Sellafield Ltd

Particles in the Environment

Annual Report for 2015/16 and Forward Programme

June 2016 **EM/2016/21**

This page is intentionally blank

Particles in the Environment Annual Report 2015/16

Executive Summary

This report details the progress that has been made during the 2015/16 financial year on the Particles in the Environment work programme. It also sets out the forward programme of work, with objectives, as previously submitted to the Environment Agency and agreed in February 2016 through the Sellafield Particles Working Group.

Beach monitoring covered an area in 2015/16 of 166.75 ha and exceeded the Environment Agency's specification of 160 ha. The surveying identified 349 discrete radioactive items, of which 290 were classified as particles (less than 2 mm in size) and 59 were classified as stones (larger than 2 mm in size). A total of 262 of the finds were designated alpha rich, with higher ^{241}Am activity than ^{137}Cs activity, 85 were designated beta rich where ^{137}Cs was the major radionuclide, 1 was designated as ^{60}Co rich and 1 find contained predominately ^{226}Ra and was therefore unrelated to Sellafield discharges. All of the stones were designated beta rich. As in previous years, the majority of finds were recovered from Sellafield beach (83 %). The number of finds in all categories were typical of those found in recent years. The increase in find rate in 2014/15 that coincided with the introduction of the improved monitoring system, Groundhog Synergy 2, was not found to persist.

Further analyses of selected finds have been performed using various radiometric and petrological techniques. The highest total beta and ^{137}Cs activities on particle finds sent for analysis was 5.09E+04 and 5.82E+04 Bq respectively. These activities were associated with 'Metal and corroded metal' particles from the Sellafield beach. An analysis of the relationship between ^{90}Sr and ^{137}Cs activities of particles showed that the ^{137}Cs activity was highly variable for ^{90}Sr activities of 2-3 kBq. However, a strong linear trend was shown between ^{90}Sr and ^{137}Cs for activities greater than 3 kBq of ^{90}Sr.

An update is provided on the assessment of the Best Available Techniques (BAT) for particles monitoring. This details the results of trials to (i) evaluate the performance of Synergy 2 and (ii) evaluate 'plastic scintillator' detectors which were shown to be able to detect ^{90}Sr at a level approximately 10 times lower than that achieved by Synergy 2. The Synergy 2 trials showed that the system provided a detection performance that was in-line with the engineers' expectations whilst the 'plastic scintillator' trials did not find any evidence of a substantial population of ^{90}Sr rich particles after surveying 3.55 ha of beach over the course of 18 days. The use of plastic scintillators in routine monitoring was therefore not considered to represent BAT.

The types of material being recovered during 2015/16 remained consistent with those retrieved since commencement of the monitoring programme. The distribution of ^{137}Cs and ^{241}Am activities of current particles remain within observed ranges of all particles to date, providing reassurance that they are part of the same general population. This provides further evidence that the conclusion of the Public Health England risk assessment in 2011 remains valid, and are as follows.

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches." *(Brown and Etherington, 2011)*

Table of Contents

List of Tables

List of Figures

1 Introduction

The overall objective of the Sellafield Ltd Particles in the Environment programme is to understand the nature of radioactive objects being detected on local beaches and to quantify the potential health risk they pose. This report details the progress that has been made in 2015/16 on the Particles in the Environment work streams and sets out the programme of work for 2016/17.

In June 2011, the most comprehensive report to date on Particles in the Environment was produced and submitted to the Environment Agency (EA) (see Sellafield Ltd, 2011). Readers are directed to this, and subsequent reports, as a source of further information. Extensive information is available via the sellafieldsites.com website at the following address:

http://sustainability.sellafieldsites.com/environment/environment-page/particles-in-the-environment/

In summary, this report includes the following:

Section 2 provides information on the particle detection systems used for beach monitoring.

Section 3 details the progress made in 2015/16 against the beach monitoring programme.

Section 4 provides the analysis of the monitoring and find data gathered up to the end of the 2015/16 financial year.

Section 5 provides an update on work completed on developing an updated Best Available Techniques (BAT) case for work on particles detection in the environment.

Section 6 explains how the regulators and stakeholders are being engaged by Sellafield Ltd and the framework for continued interactions.

Section 7 provides a brief update on the assessment of health risk posed by beach finds, being led by Public Health England (PHE) Centre for Radiation, Chemical and Environmental Hazards (formally Health Protection Agency, HPA CRCE) under contract to the EA.

Section 8 outlines the work programme and objectives for 2016/17. It identifies the individual work streams with respect to beach monitoring and beach find analysis that were agreed with the EA in February 2016.

