should be designated as radioactive contaminated land.

2.3. Site Prioritisation

In 2008, following the issue of the Statutory Guidance for radioactive contamination land legislation, SEPA prioritised Dalgety Bay for assessment over other potential sites due to the:

- high hazards historically detected on the beach;
- relatively high numbers of radioactive sources recovered;
- absence of any detectable decline in the numbers of particles detected on the beach over time;
- lack of management arrangements; and
- lack of detailed knowledge about the contamination.

This assessment was undertaken in view of the historic information indicating the presence of a significant hazard from radioactive contamination at this site and the continued presence of high numbers of people using the area.

3. Background

3.1. Site Location and General Description

Dalgety Bay is located on the north side of the Firth of Forth in Fife, about 5km east of the Forth Rail Bridge (Grid Reference NT 165 833).

Dalgety Bay is part of the Firth of Forth Special Site of Scientific Interest (SSSI) and also part of the Firth of Forth RAMSAR sites.

The bay is approximately 400m wide by 500m long. At low tide the bay is exposed and reveals extensive mud flat habitat, interspersed with rocky outcrops. Along the southern margin of the bay is a pebble and shingle beach on which there is a collection of miscellaneous debris, including building materials (bricks and fragments of suspected asbestos sheeting), clinker, broken glass, pieces of broken plates, porcelain and general litter (Meehan, 2003). A foot path follows the bay round to the remains of St. Bridget's Kirk. Behind the western side of the mudflats is a wooded area (Ross Plantation) with grass, trees, shrubs and a network of paths. South east of this area, near the headland, is Dalgety Bay Sailing Club, which has a clubhouse and slipways for launching boats. There is a boat park for several dozen boats and a car park; the latter used by both Sailing Club members and the general public. Close by there is also an Inshore Rescue Boat station. Beyond the headland (heading south west) there is the New Harbour and the Pier of St. David's Bay, with another slipway for launching boats. The entire area is open to the public and is a favoured location for dog walking and for children to play (Heaton, 1996), although it is noted that the intertidal area is privately owned.

Main features of the bay:

- Includes site of Donibristle – New Harbour area
- Made ground – rock armour emplacement
- Slipways
- Boat storage area
- Mudflats – pipeline, coastal path, St. Bridget's Kirk, old landfills

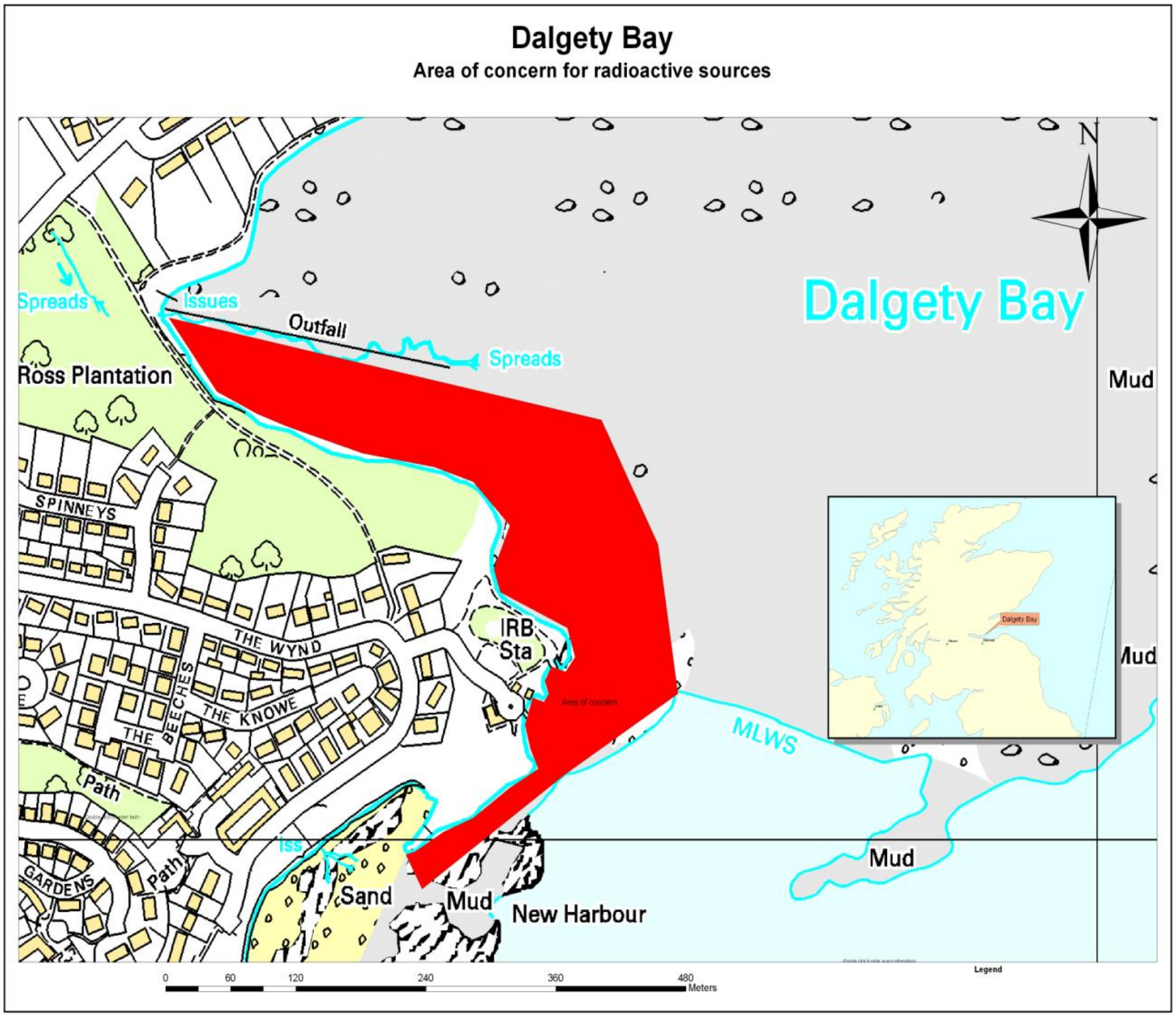

Figure 1: Dalgety Bay & main area of concern (an area of around 2.5 hectares)

3.2. Summary of previous surveys, 1997-2008

A brief summary of previous monitoring activities, conducted for SEPA, is detailed in our 2006 report (sepa.org.uk). Table 1 details the items recovered by SEPA surveys using different types of monitoring equipment during the period 1997 – 2008:

Table 1 Summary of previous surveys by SEPA

Year	Area Covered (hectares)	Items identified	Notes
2008	5	39	Point source activity up to 0.87 MBq radium activity
2006	1.1	37	2.2 MBq, 1,227 g total waste
2005	1.75	97	Range 30 – 2,350 cps (background 50-55 cps).
2002	1.75	93	The same approximate area as 2000
2000	1.6	80	Range 50 -11,000 cps, 15,000 at slipway (75 cps background)
1998	3	11	Not including slipways (pipeline area)
1997	8	120	Large area, including area near pipeline

3.3. 2006, 2009 and 2011 Assessments

The 2006, 2009 and 2011 assessments did not attempt to determine the source of the contamination, however, in undertaking the assessment and reviewing available information, SEPA has not identified any other potential source of radium other than activities associated with the previous Ministry of Defence (MoD) site at Dalgety Bay.

3.4. Signage and Current Interventions

Following the 2011 report, the wording, position and number of signs is currently under review. Following the detection of extremely high activity sources on a portion of the affected area, further restrictions were brought into place for that area which remain.

The MoD has committed to a monthly monitoring programme at Dalgety Bay using a system set to the detection criteria as specified by the Dalgety Bay Expert Group in December 2011. SEPA understands that the first use of this system which can achieve this criteria will be at the end of February 2012. Until robust information can be obtained on the number of sources which are or will be arising on the beach in the future, it is impossible to make accurate predictions on the potential future risks at Dalgety Bay.

4. Source selection for assessment

To provide SEPA with information on the current potential hazards to the public at Dalgety Bay, SEPA chose to undertake a characterisation of a sample of the point sources recovered by SEPA at Dalgety Bay in 2011. This included measurements of the physical size and activity together with the mass of these sources.

SEPA planned to characterise over 100 of the source recovered of which 30 were to be selected to provide information on the potential hazard. Information on those sources is available on our website, http://www.sepa.org.uk/radioactive_substances/ dalgety_bay.aspx.

5. Pathways of Exposure

5.1. Observations of habits

In 2009 SEPA observed that the area of Dalgety Bay from which sources have been recovered is used by bait diggers, sunbathers, dog walkers and horse riders. SEPA also investigated an enquiry relating to the regular visits of a class of nursery-school children to the area. Thus, we concluded, albeit from a short observation period, that the area is used by all age ranges undertaking a range of activities.

More recently, SEPA has been informed that "the foreshore in question has, since the 1970's, been actively used by members of the Sailing Club which has junior members and runs a youth week every year. In addition, "young children with parents who are members of the Sailing Club constantly use the area during the sailing season" (Dalgety Bay Community Council Chairman, September, 2010). SEPA has also been informed that there have been instances of people to remove material from beaches they visit as a souvenir of the visit.