2 Detection Systems

2.1 The Synergy 2 Detection System

The Groundhog Synergy system was a development of the Groundhog Evolution system that has been used for particle detection on beaches at Dounreay. The Evolution2 system was used at Sellafield up to August 2009 and was primarily designed to detect particles containing ^{137}Cs.

The Synergy system was used between August 2009 and May 2014 and was developed to improve detection of particles containing ^{241}Am, principally by improving radiation transmission through the detector cases and by the introduction of low-energy radiation detectors (Field Instrument for the Detection of Low Energy Radiation, FIDLER, detectors). The Synergy system used five 76 x 400 mm sodium iodide (NaI) detectors which provided a continuous monitoring swathe of two metres. This size of detector has a high efficiency of detection for high energy gamma radiation such as that emitted by ^{137}Cs and ^{60}Co. These detectors were individually mounted in 2 mm thick carbon fibre cases to improve the transmission of radiation, particularly the low energy gamma radiation from ^{241}Am. The five detectors were mounted in a large carbon fibre box. The system also included eight FIDLER detectors that are optimal for the detection of low energy gamma radiation from ^{241}Am. Each detector was mounted in a carbon fibre case which has a 0.4 mm thick detection window. The eight FIDLER detectors were also mounted in the carbon fibre box and used a further 0.4 mm carbon fibre protective window.

In May 2014 Nuvia Ltd commissioned the Groundhog Synergy 2 system. The Synergy 2 system is a development of the Synergy system, designed to further improve detection of ^{241}Am and ^{90}Sr/^{90}Y. The detection system of Synergy 2 is physically the same as Synergy (Figure 1), except that it includes a thinner window of carbon fibre below the large volume NaI detectors to improve the transmission of beta radiation. The Synergy 2 system also includes additional specific strontium / americium alarms both for the sodium iodide and FIDLER detectors, measuring decay energies in a detection window centred on 80 keV. Based on information provided by Nuvia Ltd, this revised alarm was predicted to reduce the limits of detection of ^{241}Am by a factor of two (Davies, 2014). However, whilst it was anticipated that the performance for ^{90}Sr detection would also be improved, it was less clear what might be achieved because detection of both beta particles and Bremsstrahlung radiation was possible.

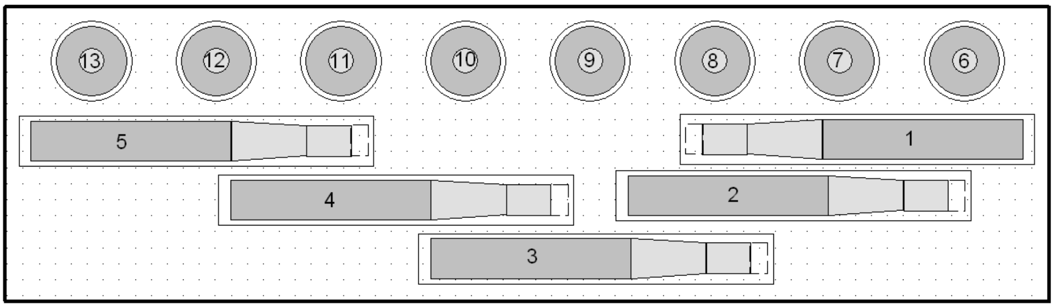


Figure 1: Synergy 2 detector layout: 1 – 5 NaI detectors, 6 – 13 FIDLER detectors.

2.2 Strandline and Stormline Monitoring

Monitoring of both the most recent tide-line (referred to as the Strandline) and the line of wind-blown debris or highest tide-line (referred to as the stormline) is included in the CEAR (EA, 2016) and has been part of the wider environmental monitoring programme since 1983.

Much of the monitoring of the most recent tide-line is conducted using the vehicle mounted Groundhog Synergy 2 system. However, monitoring of the stormline often requires access to areas of the beach that cannot be safely traversed by the vehicle mounted equipment hence walked surveys are required. These surveys are conducted between Drigg and St. Bees (with the exception of Nethertown beach where the rocky foreshore cannot be safely monitored) using the following methods:

- Surveys conducted by Nuvia Ltd use a single 76x400 mm detector crystal of NaI, mounted in a lightweight case, carried between two operators (Figure 2); and,
- Surveys conducted by Sellafield Ltd staff use a FIDLER probe for low energy photons. These surveys are part of Sellafield Ltd's wider environmental monitoring programme, which includes the requirement to complete biannual FIDLER probe monitoring of the extreme high water mark and wind-blown debris between Drigg Point and St. Bees Head.

Surveys are walked slowly (with a maximum speed of 1.0 m/s or 2.3 mph) and the probes are kept above the ground surface and FIDLER probes are moved in side to side sweeps allowing for instrument response time, such that an increase in count rate can be detected. Radioactive items are detected and retrieved through an increase in the count rate of the monitor. A general count rate is recorded for each defined transect that has been surveyed (*e.g.* <200 cps for FIDLER). Any items that are retrieved are bagged and returned to site and their position is recorded with the GPS.