Further radioactive artefacts recognisably originating from WWII aircraft were recovered by SEPA in 2011 (one being ¾ of an instrument dial); such items could be attractive to adults or children wishing to collect a souvenir from the beach. Other radioactive artefacts of potential interest to members of the public have been recovered on earlier surveys. Exposures via these pathways are not inadvertent exposures as assessed in our 2006 and 2009 and would be difficult to assess without specific habits data and knowledge of the potential number of artefacts. Estimating the probability of encounter for deliberate selection of contaminated items requires further study. Thus, SEPA reiterates the advice on the signs not to remove any items from the beach.

5.2. Repopulation rates

Previous monitoring and recovery exercises at Dalgety Bay have indicated that, within a year, contamination had returned to similar (re-populated) levels across the Dalgety Bay beach area (Table 1). In 2009, SEPA reported that over a small area some repopulation was occurring within a few days. The work undertaken by the MoD from 2008-2010 confirmed that repopulation with a period of months continues to occur and has estimated by "*extrapolating the measured average recontamination rate to future years results in an overall quota of 100 new sources being deposited on the site each year*". (Defence Estates 2010). During the autumn and winter of 2011 and 2012, SEPA's work indicated re-population of the beach by hundreds of new sources over that short period.

6. Analytical Results

6.1. Gamma-ray spectrometric analysis of point sources

Following selection, the sources characterised by the University of Stirling were analysed in a specially calibrated gamma spectrometer to determine the activity of key radionuclides. Results for the sources are available on our SEPA's website (www.sepa.org.uk). All positively detected radionuclides are reported.

6.2. Solubility testing of point sources

The solubility of the source determines the amount which can enter the body, and in the case of radium this is important as material entering the body from the gastrointestinal tract (GI tract) presents a greater hazard than that remaining in the GI tract. In order for SEPA to have sufficient data to assess the hazard against the criteria specified in the RCL Statutory Guidance, it was necessary to calculate the committed effective dose resulting from the ingestion of a point source. Consistent with the SEPA leachate (solubility) studies reported in 2011, SEPA conducted a specific experiment to mimic the acidic, enzymatic and temperature conditions of the stomach and small intestine.

The protocol for assessing this followed the same procedure as that undertaken for Dounreay particles by the Health Protection Agency for SEPA (Harrison et al., 2005)[4]. The composition of simulated stomach and small intestinal fluids used is shown in Tables 6 and 7.

Thirty point sources were selected for the solubility analysis. The results for these point sources are reported in the tables in Appendix 1, which show a range of solubilities from practically zero to 25%. The maximum value of this range is consistent with that reported in our 2011 work but higher than the maximum value reported in earlier work (SEPA, 2009), however the methodology was slightly different.

In total, 72 Dalgety Bay sources have now been subjected to solubility testing; 6 in 2006, 16 in 2009, 10 in 2010 and 10 reported in 2011 with a further 30 reported here. Overall, the solubility range is from effectively 0 to 25% and there is no apparent direct relationship between initial source activity and solubility.

[4] www.sepa.org.uk/radioactive_substances/publications/dounreay_reports

Table 2 Composition of the 'Stomach' solution[5]

Compound	**g dm^{-3}**	**mmol.dm^{-3}**
Calcium carbonate (Anhydr.)	0.200	Ca^{2+} 2.0
Magnesium carbonate	0.200	Mg^{2+} 2.1
Potassium chloride	0.670	K^+ 9.0; Cl^- 9.0
Sodium chloride	2.800	Na^+ 48.0; Cl^- 48.0
Sodium Lactate	0.250	Na^+ 2.2; $(lact)^-$ 2.2
Citric acid	0.040	2.1 x 10^{-1}
Urea	0.300	5.0
Pepsin (powder)	1.000	–

Table 3 Composition of the 'Small intestine'[5]

Compound	**g dm^{-3}**	**mmol.dm^{-3}**
Calcium carbonate (Anhydr.)	0.200	Ca^{2+} 2.0
Magnesium carbonate	0.200	Mg^{2+} 2.1
Potassium chloride	0.670	K^+ 9.0; Cl^- 9.0
Sodium chloride	2.800	Na^+ 48.0; Cl^- 48.0
Sodium Lactate	0.250	Na^+ 2.22; $(lact)^-$ 2.22
Citric acid	0.040	2.1 x 10^{-1}
Urea	0.800	13.3
Ox Gall	2.000	
Glucose	0.400	2.2
Pancreatin	2.000	–

Analyses of the leachates were performed using standard accredited gamma spectrometry techniques. The results are in tables 8, 9 10 and 11.

[5] The composition of the leachate solution was taken from that used for the Dounreay particles by the Health Protection Agency and reported in module 6 of SEPA's work (www.sepa.org.uk/radioactive_substances/publications/dounreay_reports.aspx)

7. Assessment

7.1. Nature of Hazard

This section details the potential hazard from radium point sources and draws on previous work conducted for the 2006 and 2009 assessments.

7.1.1. Physical Form

This section was detailed in our 2006 screening assessment report and is included here for completeness.

The radioactive contamination at Dalgety Bay is believed to have originated from historic MoD operations. The radium used by the MoD was primarily in luminescent paints. Radium-based luminescent paint was typically made by mixing a radium salt, zinc sulphide and a carrier material (typically varnish or lacquer).

Documents from Oak Ridge Associated Universities state that aircraft and ship instruments could contain 215 μg of radium per gram of material to conform to British Admiralty standards, while lower grade material used on watches, switch markings and other devices requiring less critical reading could contain between 50 and 100 μg of radium per gram of material. It is likely that in most cases radium sulphate was the form of radium used by the MoD in luminescent paints during the Second World War. However, radium chloride and radium bromide have been used in luminescent paints in the UK, both of which are very soluble (Ferguson, 1999).

7.1.2. The effect of burning

This section was detailed in our 2006 screening assessment report and is updated here.

At Dalgety Bay anecdotal evidence suggests that during the break-up of some aircraft it was common for at least some of the redundant luminescent materials to be burnt. It is suspected that the resultant ash and clinker produced from burning were either buried or spread on the ground surface.

Little information is available on the effect of a fire on the chemical reactions of radium sulphate. The temperature of open fires is unlikely to allow radium sulphate to form radium oxide; however, the burning of radium sulphate with other materials such as wood may allow the formation of radium sulphide.

When radium bromide is heated it is possible that this, together with other forms of radium, can be converted into carbonate.

It is therefore possible that the burning of luminised dials could have produced radium in a variety of chemical forms, with a range of potentials for absorption and uptake by man.

7.1.3. Point source size and fragmentation

The point sources recovered in 2008 were often associated with other material, which, where practicable, was separated and the radioactive component identified. In two cases, during the recovery of a point source, a number of discrete sources were recovered, which may imply some form of physical break-down in situ.

When a sample of the point sources was analysed in laboratory conditions some were found to consist of a number of lower activity point sources combined with inert material, which may indicate that radium is not uniformly distributed throughout a given source.

It may therefore be problematic to classify point sources according to physical size, for prospective radiological assessment, as some may be prone to break down, creating other potential exposure pathways, e.g. ingestion and inhalation may become possible.

7.2. Exposure Pathways

There are several potential exposure pathways to consider for the probability assessment both for human and non-human species, which were discussed in our 2009 report. These include inhalation, ingestion and skin contact.

7.2.1. Inhalation

Individuals could inhale an item that was (re)suspended in the air. The maximum diameter that can be inhaled is typically reported to be sub-millimeter generally in the order of a few tens of microns i.e. 0.01mm. Similar to the 2006 survey, the recorded dimensions of the items recovered from the beach were greater than 0.2 mm. However, the recent observations of friability suggest that initial source size merits further investigation. In addition, the Defence Estates report states that sources were recovered from an ashy layer around the slipways; this suggests it is possible that the burning of aircraft instruments may have produced sources similar in size to ash particles, which may therefore be inhalable. As the Defence Estates work was focussed on the detection of high activity sources, small sources of 1 kBq may not have been detected. However, given the area is wet for a large period of time and the ashy layer was reported to be present at depth it is unlikely that these would be inhalable at present.

7.2.2. Skin Contact (inadvertent)

It is possible that an item could come into contact with the skin, or could become trapped, for example, under nails. It was assumed in earlier work that there was no deliberate selection of radioactive items; however we now believe this cannot be ruled out[6]. As the rate of sediment mobilisation is unknown, it is assumed that all of the items detected could be available for skin contact irrespective of the depth of the recovered item.

There are several possible exposure pathways leading to direct skin contact, which have been studied in research conducted for SEPA by the Health Protection Agency and also in work done by the Dounreay Particles Advisory Group (DPAG).

- Under the fingernails

It is possible that a small item could be trapped underneath the fingernails. It is assumed that the maximum size of an item that could become trapped and remain there for a reasonable period of time (> 10 minutes) is 2 mm x 2 mm.

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[6] The presence of artefacts e.g. a dial and fuel gauge lever may mean that adults and children are attracted to these objects.

- On clothes

It is possible that an item could attach to an individual's clothes, whether by their sitting/lying on the beach or by the settling of material suspended in the air.

- In a shoe

It is possible that an item could become trapped inside an individual's shoe during a visit to the beach.

- Food Pathways

Potential exposure through ingestion of related foods has not been considered in this SEPA report[7].

7.2.3. Ingestion

It is assumed that the radioactive sources at Dalgety Bay are unlikely to be deliberately ingested. However, there are a number of potential scenarios which could result in inadvertent exposure, including: direct ingestion via an open mouth; or ingestion of material already on the body e.g. via biting of a fingernail which has material trapped beneath it; or via ingestion of material sticking to an object which has been placed in the mouth.

The Heaton report in 1996 indicated that around 10% of the material may be available for absorption if ingested. Our 2006 and 2009 reports indicated solubilities up to 15%. However our 2011 work, which used a more accurate representation of gut conditions, indicated that this value could be up to 25%. As this work was conducted on different samples it does not necessarily invalidate the earlier work, but data derived using a true gut solution are clearly preferable to a more basic representation. However, given that only 40 sources have been subjected to this 'true gut solution' it may be that the solubility could be greater in other samples. A value of 25% solubility as a true value of a soluble particle would have increased the potential doses calculated in 2006 and 2008.

The selection of sources for examination was done without regard to the location of recovery. It may also be worthwhile exploring whether sources recovered from a specific location had greater solubility than those recovered from elsewhere. However, the current small total sample size (n = 40) means that any observed correlation between different source locations and solubility is not statistically robust.

7.2.4. Deliberate encounter

In SEPA's 2009 and 2006 assessments, it was assumed that there was no possibility of preferential selection of contaminated items from the beach. However, the work undertaken by SEPA and on behalf of the MoD has shown that items are present at Dalgety Bay which retain the radium paint. It is therefore possible that people seeing an artefact, such as a luminised dial, may collect it as an object of interest.

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[7] Radiation exposure from foodstuffs is the responsibility of the Food Standards Agency (FSA). However, analysis of winkles, cockles and mussels from Dalgety Bay has not shown the presence of any point sources.

In 2011, SEPA was informed of at least one instance of people collecting stones or artefacts as souvenirs from the beach at Dalgety Bay. .One such person has told SEPA that they were walking the Fife coastal path and had not seen the signs advising people not to remove items from the beach, although when SEPA visited the area the signs were present. This may indicate that the current signs are not effective. It has been suggested that one possible reason for this is the large amount of information on the signs.

Some activities currently occurring at Dalgety Bay may result in a significant increase in the potential for exposures to occur than was assessed in SEPA's 2006 report. However, this is impossible to fully quantify without specific information on these activities and the number of artefacts which are contaminated and may be visually attractive.

7.2.5. Assessment of the probability of exposure

An assessment of the likelihood of an inadvertent exposure occurring was undertaken in the 2006 and 2009 assessments, however this has not been updated in the current assessment. The factors that present difficulties in providing an update to or any refinement of those assessments are:

- The need to consider the deliberate collection of items from the beach;
- The highly heterogeneous nature of the sources, in terms of physical size, activity and solubility;
- The limited proportion of the total number of sources recovered that have been fully characterised; and
- The lack of comprehensive site-specific information on public usage of the beach.

Without more information to better quantify these factors it is impossible to determine with any accuracy the potential for inadvertent exposure. A robust assessment of the probability of encounter should also consider the correction needed for non-detected point sources.

8. Hazard

SEPA's previous reports have provided details of the potential hazard of both high activity particles and potential low level widespread contamination. In 2009, SEPA concluded that discrete point sources of radioactive contamination could give rise to doses in excess of the relevant criteria, whilst the low level contamination of the environment at Dalgety Bay would not be high enough to trigger the relevant criteria in the guidance issued to SEPA by the Scottish Government for Radioactive Contaminated Land. SEPA has no reason to believe that the concentrations of homogenous low level contamination in the environment have changed since the 2009 report and for this reason it is not considered further in this assessment. Thus, for this assessment of hazard we have only considered the potential effects of encountering a radium source, either by inhalation, ingestion or skin contact.

8.1.1. Inhalation

In the 2009 report SEPA considered that there was a possibility that some of the Dalgety Bay sources could have been sufficiently small to be inhaled. Although point sources will physically break down in coastal environments such as that found at Dalgety Bay, the specific activity of some of the residual items may be greater after breakdown occurs, increasing the potential hazard such friable sources pose. The co-location of point sources at two positions during the SEPA 2008 survey suggests that such a breakdown may be occurring. Further evidence of this has been reported during the analysis of the high activity sources recovered from Dalgety Bay. SEPA needs to obtain further information on this potential pathway before updating its assessment and work is progressing on this matter.

8.1.2. Ingestion

Section 4 reports that thirty point sources were selected to determine the potential solubility. The methodology used to perform this experiment was the same as that used to assess the Dounreay particles and provides a more representative assessment of the gut conditions.

In the work reported here the solubility ranged from less than 1% to almost 25% which was comparable with results from the 2011 work. The existence of large numbers of higher activity sources with a solubility of around 25% would be of significant concern.

In the absence of actual data, we have also assumed that the ^{210}Po and ^{210}Pb are in secular equilibrium. That is to say, ^{210}Po is present with the same activity as its parent, ^{210}Pb. HPA have advised this is a reasonable approach. Given that it is believed the sources have been in their present form for around 50 years this would give sufficient time for the in growth of ^{210}Po. As the report on skin doses shows that the alpha emitting radionuclides have not been lost from the sources in any quantity since their creation, it would be prudent to assume that ^{210}Po would also not have been lost. If a precise value is required further analysis could be undertaken, however given the hetrogenous nature of the contamination this may not provide clarity on the hazards posed. The doses were derived using standard ICRP dose coefficients (ICRP 72). It is noted that in the 2010/11 analytical work the ^{210}Pb results are accredited.

The highest estimated dose from ingestion of one the point sources subjected to the solubility analysis, using the methodology adopted, was 205 mSv to a nominal 3 month old child, (which covers the age range of zero to one year) with contributions from ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi and ^{210}Po. For children of an age more likely to use the beach the maximum doses were 72 mSv (1 to 2 years old) and 39 mSv (2 to 7 years old; nominal 5 years old). These data should be considered as indicative rather than precise for reasons detailed in Sections 4 and 7.

8.1.3. Skin contact

The point sources recovered from Dalgety Bay spanned a wide range of mass, physical size and radioactive content. Potentially the dose rate to the surface of the skin could be very high and in the SEPA 2009 report, SEPA recommended specific work be undertaken to determine the realistic dose rate for exposure to the skin. This work was completed on a range of sources recovered from Dalgety Bay by SEPA in 2008 which is reported separately and available on the SEPA website (www.sepa.org.uk). In 2011, sources were recovered which appeared to be have significantly greater dose rates than that reported previously which would be consistent with a new ‘type’ of source being detected at Dalgety Bay. Until work on these sources can be undertaken SEPA recommend that people should continue to follow the advice on the signs in order to minimise the possibilities of exposures. Direct skin contact with some of the high activity sources, *viz*. 76MBq, would result in a radiation burn to the skin, which is why the area where such sources have been found remains restricted.

9. Probability of Encounter

Section 7 considered the difficulties in estimating the probability of an individual encountering a radioactive point source at Dalgety Bay. The Defence Estates report concluded that it expected that around 100 sources would populate the beach each year. However, work conducted in late 2011 and early 2012 strongly suggests a much higher repopulation rate. Consistent monitoring to the criteria set by the Dalgety Bay Expert Group in December 2011 (i.e. able to detect sources with activity as low as 20 kBq ^{226}Ra to a depth at least 10cm below surface) will be required to provide any meaningful estimate of the probability of encounter. In addition, further work is required to quantify the number of people deliberately picking things up from the beach which may be radioactive.

10. Discussion

Work undertaken by Defence Estates, SEPA and HPA over the past twenty years has shown that Dalgety Bay continues to be re-populated with radium sources, some of which have individual activities greater than one MBq Ra-226. Since September 2011, the number of and hazard posed by the sources cloase to the surface has increased significantly from that assessed previously, and further work is needed to quantify the residual numbers present and the hazard that these pose to the public.

Results from solubility experiments, using a realistic representation of gut fluids, have given an indication of the potential committed effective doses that could be incurred from the inadvertent ingestion of such sources. The highest hazard source tested in this way (0.05 MBq), which measured 1 x 0.5 mm could deliver around 205 mSv to a 3 month old infant. For consistency with earlier work we have limited the physical size of ingestion to 4 x 4 mm (Heaton 1998). However, it is clear that children and adults could inadvertently ingest much larger sources for example, the 20 mm diameter, 3 V lithium battery has been implicated in many of the complications from button battery ingestions by children less than 4 years of age[8]. Although it must be noted that such batteries are smooth, whereas, most of the recovered sources are irregular in shape.

From the sources selected for analysis the potential committed effective doses to a 1 year old and 5 year old child, (which covers the age range 1 - 2 years and 2 - 5 years), would be 72 and 39 mSv respectively, with the dose to an adult being 11 mSv. The doses for the second most hazardous source would be 129 mSv to a 3 month old infant, and 44 and 24 mSv to 1 year and 5 year old children respectively, with the dose to an adult being around 7 mSv. However, these should be considered indicative of the potential range of doses due to the highly heterogeneous nature of the contamination.

The solubility data obtained in this work is consistent with our 2011 work which showed that using a realistic representation of the gut fluid the solubility ranged from practically zero to around 25%.

This report presents a retrospective assessment of the potential risks from radioactive contamination at Dalgety Bay. It is clear that the contamination is highly heterogeneous in terms of size, radioactive content and occurrence and there are no robust correlations between activity or size and potential effective doses. However, the potential committed effective doses from ingestion are greatest to infants and it is known that nursery age children have used the beach.

10.1. Current intervention measures

In our 2011 report we recommended that the use of signs, in respect of location, number and wording, should be reconsidered which is currently being undertaken by DIO.