Figure 2: Photograph of a walking survey conducted on the West Cumbrian coast.

3 Monitoring Conducted During 2015/16

This section covers the large area beach monitoring programme. It does not cover the strandline monitoring that has been carried out routinely by Sellafield Ltd (reported regularly to EA as part of the Sellafield statutory environmental monitoring programme). For the beach monitoring programme, information is presented on the areas monitored and the challenges presented by equipment failures and the environment. The number of finds recovered during monitoring and their distribution on beaches surrounding Sellafield are described. Results from the 2015/16 programme are compared with those from previous years to identify any changes that may affect the overall risk to beach users.

3.1 Planned Beach Monitoring For 2015/16

The EA places a statutory monitoring requirement on Sellafield Ltd to deliver a large scale beach monitoring programme. This is part of an agreed programme of works as specified in the current Compilation of Environment Agency Requirements (EA, 2016) which includes the following:

The Operator shall develop a programme of works, to be agreed with the Environment Agency, that:

- *Focuses on those radioactive particles in the environment that have arisen from Sellafield site operations that represent the greatest risks, so that these can be targeted and the risks to the public and the environment mitigated;*
- *Performs large area beach monitoring to detect and recover targeted radioactive particles, at locations and to a programme that is commensurate with particle numbers, distributions, environmental mobility and rates of encounter; and,*
- *Develops a risk-based approach to assess and determine the best method(s) to detect and recover targeted radioactive particles in the environment.*

The on-going aim of the programme is to continue to provide reassurance that the overall risks to beach users are not greater than those estimated in the Health Protection Agency (HPA) risk assessments (Brown & Etherington, 2011; Etherington, et al., 2012a).

The HPA risk assessment (Brown & Etherington, 2011; Etherington, et al., 2012a) recommends *"… continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that risks associated with radioactive objects in the environment remain very low."*

A programme of 160 ha was developed and agreed with the EA at the start of 2015 to meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the HPA risk assessment. As in previous years the programme ran from the start of April 2015 to the end of March 2016, consistent with the financial year.

The 160 ha was split into three programmes:

- Sellafield programme (totalling 88 ha);
- Near-field programme (totalling 62 ha); and,
- Far-field programme (totalling 10 ha).

The near-field programme focussed on the beaches at Seascale, Braystones and St. Bees, whereas the far-field programme focused on Allonby beach. The emphasis in the monitoring differed from previous years, with a greater focus being placed on Sellafield beach. The reasons for selecting the beach at Sellafield for the majority of the monitoring programme are:

- The conceptual site model (Rankine and Jackson, 2014) identified the historic Sellafield discharge lines and their decommissioning as the most probable source of the particles being recovered from West Cumbrian beaches;
- Sellafield beach has the highest recorded find rates and is in close proximity to the Sellafield site, with the majority of beta rich particles and almost all stones being recovered from this beach;
- Monitoring of the widest possible extent of the beach at Sellafield should enable the distribution of finds in this area to be better understood and should give a clearer picture on the repopulation of finds both at Sellafield, but also to the beach area to the north at Braystones; and,
- Past monitoring efforts have seen a reduction in find numbers following the introduction of the various developments of the Groundhog system, but these have typically taken three to four years to be realised. Increasing the monitoring rate to approximately twice that of previous programmes may reduce the time taken to observe falling find rates at Sellafield.

The target areas that were planned for each beach are given in Table 1, with the full schedule in Table 2.

Table 1: Planned area coverage (ha) for each beach in 2015/16.

Programme	Beach	Sellafield	Near-Field	Far-Field	Total
Sellafield	Sellafield	88	-	-	88
	Braystones	-	22	-	22
Near-Field	St. Bees	-	20	-	20
	Seascale	-	20	-	20
Far-Field	Allonby	-	-	10	10
Total		88	62	10	160

3.1.1 Sellafield programme

A programme of 88 ha monitoring at Sellafield was developed, to provide reassurance that the find rates and find characteristics on the beach with the highest historic find rates are not changing significantly. This programme scheduled three visits to Sellafield, with a target area of between 22 and 34 ha per visit.

For continuity with previous programmes, regular monitoring of the 1 ha repeat area was scheduled for Sellafield beach. This repeat area is a defined area of beach where repeated sampling has been conducted for several years. In 2015/16 this area was monitored seven times during the three scheduled monitoring periods. Monitoring was completed inside one tidal cycle, giving a footprint of that area of beach, with each visit being at least one month apart.