The series of monitoring and recovery programmes undertaken at Dalgety Bay have provided evidence of repopulation of the beach by point sources. It could be stated that these programmes provided some level of protection to the public as point sources were

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

removed. However, the monitoring work undertaken by SEPA in 2011 indicated any such protection offered by that programme was limited, due to a higher rate of repopulation than had previously been estimated. Therefore, unless carried out with sufficient frequency, it is unlikely that any monitoring and retrieval programme, in itself, would be an optimal intervention measure affording an appropriate level of public protection.

In 2011 SEPA recovered 4 extremely high activity sources from the beach at Dalgety Bay and it is unknown whether further such sources exist. In the absence of such information, SEPA have asked that the demarcated area where these sources were found remain and that people avoid using that area of the beach. It is now necessary that an appropriate investigation is undertaken and suitable remediation is adopted at Dalgety Bay. The confirmation of the 2011 work on doses from ingestion may also mean that further efforts are needed to mitigate the potential release of lower activity sources into the environment.

11. Conclusions

Work undertaken by SEPA and MoD has shown that many hundreds of radioactive sources have been present on the beach at Dalgety Bay. It has also shown that the beach area continues to be repopulated with high activity point sources once cleared Thus there remains a hazard to the public at Dalgety Bay from these point sources, and the total number of radioactive sources at Dalgety Bay remains unknown.

Based on the results of solubility analyses, indicative committed effective doses could range up to 205 mSv for a 3 month old infant, with the majority of the dose being from radium daughters. This work has confirmed that some of the sources recently recovered from Dalgety Bay have solubilities of up to 25%. The work reported in this report and in our 2006, 2009, 2011 reports has shown that several of the sources recovered from Dalgety Bay could give committed effective doses in excess of the relevant criteria, prescribed in issued to SEPA by the Scottish Government for Radioactive Contaminated Land.

Direct measurements of high activity point sources recently recovered from Dalgety Bay are also in excess of the relevant criteria specified in the Statutory Guidance. Measurements of lower activity sources also appear to result in greater potential skin doses than previously assessed which may mean that there is a greater potential for a skin burn if exposed. It is notable that it would be highly unlikely that anybody receiving such a burn would attribute it to an exposure at Dalgety Bay.

The potential committed effective doses from Dalgety Bay point sources remain significant. Any potential effects (e.g. cancer) resulting from an exposure may take many years to be expressed and be unlikely to be easily attributable to radiation exposure from a visit to Dalgety Bay.

The locations and suitability of the current signage, as an intervention measure, are being reviewed. Given the numbers of people using the beach there is also a need for an ongoing monitoring and recovery programme to reduce the hazard present on the beach. In the longer term, as radium has a half life of 1600 years, a programme of work to determine the primary source of the contamination at Dalgety Bay beach and isolate it from the environment may be the only manner in which the level of contamination can be reduced to a negligible level where no further interventions are needed. SEPA requested that the MoD develop such a plan by end February 2012 which is available on our website www.sepa.org.uk.

The absence of any programme to isolate the radioactive contamination at source will mean that sources which pose a significant hazard to health will continue to be present on the beach at Dalgety Bay. It is concluded that a programme to identify the primary source or sources is needed to reduce the number and hazard of these sources to the public using the beach at Dalgety Bay.

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Annex 1. Data Tables

Table 1: **Original Particle Activity (Bq)**

Source ID	Dimension X mm	Dimension Y mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 12-33	0.5	1.0	5.10E+04	2.53E+01	4.85E+04	2.38E+01	5.04E+04	2.37E+01	4.80E+04	2.50E+01
DBP 15-12	4.0	5.0	3.44E+04	2.49E+01	3.67E+04	2.37E+01	3.66E+04	2.36E+01	2.93E+04	2.50E+01
DBP 11-12	1.5	1.5	4.53E+04	2.47E+01	4.56E+04	2.37E+01	4.88E+04	2.36E+01	4.12E+04	2.43E+01
DBP 12-18	1.0	1.0	2.08E+04	2.56E+01	2.14E+04	2.38E+01	2.11E+04	2.37E+01	1.76E+04	2.50E+01
DBP 14-34	2.0	2.0	1.82E+04	2.60E+01	1.92E+04	2.38E+01	1.99E+04	2.38E+01	1.80E+04	2.51E+01
DBP 09-02	2.0	2.5	1.68E+04	2.51E+01	1.76E+04	2.38E+01	1.84E+04	2.37E+01	1.55E+04	2.52E+01
DBP 06-19	2.0	2.5	1.38E+04	2.51E+01	1.39E+04	2.38E+01	1.46E+04	2.37E+01	1.13E+04	2.51E+01
DBP 04-21	1.5	2.0	1.37E+04	2.63E+01	1.38E+04	2.38E+01	1.39E+04	2.38E+01	1.28E+04	2.53E+01
DBP 07-12	1.0	1.0	1.29E+04	2.63E+01	1.30E+04	2.38E+01	1.34E+04	2.37E+01	1.21E+04	2.52E+01
DBP 12-15	3.5	5.5	1.69E+04	2.50E+01	1.59E+04	2.37E+01	1.65E+04	2.36E+01	1.40E+04	2.44E+01
DBP 11-18	3.0	3.0	1.33E+04	2.56E+01	1.41E+04	2.38E+01	1.40E+04	2.37E+01	1.26E+04	2.54E+01
DBP 14-30	1.0	1.0	1.12E+04	2.55E+01	1.14E+04	2.37E+01	1.16E+04	2.36E+01	1.12E+04	2.44E+01
DBP 13-16	3.0	4.0	1.02E+04	2.35E+01	1.09E+04	2.36E+01	1.14E+04	2.35E+01	7.32E+03	2.36E+01
DBP 04-03	3.0	4.5	9.59E+03	2.94E+01	1.08E+04	2.40E+01	1.09E+04	2.41E+01	9.88E+03	2.69E+01
DBP 10-23	2.0	3.0	1.12E+04	2.69E+01	1.27E+04	2.38E+01	1.33E+04	2.38E+01	1.06E+04	2.55E+01
DBP 13-09	1.0	1.5	7.53E+03	2.43E+01	7.88E+03	2.37E+01	8.13E+03	2.36E+01	7.21E+03	2.41E+01
DBP 12-21	1.5	2.0	6.64E+03	2.95E+01	6.86E+03	2.40E+01	7.36E+03	2.42E+01	5.44E+03	2.87E+01
DBP 07-04	1.0	1.0	6.59E+03	2.57E+01	6.74E+03	2.38E+01	6.79E+03	2.37E+01	6.28E+03	2.52E+01
DBP 14-03	3.5	5.0	6.74E+03	2.53E+01	7.33E+03	2.37E+01	7.25E+03	2.37E+01	6.18E+03	2.49E+01
DBP 16-45	2.0	3.0	6.66E+03	2.38E+01	7.81E+03	2.36E+01	8.33E+03	2.35E+01	1.44E+03	2.55E+01
DBP 14-07	3.5	3.5	6.33E+03	2.46E+01	6.40E+03	2.37E+01	6.84E+03	2.36E+01	4.86E+03	2.42E+01
DBP 03-05	0.5	1.5	4.53E+03	2.60E+01	4.56E+03	2.38E+01	4.73E+03	2.37E+01	3.36E+03	2.59E+01
DBP 15-01	2.0	2.5	5.33E+03	2.37E+01	5.51E+03	2.36E+01	5.64E+03	2.35E+01	4.62E+03	2.37E+01
DBP 11-03	1.5	2.5	5.11E+03	2.51E+01	5.17E+03	2.37E+01	5.32E+03	2.36E+01	4.34E+03	2.44E+01

Source ID	Dimension X mm	Dimension Y mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 13-31	1.0	1.0	2.91E+03	2.55E+01	3.15E+03	2.38E+01	3.34E+03	2.37E+01	2.98E+03	2.48E+01
DBP 11-09	2.0	3.0	2.32E+03	2.38E+01	2.46E+03	2.36E+01	2.54E+03	2.35E+01	2.18E+03	2.36E+01
DBP 09-32	<1	1.0	2.64E+03	2.67E+01	2.78E+03	2.39E+01	2.83E+03	2.39E+01	2.75E+03	2.64E+01
DBP 11-25	0.5	1.0	2.60E+03	2.72E+01	2.32E+03	2.41E+01	2.51E+03	2.40E+01	2.37E+03	2.63E+01
DBP 04-16	<1	<1	2.04E+03	2.90E+01	2.06E+03	2.41E+01	2.16E+03	2.40E+01	1.88E+03	2.84E+01
DBP 11-13	1.0	2.0	1.94E+03	2.68E+01	2.02E+03	2.39E+01	2.04E+03	2.39E+01	1.69E+03	2.63E+01
BLANK	0.0	0.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 2: **Total Activity in Simulated Stomach Acid (Bq)**