Each visit to Sellafield beach is immediately followed by a visit to the adjoining beach at Braystones. This is to investigate whether the removal of finds from Sellafield beach also has an impact on the find rates observed at Braystones.

Table 2: Beach monitoring programme for 2015/16.

Quarter	Week Starting	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near-Field Programme: Target Area (ha)	Far-Field Programme: Target Area (ha)
Q1 2015/16	01-Apr	Easter Holidays			
	06-Apr				
	13-Apr	St Bees (1)		4	
	20-Apr	Seascale (1)		4	
	27-Apr	Sellafield (1)	34		
	04-May				
	11-May				
	18-May				
	25-May				
	01-Jun				
	08-Jun				
	15-Jun				
	22-Jun	Braystones (1)		8	
Q2 2015/16	29-Jun				
	06-Jul	St Bees (2)		4	
	13-Jul	Seascale (2)		4	
	20-Jul	Summer Holidays			
	27-Jul				
	03-Aug				
	10-Aug	Monitoring the inaccessible areas of local beaches			
	17-Aug				
	24-Aug				
	31-Aug	St Bees (3)		4	
	07-Sep	Seascale (3)		4	
	14-Sep	Q4 Strandline			
	21-Sep	Allonby (1)			10
Q3 2015/16	28-Sep				
	05-Oct	Sellafield (2)	32		
	12-Oct				
	19-Oct				
	26-Oct				
	02-Nov				
	09-Nov				
	16-Nov				
	23-Nov				
	30-Nov	Braystones (2)		8	
	07-Dec				
	14-Dec	Maintenance Week			
	21-Dec	No Monitoring (Christmas Holidays)			
Q4 2015/16	28-Dec				
	04-Jan	St Bees (4)		4	
	11-Jan	Seascale and Drigg Strandline Monitoring		4	
	18-Jan	Sellafield (3)	22		
	25-Jan				
	01-Feb				
	08-Feb				
	15-Feb				
	22-Feb	Braystones (3)		6	
	29-Feb				
	07-Mar	Q4 Strandline			
	14-Mar	St Bees (5)		4	
	21-Mar	Seascale (4)		4	
	28-Mar	Easter Holidays			
		Cumulative Totals ==>	**88 ha**	**62 ha**	**10 ha**
		OVERALL TOTAL ==>	**160 ha**		

3.1.2 Near-field programme

A near-field programme was developed to provide information on the distribution of finds, improve the estimate of find rates and the total population of beach finds and to provide reassurance of low find rates on beaches occasionally visited by the public. The latter meets the Committee on Medical Aspects of Radiation in the Environment (COMARE) requirement to monitor the more popular beaches close to the breaks in monitoring around the school holiday periods. In setting the areas a number of factors were taken into account including; historic find distribution, habit survey data and the need to recover finds for analysis.

The reasons for selecting the beaches as part of the near-field programme were:

- **Braystones** has the second highest historic find rate, is a popular public beach and has a community living just above high water and is adjacent to Sellafield beach;
- **St. Bees** has the third highest find rates and is a popular public beach; and,
- **Seascale** has a lower historic find rate when compared to both Braystones and St. Bees beaches although is a popular public beach.

The near-field programme will be used in particular to improve the current understanding of repopulation rates, total population of beach finds and changes to the beach profile, as well as to provide continued reassurance that find rates and find characteristics are not changing across the wider beach area. Monitoring of these beaches, particularly at Braystones, allow the statistical analysis of longer term trends as well as the analysis of the radioactivity distribution of the finds.

The three programmed visits to Braystones each followed a visit to Sellafield beach. Each of these visits spanned two weeks and covered between 6 and 8 ha.

For St. Bees and Seascale beaches this resulted in five visits to each of these two beaches, with each visit covering 4 ha. The primary focus of these visits was the designated repeat areas, located close to the public access points, supplemented with coverage of recent strandlines and other sandy areas that are readily accessible.

3.1.3 Far-field programme

The far-field programme (10 ha) targets beaches with historically lower find rates. For 2015/16 this resulted in a single visit to the Northern Beaches, specifically Allonby, which is a popular beach with low find rates that are not dissimilar to those observed at Seascale. As with St. Bees and Seascale, the primary focus of this visit was the areas located close to the public access points.

In addition, and to address the requirement to include a vehicle based strandline covering the accessible areas between St. Bees Head and Drigg Point, the fourth visit to Seascale beach in January 2016 included the strandline between Seascale beach and Drigg Point.

The sequence of the beach monitoring programmes also takes into account some operational factors:

- There is time in the programme to carry out sufficient maintenance of the monitoring vehicle, Land Rover and equipment;
- During weeks when the amount of available monitoring time (based on tides and sunlight) is high, the target areas are also higher. In contrast when the amount of time available is less the targets are reduced; and,

- Monitoring visits were scheduled throughout the year for each beach to give the best temporal resolution, allowing for repopulation to occur and to provide coverage of the high occupancy beaches close to the school holidays.