Source ID	**Dimension X mm**	**Dimension Y mm**	**Ra 226**	% uncertainty	**Pb 214**	% uncertainty	**Bi 214**	% uncertainty	**Pb 210**	% uncertainty
DBP 12-33	0.5	1.0	2710.7	6.3	72.2	8.4	96.4	7.9	5605.5	6.6
DBP 15-12	4.0	5.0	181.1	9.1	4.2	20.0	0.1	0.0	165.2	10.7
DBP 11-12	1.5	1.5	3034.3	5.9	129.3	7.9	185.2	7.6	3313.5	6.3
DBP 12-18	1.0	1.0	469.7	6.8	27.4	11.7	47.5	10.6	425.5	7.3
DBP 14-34	2.0	2.0	12.3	34.1	0.2	0.0	0.3	0.0	18.7	26.4
DBP 09-02	2.0	2.5	2.2	38.4	0.1	0.0	0.1	0.0	2.8	29.4
DBP 06-19	2.0	2.5	41.8	10.7	15.7	15.0	20.0	17.1	75.8	8.7
DBP 04-21	1.5	2.0	12.9	16.9	0.9	32.5	0.1	0.0	63.8	8.9
DBP 07-12	1.0	1.0	308.8	8.7	11.1	15.5	9.0	20.6	325.8	9.4
DBP 12-15	3.5	5.5	133.7	8.3	10.0	10.5	9.1	11.8	135.4	9.4
DBP 11-18	3.0	3.0	9.8	10.9	1.0	13.5	1.0	15.2	23.7	7.4
DBP 14-30	1.0	1.0	790.6	6.3	212.9	6.8	197.3	6.4	978.3	6.7
DBP 13-16	3.0	4.0	15.5	13.1	4.7	9.1	4.5	8.6	21.1	10.2
DBP 04-03	3.0	4.5	442.9	6.1	128.0	6.6	118.2	6.1	348.6	6.5
DBP 10-23	2.0	3.0	11.5	11.1	2.8	9.0	2.7	9.3	6.0	16.8
DBP 13-09	1.0	1.5	1186.0	6.1	374.3	6.8	348.9	6.2	652.6	6.7
DBP 12-21	1.5	2.0	63.7	8.4	22.9	7.1	21.3	6.8	154.2	6.8
DBP 07-04	1.0	1.0	8.5	16.2	3.4	9.3	3.1	10.4	7.3	18.4
DBP 14-03	3.5	5.0	256.2	7.1	96.1	7.0	90.7	6.5	211.3	7.8
DBP 16-45	2.0	3.0	83.6	7.1	31.1	6.9	29.3	6.4	91.9	7.3
DBP 14-07	3.5	3.5	304.9	6.3	132.3	6.8	124.4	6.3	258.7	6.8
DBP 03-05	0.5	1.5	139.3	6.2	61.1	6.6	56.7	6.0	154.8	6.5
DBP 15-01	2.0	2.5	278.1	5.9	126.0	6.5	115.5	5.9	290.8	6.3
DBP 11-03	1.5	2.5	17.7	10.9	9.4	7.5	8.8	7.7	26.1	9.9
DBP 13-31	1.0	1.0	33.9	9.5	16.8	7.2	16.5	6.7	29.3	9.8
DBP 11-09	2.0	3.0	12.9	18.4	6.9	8.7	6.4	9.3	11.5	21.6
DBP 09-32	<1	1.0	0.6	0.0	0.1	0.0	0.1	0.0	4.7	28.4
DBP 11-25	0.5	1.0	26.8	9.0	13.7	7.1	12.4	6.8	39.8	7.9

Source ID	**Dimension X mm**	**Dimension Y mm**	**Ra 226**	% uncertainty	**Pb 214**	% uncertainty	**Bi 214**	% uncertainty	**Pb 210**	% uncertainty
DBP 04-16	<1	<1	492.3	6.3	288.3	6.8	269.2	6.2	403.9	7.0
DBP 11-13	1.0	2.0	110.7	6.7	67.1	6.6	62.3	6.1	82.4	7.3
BLANK			0.7	55.7	0.0	0.0	0.0	0.0	0.2	0.0

Table 3: **Percentage in Simulated Stomach Acid Leachate (percent)**

Source ID	Dimension X mm	Dimension Y mm	Ra 226	Range min	Range Max	Pb 214	Range min	Range Max	Bi 214	Range min	Range Max	Pb 210	Range min	Range Max
DBP 12-33	0.5	1	**5.32**	3.98	7.57	**0.15**	0.11	0.21	**0.19**	0.14	0.27	**11.68**	8.72	16.61
DBP 15-12	4	5	**0.53**	0.38	0.76	**0.01**	0.01	0.02	**0.00**	0.00	0.00	**0.56**	0.40	0.83
DBP 11-12	1.5	1.5	**6.70**	5.05	9.42	**0.28**	0.21	0.40	**0.38**	0.28	0.53	**8.04**	6.06	11.29
DBP 12-18	1	1	**2.26**	1.68	3.25	**0.13**	0.09	0.19	**0.22**	0.16	0.33	**2.41**	1.79	3.45
DBP 14-34	2	2	**0.07**	0.04	0.12	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.10**	0.06	0.18
DBP 09-02	2	2.5	**0.01**	0.01	0.02	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.02**	0.01	0.03
DBP 06-19	2	2.5	**0.30**	0.22	0.45	**0.11**	0.08	0.17	**0.14**	0.09	0.21	**0.67**	0.49	0.97
DBP 04-21	1.5	2	**0.09**	0.06	0.15	**0.01**	0.00	0.01	**0.00**	0.00	0.00	**0.50**	0.36	0.73
DBP 07-12	1	1	**2.40**	1.73	3.54	**0.09**	0.06	0.13	**0.07**	0.04	0.11	**2.70**	1.95	3.94
DBP 12-15	3.5	5.5	**0.79**	0.58	1.14	**0.06**	0.05	0.09	**0.06**	0.04	0.08	**0.97**	0.71	1.40
DBP 11-18	3	3	**0.07**	0.05	0.11	**0.01**	0.00	0.01	**0.01**	0.01	0.01	**0.19**	0.14	0.27
DBP 14-30	1	1	**7.04**	5.26	10.03	**1.86**	1.40	2.61	**1.70**	1.29	2.36	**8.77**	6.57	12.38
DBP 13-16	3	4	**0.15**	0.11	0.23	**0.04**	0.03	0.06	**0.04**	0.03	0.06	**0.29**	0.21	0.41
DBP 04-03	3	4.5	**4.62**	3.35	6.94	**1.19**	0.89	1.67	**1.09**	0.82	1.52	**3.53**	2.60	5.15
DBP 10-23	2	3	**0.10**	0.07	0.16	**0.02**	0.02	0.03	**0.02**	0.01	0.03	**0.06**	0.04	0.09
DBP 13-09	1	1.5	**15.74**	11.89	22.07	**4.75**	3.58	6.65	**4.29**	3.26	5.96	**9.05**	6.81	12.73
DBP 12-21	1.5	2	**0.96**	0.68	1.48	**0.33**	0.25	0.47	**0.29**	0.22	0.41	**2.83**	2.05	4.24
DBP 07-04	1	1	**0.13**	0.09	0.20	**0.05**	0.04	0.07	**0.05**	0.03	0.07	**0.12**	0.08	0.18
DBP 14-03	3.5	5	**3.80**	2.82	5.45	**1.31**	0.99	1.84	**1.25**	0.95	1.74	**3.42**	2.52	4.91
DBP 16-45	2	3	**1.26**	0.94	1.76	**0.40**	0.30	0.56	**0.35**	0.27	0.49	**6.40**	4.73	9.21
DBP 14-07	3.5	3.5	**4.81**	3.62	6.78	**2.07**	1.56	2.89	**1.82**	1.38	2.53	**5.32**	3.99	7.50
DBP 03-05	0.5	1.5	**3.08**	2.29	4.42	**1.34**	1.01	1.88	**1.20**	0.91	1.67	**4.61**	3.43	6.62
DBP 15-01	2	2.5	**5.22**	3.97	7.25	**2.28**	1.73	3.19	**2.05**	1.56	2.83	**6.29**	4.77	8.76
DBP 11-03	1.5	2.5	**0.35**	0.25	0.51	**0.18**	0.14	0.25	**0.17**	0.12	0.23	**0.60**	0.44	0.88
DBP 13-31	1	1	**1.16**	0.84	1.71	**0.53**	0.40	0.75	**0.49**	0.37	0.69	**0.98**	0.71	1.43
DBP 11-09	2	3	**0.56**	0.37	0.86	**0.28**	0.21	0.40	**0.25**	0.19	0.36	**0.53**	0.34	0.84
DBP 09-32	<1	1	**0.02**	0.02	0.03	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.17**	0.10	0.30
DBP 11-25	0.5	1	**1.03**	0.74	1.54	**0.59**	0.44	0.83	**0.49**	0.37	0.70	**1.68**	1.22	2.45

Source ID	Dimension X mm	Dimension Y mm	Ra 226	Range min	Range Max	Pb 214	Range min	Range Max	Bi 214	Range min	Range Max	Pb 210	Range min	Range Max
DBP 04-16	<1	<1	**24.17**	17.55	36.19	**14.00**	10.52	19.68	**12.45**	9.41	17.41	**21.43**	15.52	32.02
DBP 11-13	1	2	**5.71**	4.20	8.32	**3.32**	2.50	4.65	**3.05**	2.31	4.25	**4.88**	3.58	7.10
BLANK	0	0												