3.2 Beach Areas Monitored in 2015/16

3.2.1 Determination of the area monitored

The area that is covered in the monitoring programme is determined using a high accuracy Global Positioning System (GPS) that records the position of the monitoring vehicle or surveyors for walked monitoring. This generates large amounts of raw GPS data that needs to be processed, using a Geographical Information System (GIS) called ArcGIS. Nuvia Ltd provides an estimate of the area monitored during each beach survey (of multiple days), based on the processed data, to show they have achieved the target area specified in the monitoring programme. To ensure that the required area is monitored, Nuvia assess the area by visit using tight GIS processing parameters and remove any overlap between days.

Sellafield Ltd uses data provided by Nuvia to generate daily GIS shape files that can be displayed on a map and provides a measurement of daily monitored area. It is recognised that Nuvia's monitored area assessment for a visit to a beach and the sum of Sellafield Ltd's daily areas over the same period will be different as they are generated in different ways. The 2013/14 annual particles report (Sellafield Ltd, 2014a) describes in detail the difference between the two methodologies.

The Sellafield methodology is very conservative in its calculation of monitored area from the detector point data, typically giving areas up to 7 % smaller than those reported by Nuvia. Nuvia's reported coverage is used to maintain compliance with the CEAR, whilst find rates are calculated using the smaller Sellafield Ltd figure. This ensures a degree of conservatism is built into the calculation of find rates for comparison to the values used in the PHE risk assessment.

3.2.2 Areas monitored in 2015/16

The beach monitoring programme for the 2015/16 financial year was completed with a total area of between 171.99 ha (Nuvia estimate) and 166.76 ha (Sellafield Ltd estimate), against a programme target of 160 ha (Table 3, Figure 3 to Figure 6 and Appendix 1). The following data and maps are based on Sellafield Ltd processed data.

Table 3 presents the area monitored in 2015/16 as a percentage of the available area of each beach. The available area is a simple estimate based on the total area of sand/shingle to the mean low water, excluding rocks and other inaccessible areas of the beach and is provided purely for comparative purposes.

Comparing the information in Table 3 with Table 2 illustrates that the total area monitored was higher than that originally included in the programme, with significantly more area being monitored at Seascale and Braystones beaches and a slight reduction in the area monitored at Sellafield. This was due to storm damage to the access point for Sellafield beach. It is also notable that a limited amount of monitoring at Drigg beach was also undertaken as part of the strandline monitoring.

Table 3: Beach monitoring conducted during 2015/16.

Programme	Monitoring area	Number of days	Area covered (ha)	Available area (ha)	Monitoring as % of available
Sellafield	Sellafield	96	82.6	53.3	155%
Near-Field	Braystones	29	24.3	18.9	129%
	St. Bees	19	21.3	28.5	75%
	Seascale	22	27.1	81.6	33%
Far-Field	Allonby	7	10.4	136.9	8%
	Drigg	2	1.1	196.7	1%
Total		175	166.8	515.9	32%

3.3 Numbers of Finds Recovered in 2015/16

There were 349 finds recovered during the 2015/16 monitoring programme from the beaches surrounding the Sellafield Nuclear Licensed Site (Table 4). Of these, 290 were classified as particles and the remaining 59 were classified as stones[1]. The locations of these finds are shown in Figure 7. The maps included in Appendix 1 show the distribution of beach finds for all beaches and the areas monitored during each visit.

The majority of beach finds (approximately 98 %) were recovered from Sellafield (83 %), Braystones (5 %) and St. Bees (10 %) beaches during 2015/16. In excess of 128 ha of beach were monitored at these three locations, which accounted for almost 77 % of the total area surveyed in 2015/16. A total of 59 radioactive stones were detected in 2015/16 and all were recovered from Sellafield beach (Figure 7). Of the 290 particles recovered in 2015/16 the majority were detected on Sellafield beach (80%), with most of the others being from St. Bees (12%) and Braystones (7%). All of the stones were recovered from Sellafield beach.

Table 4: Particle and stone beach finds recovered during 2015/16

Programme	Monitoring area	Particles recovered in 2015/16	Stones recovered in 2015/16	Total in 2015/16
Sellafield	Sellafield	230	59	289
Near Field	Braystones	19	0	19
	St. Bees	34	0	34
	Seascale	5	0	5
Far field	Allonby	0	0	0
	Drigg	2	0	2
Total		290	59	349

[1] Stones are defined as >= 2mm in diameter and particles are < 2 mm in diameter. A beta-rich beach find has a positive ^{137}Cs activity greater than its ^{241}Am activity. A ^{60}Co-rich beach find has a positive ^{60}Co activity greater than its ^{137}Cs activity. An alpha-rich beach find has a positive ^{241}Am activity greater than its ^{137}Cs activity.