Table 4: **Particle Activity following lower intestine Digestion (Bq)**

Source ID	**Dimension X mm**	**Dimension Y mm**	**Ra 226**	% uncertainty	**Pb 214**	% uncertainty	**Bi 214**	% uncertainty	**Pb 210**	% uncertainty
DBP 12-33	0.5	1	45752	24	42742	24	44473	24	39261	24
DBP 15-12	4	5	33987	24	35601	24	36578	23	27714	24
DBP 11-12	1.5	1.5	39708	24	40927	24	42998	24	33580	24
DBP 12-18	1	1	18970	24	19655	24	20580	24	16715	24
DBP 14-34	2	2	18835	24	18572	24	19549	24	17331	24
DBP 09-02	2	2.5	14475	25	15749	24	16323	24	13225	25
DBP 06-19	2	2.5	14045	26	13838	24	13927	24	11575	25
DBP 04-21	1.5	2	12653	25	13349	24	13551	24	12513	25
DBP 07-12	1	1	12513	26	12394	24	12698	24	11315	25
DBP 12-15	3.5	5.5	14695	25	14944	24	15721	24	11107	25
DBP 11-18	3	3	13384	25	13962	24	14236	24	11650	24
DBP 14-30	1	1	9857	25	9960	24	10301	24	9970	25
DBP 13-16	3	4	10387	24	10852	24	11287	24	7544	24
DBP 04-03	3	4.5	9728	25	9832	24	10167	24	8957	25
DBP 10-23	2	3	12202	25	12747	24	13241	24	11425	25
DBP 13-09	1	1.5	6061	27	6293	24	6365	24	6200	25
DBP 12-21	1.5	2	6456	25	6594	24	6832	24	5748	25
DBP 07-04	1	1	6231	25	6613	24	6810	24	6679	24
DBP 14-03	3.5	5	6388	26	6960	24	6992	24	6079	25
DBP 16-45	2	3	7951	25	8075	24	8488	24	4156	26
DBP 14-07	3.5	3.5	5693	25	5970	24	6383	24	4714	25
DBP 03-05	0.5	1.5	4304	26	4325	24	4467	24	3092	26
DBP 15-01	2	2.5	5155	25	5191	24	5383	24	4756	25
DBP 11-03	1.5	2.5	5042	26	5042	24	5114	24	4243	25
DBP 13-31	1	1	2892	25	3049	24	3109	24	2964	25
DBP 11-09	2	3	2276	24	2413	24	2515	24	2063	24
DBP 09-32	<1	1	2796	26	2724	24	2785	24	2610	25

Source ID	Dimension X mm	Dimension Y mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 11-25	0.5	1	2163	27	2292	24	2441	24	2197	26
DBP 04-16	<1	<1	1411	27	1300	24	1321	24	1241	27
DBP 11-13	1	2	1695	27	1848	24	1925	24	1636	26
BLANK	0	0	13	0	3	0	4	0	11	0

Table 5: **Lower Intestine Activity (Bq)**

Source ID	Min mm	Max mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 12-33	0.5	1.0	2.961E+01	8.77	2.076E+00	13.28	2.016E+00	13.97	6.574E-01	
DBP 15-12	4.0	5.0	5.943E-01		7.050E-02		8.940E-02		4.949E-01	
DBP 11-12	1.5	1.5	5.206E+01	8.37	1.328E+01	7.56	1.205E+01	7.77	1.089E+01	23.42
DBP 12-18	1.0	1.0	6.887E-01		1.337E+00	15.57	1.283E+00	17.29	5.796E-01	
DBP 14-34	2.0	2.0	4.206E-01		8.760E-02		8.540E-02		3.231E-01	
DBP 09-02	2.0	2.5	3.063E+00	27.33	6.570E-02		7.280E-02		4.533E-01	
DBP 06-19	2.0	2.5	4.593E-01		6.440E-02		5.767E-01	30.48	4.682E-01	
DBP 04-21	1.5	2.0	7.853E-01		8.640E-02		9.270E-02		6.927E-01	
DBP 07-12	1.0	1.0	7.716E+00	16.79	6.789E+00	7.67	6.148E+00	7.26	3.085E+00	35.29
DBP 12-15	3.5	5.5	4.369E-01		6.110E-02		6.800E-02		4.210E-01	
DBP 11-18	3.0	3.0	5.426E-01		6.290E-02		9.370E-02		5.694E-01	
DBP 14-30	1.0	1.0	2.305E+00	54.80	1.211E+00	16.52	8.960E-02		3.997E-01	
DBP 13-16	3.0	4.0	9.766E+00	14.89	1.885E+00	11.65	1.604E+00	14.15	2.523E+00	42.71
DBP 04-03	3.0	4.5	1.059E+00		9.670E-02		1.040E-01		8.518E-01	
DBP 10-23	2.0	3.0	3.571E+00	22.41	5.300E-02		6.260E-02		4.298E-01	
DBP 13-09	1.0	1.5	5.907E+00	26.42	3.808E+00	9.74	3.977E+00	10.57	4.777E-01	
DBP 12-21	1.5	2.0	6.808E-01		1.466E+00	18.42	9.610E-02		5.724E-01	
DBP 07-04	1.0	1.0	8.861E-01		8.580E-02		1.090E-01		6.248E-01	
DBP 14-03	3.5	5.0	8.312E+00	14.38	7.890E-02		8.370E-02		4.802E-01	
DBP 16-45	2.0	3.0	3.697E+00	21.19	6.350E-02		4.980E-02		3.965E-01	
DBP 14-07	3.5	3.5	6.458E-01		8.540E-01	27.63	9.180E-02		5.965E-01	
DBP 03-05	0.5	1.5	5.046E-01		6.570E-02		7.110E-02		4.473E-01	
DBP 15-01	2.0	2.5	6.456E+00	13.88	4.719E+00	7.47	3.580E-02		2.732E-01	
DBP 11-03	1.5	2.5	7.951E-01	50.79	3.240E-02		3.780E-02		2.415E-01	
DBP 13-31	1.0	1.0	2.902E-01		3.720E-02		5.880E-02		2.820E-01	
DBP 11-09	2.0	3.0	2.959E-01		3.530E-02		3.770E-02		2.560E-01	
DBP 09-32	<1	1.0	3.142E-01		3.980E-02		5.620E-02		1.350E-01	
DBP 11-25	0.5	1.0	2.668E-01		4.660E-02		3.970E-02		1.994E-01	

Source ID	Min mm	Max mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 04-16	<1	<1	2.355E+00	23.74	1.547E+00	9.26	1.394E+00	9.99	3.176E-01	
DBP 11-13	1.0	2.0	2.771E-01	0.00	3.840E-02		4.680E-02		2.419E-01	
BLANK	0.0	0.0	2.560E-01		3.470E-02		3.500E-02		1.988E-01	

Table 6: **Percentage in Simulated Lower Intestine Leachate (percent of original activity)**