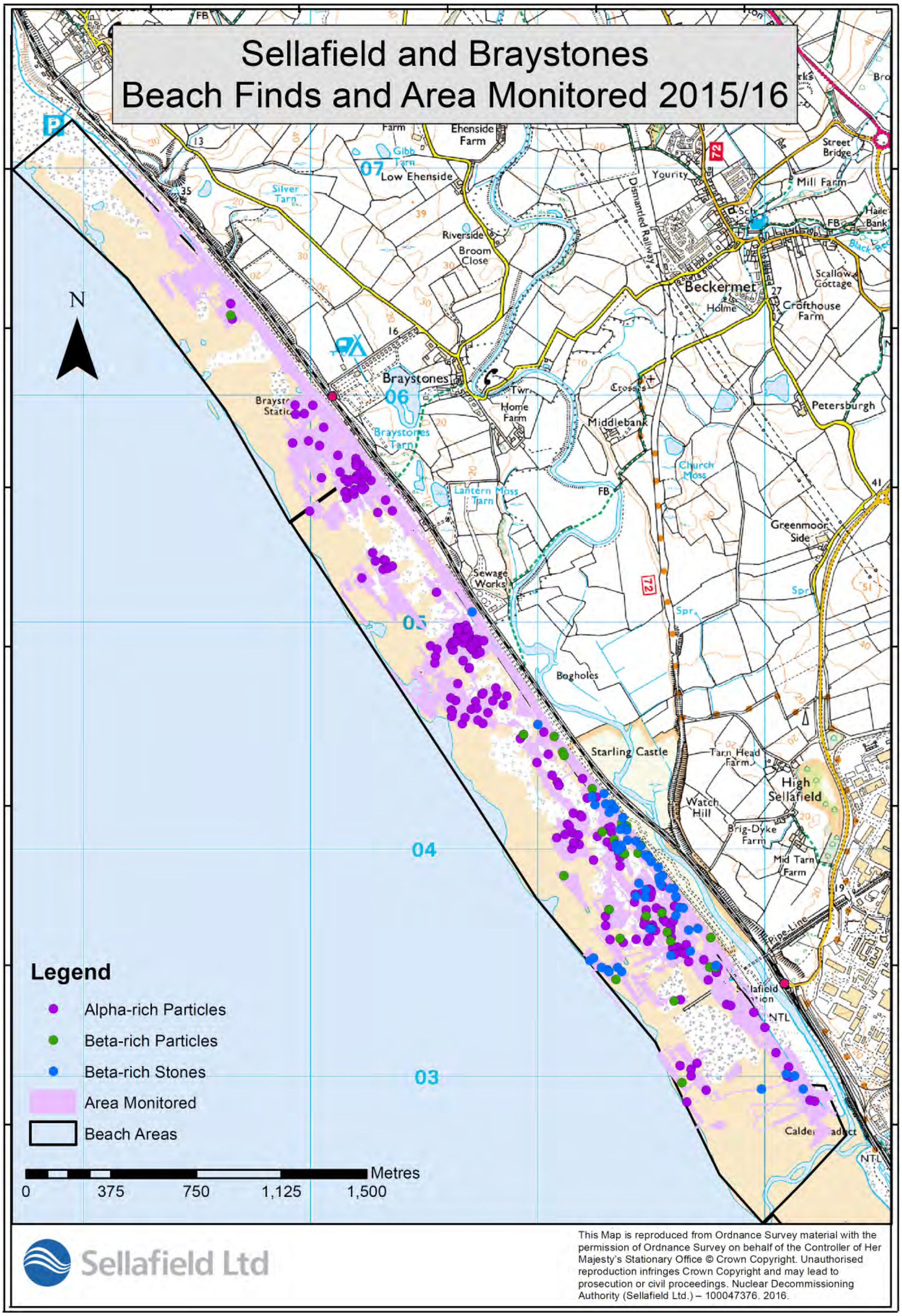


Figure 3: Sellafield and Braystones beach find locations and areas monitored in 2015/16.