Source ID	**Dimension (mm)**		**Ra 226**	Range min	Range Max	**Pb 214**	Range min	Range Max	**Bi 214**	Range min	Range Max	**Pb 210**	Range min	Range Max
	X	**Y**												
DBP 12-33	0.5	1.0	**5.81E-02**	4.23E-02	8.46E-02	**4.28E-03**	3.00E-03	6.36E-03	**4.00E-03**	2.78E-03	5.97E-03	**1.37E-03**	1.10E-03	1.83E-03
DBP 15-12	4.0	5.0	**1.73E-03**	1.38E-03	2.30E-03	**1.92E-04**	1.55E-04	2.52E-04	**2.44E-04**	1.98E-04	3.20E-04	**1.69E-03**	1.35E-03	2.25E-03
DBP 11-12	1.5	1.5	**1.15E-01**	8.44E-02	1.65E-01	**2.91E-02**	2.17E-02	4.10E-02	**2.47E-02**	1.84E-02	3.48E-02	**2.64E-02**	1.63E-02	4.31E-02
DBP 12-18	1.0	1.0	**3.32E-03**	2.64E-03	4.46E-03	**6.25E-03**	4.26E-03	9.48E-03	**6.07E-03**	4.06E-03	9.33E-03	**3.28E-03**	2.63E-03	4.38E-03
DBP 14-34	2.0	2.0	**2.31E-03**	1.83E-03	3.12E-03	**4.55E-04**	3.68E-04	5.98E-04	**4.29E-04**	3.46E-04	5.62E-04	**1.79E-03**	1.43E-03	2.39E-03
DBP 09-02	2.0	2.5	**1.83E-02**	1.06E-02	3.11E-02	**3.73E-04**	3.01E-04	4.89E-04	**3.96E-04**	3.20E-04	5.20E-04	**2.92E-03**	2.33E-03	3.90E-03
DBP 06-19	2.0	2.5	**3.32E-03**	2.65E-03	4.43E-03	**4.65E-04**	3.76E-04	6.10E-04	**3.95E-03**	2.22E-03	6.75E-03	**4.14E-03**	3.31E-03	5.53E-03
DBP 04-21	1.5	2.0	**5.74E-03**	4.54E-03	7.79E-03	**6.28E-04**	5.07E-04	8.24E-04	**6.68E-04**	5.39E-04	8.76E-04	**5.41E-03**	4.31E-03	7.24E-03
DBP 07-12	1.0	1.0	**6.00E-02**	3.95E-02	9.50E-02	**5.21E-02**	3.89E-02	7.36E-02	**4.60E-02**	3.45E-02	6.47E-02	**2.55E-02**	1.32E-02	4.61E-02
DBP 12-15	3.5	5.5	**2.58E-03**	2.07E-03	3.44E-03	**3.84E-04**	3.10E-04	5.03E-04	**4.13E-04**	3.34E-04	5.40E-04	**3.01E-03**	2.42E-03	3.99E-03
DBP 11-18	3.0	3.0	**4.08E-03**	3.25E-03	5.48E-03	**4.47E-04**	3.61E-04	5.87E-04	**6.67E-04**	5.39E-04	8.74E-04	**4.53E-03**	3.62E-03	6.08E-03
DBP 14-30	1.0	1.0	**2.05E-02**	7.39E-03	4.26E-02	**1.06E-02**	7.15E-03	1.62E-02	**7.71E-04**	6.23E-04	1.01E-03	**3.58E-03**	2.88E-03	4.74E-03
DBP 13-16	3.0	4.0	**9.59E-02**	6.61E-02	1.44E-01	**1.73E-02**	1.24E-02	2.53E-02	**1.41E-02**	9.80E-03	2.10E-02	**3.44E-02**	1.60E-02	6.43E-02
DBP 04-03	3.0	4.5	**1.10E-02**	8.53E-03	1.56E-02	**8.97E-04**	7.23E-04	1.18E-03	**9.55E-04**	7.70E-04	1.26E-03	**8.62E-03**	6.79E-03	1.18E-02
DBP 10-23	2.0	3.0	**3.20E-02**	1.96E-02	5.35E-02	**4.18E-04**	3.38E-04	5.48E-04	**4.72E-04**	3.81E-04	6.19E-04	**4.04E-03**	3.22E-03	5.42E-03
DBP 13-09	1.0	1.5	**7.84E-02**	4.64E-02	1.31E-01	**4.83E-02**	3.53E-02	6.95E-02	**4.89E-02**	3.54E-02	7.08E-02	**6.63E-03**	5.34E-03	8.73E-03
DBP 12-21	1.5	2.0	**1.02E-02**	7.91E-03	1.45E-02	**2.14E-02**	1.41E-02	3.33E-02	**1.31E-03**	1.05E-03	1.72E-03	**1.05E-02**	8.17E-03	1.47E-02
DBP 07-04	1.0	1.0	**1.34E-02**	1.07E-02	1.81E-02	**1.27E-03**	1.03E-03	1.67E-03	**1.60E-03**	1.30E-03	2.10E-03	**9.96E-03**	7.95E-03	1.33E-02
DBP 14-03	3.5	5.0	**1.23E-01**	8.42E-02	1.89E-01	**1.08E-03**	8.70E-04	1.41E-03	**1.15E-03**	9.34E-04	1.51E-03	**7.77E-03**	6.22E-03	1.03E-02
DBP 16-45	2.0	3.0	**5.55E-02**	3.53E-02	8.82E-02	**8.13E-04**	6.58E-04	1.06E-03	**5.98E-04**	4.84E-04	7.81E-04	**2.76E-02**	2.20E-02	3.70E-02
DBP 14-07	3.5	3.5	**1.02E-02**	8.18E-03	1.35E-02	**1.33E-02**	7.81E-03	2.23E-02	**1.34E-03**	1.09E-03	1.76E-03	**1.23E-02**	9.87E-03	1.62E-02
DBP 03-05	0.5	1.5	**1.11E-02**	8.85E-03	1.51E-02	**1.44E-03**	1.16E-03	1.89E-03	**1.50E-03**	1.22E-03	1.97E-03	**1.33E-02**	1.06E-02	1.80E-02
DBP 15-01	2.0	2.5	**1.21E-01**	8.44E-02	1.81E-01	**8.56E-02**	6.41E-02	1.20E-01	**6.34E-04**	5.14E-04	8.29E-04	**5.91E-03**	4.78E-03	7.74E-03
DBP 11-03	1.5	2.5	**1.56E-02**	6.12E-03	3.13E-02	**6.26E-04**	5.06E-04	8.21E-04	**7.11E-04**	5.75E-04	9.31E-04	**5.57E-03**	4.48E-03	7.36E-03
DBP 13-31	1.0	1.0	**9.96E-03**	7.93E-03	1.34E-02	**1.18E-03**	9.54E-04	1.55E-03	**1.76E-03**	1.42E-03	2.31E-03	**9.45E-03**	7.57E-03	1.26E-02
DBP 11-09	2.0	3.0	**1.28E-02**	1.03E-02	1.67E-02	**1.44E-03**	1.16E-03	1.88E-03	**1.48E-03**	1.20E-03	1.94E-03	**1.18E-02**	9.52E-03	1.54E-02
DBP 09-32	<1	1.0	**1.19E-02**	9.39E-03	1.62E-02	**1.43E-03**	1.16E-03	1.88E-03	**1.98E-03**	1.60E-03	2.61E-03	**4.91E-03**	3.89E-03	6.68E-03

Source ID	Dimension (mm)		Ra 226	Range min	Range Max	Pb 214	Range min	Range Max	Bi 214	Range min	Range Max	Pb 210	Range min	Range Max
DBP 11-25	0.5	1.0	**1.03E-02**	8.07E-03	1.41E-02	**2.01E-03**	1.62E-03	2.65E-03	**1.58E-03**	1.28E-03	2.08E-03	**8.40E-03**	6.65E-03	1.14E-02
DBP 04-16	<1	<1	**1.16E-01**	6.83E-02	2.01E-01	**7.51E-02**	5.49E-02	1.08E-01	**6.45E-02**	4.68E-02	9.34E-02	**1.69E-02**	1.31E-02	2.35E-02
DBP 11-13	1.0	2.0	**1.43E-02**	1.13E-02	1.95E-02	**1.90E-03**	1.53E-03	2.49E-03	**2.29E-03**	1.85E-03	3.01E-03	**1.43E-02**	1.13E-02	1.94E-02

Table 7 **Total Activity in Stomach Solutions (Stomach Acid + Lower Intestine) Activity (Bq)**

Source ID	Min mm	Max mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 12-33	0.5	1.0	2740.3	6	74.3	8	98.4	8	5606.2	7
DBP 15-12	4.0	5.0	181.7	9	4.2	20	0.2	0	165.6	11
DBP 11-12	1.5	1.5	3086.4	6	142.6	7	197.2	7	3324.4	6
DBP 12-18	1.0	1.0	470.4	7	28.7	11	48.8	10	426.1	7
DBP 14-34	2.0	2.0	12.7	33	0.2	0	0.4	0	19.0	26
DBP 09-02	2.0	2.5	5.3	23	0.1	0	0.1	0	3.3	25
DBP 06-19	2.0	2.5	42.2	11	15.8	15	20.5	17	76.3	9
DBP 04-21	1.5	2.0	13.6	16	1.0	30	0.2	0	64.5	9
DBP 07-12	1.0	1.0	316.6	9	17.9	10	15.2	13	328.9	9
DBP 12-15	3.5	5.5	134.1	8	10.0	10	9.2	12	135.9	9
DBP 11-18	3.0	3.0	10.4	10	1.1	13	1.1	14	24.3	7
DBP 14-30	1.0	1.0	792.9	6	214.1	7	197.4	6	978.7	7
DBP 13-16	3.0	4.0	25.3	10	6.6	7	6.1	7	23.6	10
DBP 04-03	3.0	4.5	444.0	6	128.0	7	118.3	6	349.4	7
DBP 10-23	2.0	3.0	15.0	10	2.9	9	2.7	9	6.5	16
DBP 13-09	1.0	1.5	1191.9	6	378.1	7	352.8	6	653.0	7
DBP 12-21	1.5	2.0	64.4	8	24.4	7	21.4	7	154.8	7
DBP 07-04	1.0	1.0	9.4	15	3.5	9	3.2	10	7.9	17
DBP 14-03	3.5	5.0	264.5	7	96.2	7	90.8	6	211.8	8
DBP 16-45	2.0	3.0	87.3	7	31.1	7	29.3	6	92.3	7
DBP 14-07	3.5	3.5	305.5	6	133.2	7	124.5	6	259.3	7
DBP 03-05	0.5	1.5	139.8	6	61.2	7	56.7	6	155.3	6
DBP 15-01	2.0	2.5	284.5	6	130.7	6	115.5	6	291.1	6
DBP 11-03	1.5	2.5	18.5	11	9.4	7	8.8	8	26.4	10
DBP 13-31	1.0	1.0	34.2	9	16.9	7	16.5	7	29.5	10
DBP 11-09	2.0	3.0	13.2	18	6.9	9	6.5	9	11.8	21
DBP 09-32	<1	1.0	0.9	0	0.1	0	0.1	0	4.9	28

Source ID	Min mm	Max mm	Ra 226	% uncertainty	Pb 214	% uncertainty	Bi 214	% uncertainty	Pb 210	% uncertainty
DBP 11-25	0.5	1.0	27.0	9	13.7	7	12.5	7	40.0	8
DBP 04-16	<1	<1	494.7	6	289.9	7	270.6	6	404.2	7
DBP 11-13	1.0	2.0	111.0	7	67.1	7	62.4	6	82.6	7
BLANK	0.0	0.0	1.0	41	0.1	0	0.1	0	0.4	0

Table 8: **Percentage of Total Activity Available to Simulated Stomach Solution (percent of original particle activity) *UNITS**