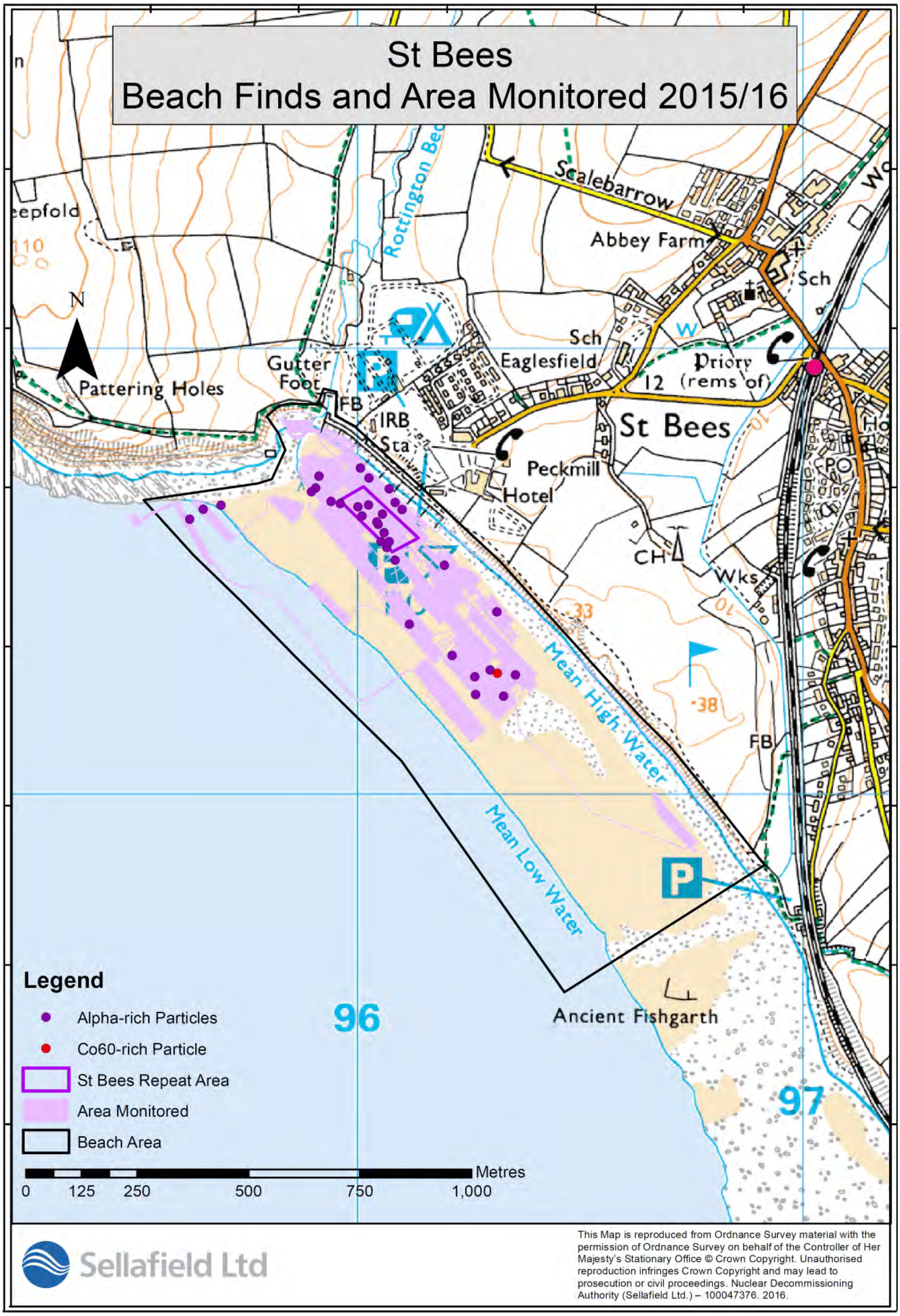


Figure 4: St. Bees beach find locations and areas monitored in 2015/16.