Source ID	Dimension (mm) X	Y	Ra 226	Range min	Range Max	Pb 214	Range min	Range Max	Bi 214	Range min	Range Max	Pb 210	Range min	Range Max
DBP 12-33	0.5	1	**5.38**	4.02	7.65	**0.15**	0.11	0.22	**0.20**	0.15	0.28	**11.68**	8.72	16.61
DBP 15-12	4	5	**0.53**	0.38	0.77	**0.01**	0.01	0.02	**0.00**	0.00	0.00	**0.57**	0.40	0.83
DBP 11-12	1.5	1.5	**6.81**	5.14	9.57	**0.31**	0.23	0.44	**0.40**	0.30	0.57	**8.06**	6.08	11.32
DBP 12-18	1	1	**2.27**	1.68	3.25	**0.13**	0.10	0.20	**0.23**	0.17	0.33	**2.41**	1.79	3.45
DBP 14-34	2	2	**0.07**	0.04	0.12	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.11**	0.06	0.18
DBP 09-02	2	2.5	**0.03**	0.02	0.05	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.02**	0.01	0.04
DBP 06-19	2	2.5	**0.31**	0.22	0.45	**0.11**	0.08	0.17	**0.14**	0.09	0.22	**0.67**	0.49	0.98
DBP 04-21	1.5	2	**0.10**	0.07	0.16	**0.01**	0.00	0.01	**0.00**	0.00	0.00	**0.50**	0.37	0.73
DBP 07-12	1	1	**2.46**	1.78	3.62	**0.14**	0.10	0.20	**0.11**	0.08	0.17	**2.72**	1.97	3.98
DBP 12-15	3.5	5.5	**0.79**	0.58	1.14	**0.06**	0.05	0.09	**0.06**	0.04	0.08	**0.97**	0.71	1.41
DBP 11-18	3	3	**0.08**	0.06	0.12	**0.01**	0.01	0.01	**0.01**	0.01	0.01	**0.19**	0.14	0.28
DBP 14-30	1	1	**7.06**	5.27	10.06	**1.87**	1.41	2.62	**1.70**	1.29	2.36	**8.77**	6.58	12.38
DBP 13-16	3	4	**0.25**	0.18	0.36	**0.06**	0.05	0.09	**0.05**	0.04	0.08	**0.32**	0.23	0.46
DBP 04-03	3	4.5	**4.63**	3.36	6.95	**1.19**	0.89	1.67	**1.09**	0.82	1.52	**3.54**	2.61	5.16
DBP 10-23	2	3	**0.13**	0.10	0.20	**0.02**	0.02	0.03	**0.02**	0.02	0.03	**0.06**	0.04	0.09
DBP 13-09	1	1.5	**15.82**	11.95	22.17	**4.80**	3.62	6.71	**4.34**	3.30	6.03	**9.06**	6.81	12.74
DBP 12-21	1.5	2	**0.97**	0.69	1.49	**0.36**	0.27	0.50	**0.29**	0.22	0.41	**2.84**	2.06	4.26
DBP 07-04	1	1	**0.14**	0.10	0.22	**0.05**	0.04	0.07	**0.05**	0.03	0.07	**0.13**	0.08	0.20
DBP 14-03	3.5	5	**3.92**	2.92	5.61	**1.31**	0.99	1.84	**1.25**	0.95	1.75	**3.43**	2.53	4.92
DBP 16-45	2	3	**1.31**	0.99	1.84	**0.40**	0.30	0.56	**0.35**	0.27	0.49	**6.42**	4.75	9.25
DBP 14-07	3.5	3.5	**4.82**	3.63	6.79	**2.08**	1.57	2.91	**1.82**	1.38	2.53	**5.33**	4.00	7.51
DBP 03-05	0.5	1.5	**3.09**	2.30	4.43	**1.34**	1.01	1.88	**1.20**	0.91	1.67	**4.63**	3.44	6.64
DBP 15-01	2	2.5	**5.34**	4.07	7.41	**2.37**	1.80	3.30	**2.05**	1.56	2.83	**6.29**	4.77	8.76
DBP 11-03	1.5	2.5	**0.36**	0.26	0.53	**0.18**	0.14	0.26	**0.17**	0.12	0.23	**0.61**	0.44	0.88
DBP 13-31	1	1	**1.17**	0.85	1.72	**0.54**	0.40	0.75	**0.50**	0.37	0.69	**0.99**	0.72	1.44
DBP 11-09	2	3	**0.57**	0.38	0.88	**0.28**	0.21	0.40	**0.26**	0.19	0.36	**0.54**	0.35	0.86

Source ID	Dimension (mm)		Ra 226	Range min	Range Max	Pb 214	Range min	Range Max	Bi 214	Range min	Range Max	Pb 210	Range min	Range Max
DBP 09-32	<1	1	**0.03**	0.03	0.05	**0.00**	0.00	0.01	**0.01**	0.00	0.01	**0.18**	0.10	0.31
DBP 11-25	0.5	1	**1.04**	0.74	1.56	**0.59**	0.44	0.84	**0.50**	0.37	0.70	**1.68**	1.23	2.47
DBP 04-16	<1	<1	**24.28**	17.64	36.35	**14.07**	10.58	19.78	**12.52**	9.47	17.49	**21.45**	15.54	32.04
DBP 11-13	1	2	**5.72**	4.21	8.34	**3.32**	2.50	4.65	**3.05**	2.32	4.25	**4.89**	3.59	7.12
BLANK	0	0												

Table 9: Balance

			Original (A)		Sum of components (B)					
Source ID	**Dimension X mm**	**Dimension Y mm**	**Ra 226**	% uncertainty	**Ra 226**	Abs uncertainty	% uncertainty	**Difference (B-A)**	***Difference (B-A) as % of A***	***Difference (B-A) as % of absolute uncertainty***
DBP 12-33	1	1	50973	25.3	48492	10982	22.6	**-2481**	*-4.9*	*-22.6*
DBP 15-12	4	5	34432	24.9	34169	8072	23.6	**-263**	*-0.8*	*-3.3*
DBP 11-12	2	2	45311	24.7	42794	9524	22.3	**-2517**	*-5.6*	*-26.4*
DBP 12-18	1	1	20751	25.6	19440	4598	23.7	**-1311**	*-6.3*	*-28.5*
DBP 14-34	2	2	18223	26.0	18848	4590	24.4	**625**	*3.4*	*13.6*
DBP 09-02	2	3	16766	25.1	14480	3575	24.7	**-2286**	*-13.6*	*-63.9*
DBP 06-19	2	3	13836	25.1	14087	3656	26.0	**251**	*1.8*	*6.9*
DBP 04-21	2	2	13683	26.3	12667	3159	24.9	**-1016**	*-7.4*	*-32.2*
DBP 07-12	1	1	12868	26.3	12830	3191	24.9	**-38**	*-0.3*	*-1.2*
DBP 12-15	4	6	16923	25.0	14829	3641	24.6	**-2094**	*-12.4*	*-57.5*
DBP 11-18	3	3	13313	25.6	13394	3284	24.5	**81**	*0.6*	*2.5*
DBP 14-30	1	1	11238	25.5	10650	2504	23.5	**-588**	*-5.2*	*-23.5*
DBP 13-16	3	4	10186	23.5	10412	2530	24.3	**226**	*2.2*	*8.9*
DBP 04-03	3	5	9593.5	29.4	10172	2448	24.1	**578**	*6.0*	*23.6*
DBP 10-23	2	3	11163	26.9	12217	3066	25.1	**1054**	*9.4*	*34.4*
DBP 13-09	1	2	7534.3	24.3	7253	1616	22.3	**-281**	*-3.7*	*-17.4*
DBP 12-21	2	2	6641.9	29.5	6521	1599	24.5	**-121**	*-1.8*	*-7.6*
DBP 07-04	1	1	6592.2	25.7	6240	1574	25.2	**-352**	*-5.3*	*-22.4*
DBP 14-03	4	5	6741.7	25.3	6653	1650	24.8	**-89**	*-1.3*	*-5.4*
DBP 16-45	2	3	6661.2	23.8	8038	1996	24.8	**1377**	*20.7*	*69.0*
DBP 14-07	4	4	6334.5	24.6	5998	1435	23.9	**-336**	*-5.3*	*-23.4*
DBP 03-05	1	2	4527.1	26.0	4444	1118	25.2	**-83**	*-1.8*	*-7.4*
DBP 15-01	2	3	5325.9	23.7	5439	1286	23.6	**113**	*2.1*	*8.8*
DBP 11-03	2	3	5112.5	25.1	5060	1290	25.5	**-52**	*-1.0*	*-4.0*
DBP 13-31	1	1	2914.9	25.5	2926	733	25.0	**11**	*0.4*	*1.5*

			Original (A)		Sum of components (B)					
Source ID	**Dimension X mm**	**Dimension Y mm**	**Ra 226**	% uncertainty	**Ra 226**	Abs uncertainty	% uncertainty	**Difference (B-A)**	***Difference (B-A) as % of A***	***Difference (B-A) as % of absolute uncertainty***
DBP 11-09	2	3	2318.8	23.8	2289	549	24.0	**-30**	*-1.3*	*-5.4*
DBP 09-32	<1	1	2642.3	26.7	2797	734	26.2	**155**	*5.9*	*21.1*
DBP 11-25	1	1	2600.4	27.2	2190	577	26.4	**-410**	*-15.8*	*-71.1*
DBP 04-16	<1	<1	2037.3	29.0	1906	375	19.7	**-131**	*-6.5*	*-35.0*
DBP 11-13	1	2	1939	26.8	1806	458	25.4	**-133**	*-6.9*	*-29.1*
BLANK	0	0	0	0.0	14	0	2.9	**14**	*#DIV/0!*	*3468.0*