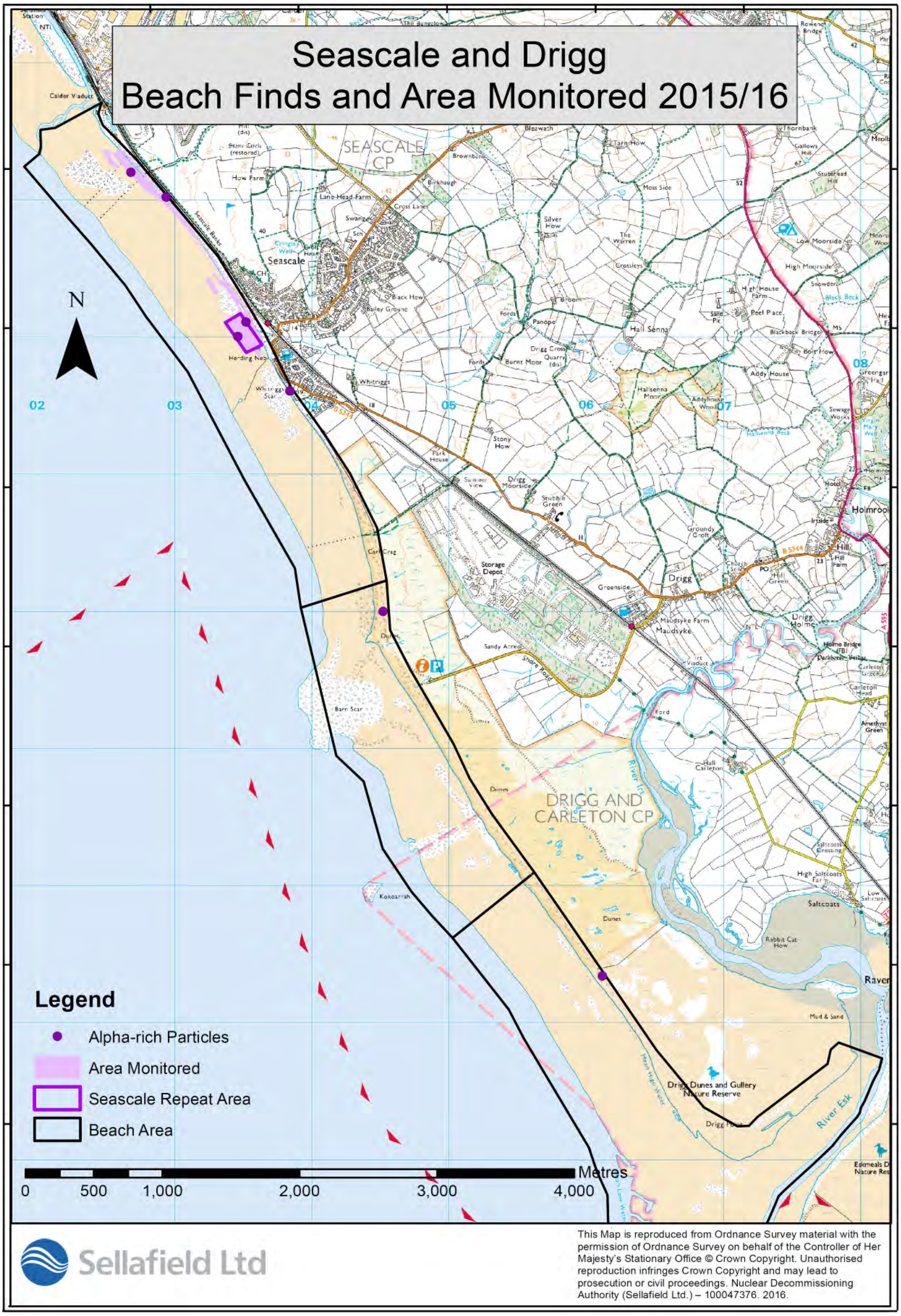


Figure 5: Seascale and Drigg beach find locations and areas monitored in 2015/16.

Figure 6: Allonby beach find locations and areas monitored in 2015/16.

A total of 289 finds (230 particles, 59 stones) were recovered from Sellafield beach during 2015/16, which is the largest number of finds recovered from Sellafield beach in a 12 month period since 2007/08 and compares with 244 finds in 2014/15. This is a direct result of the increase in monitoring which took place at Sellafield beach in 2015/16 (82.56 ha in 2015/16, 38.23 ha 2014/15) and find rates are in line with historic levels.

The appearance of clusters of beach finds within the repeat area at Sellafield (see Figure 7) is a result of the repeat area being monitored a total of seven times. Monitoring operations at Braystones, St. Bees and Seascale largely focused in and around the repeat areas, and as a consequence, a high percentage of the finds recovered during the 2015/16 programme were located within these target areas.

Monitoring at Braystones directly followed every Sellafield visit to see if the find rates at Braystones were affected by the extended monitoring campaigns on its neighbouring beach. Approximately 24 ha were monitored at Braystones, with 19 particles detected in 2015/16 and the find rate at Braystones was almost a quarter of the levels recorded for 2014/15 (0.78 finds ha^{-1} 2015/16, 3.00 finds ha^{-1} 2014/15).

Five separate surveys were scheduled for St. Bees throughout 2015/16, with 19 days of monitoring completed during this period. A total of 21.3 hectares of beach was surveyed with 34 particles detected. There was a reduction in the number of finds detected at St. Bees in 2015/16 when compared with the previous year as 46 particles were recovered in 2014/15. The total area monitored at St. Bees reduced by almost a half in 2015/16 but find rates remained within the range previously observed.

Monitoring at Seascale was conducted over 22 days (totalling of 27.1 ha) during 2015/16 with five particles being detected (note: two particles were detected in December 2015 during a walked FIDLER probe survey (CMS05A)).

A single survey took place over two weeks at Allonby during September 2015. This was conducted as part of the far-field programme to provide reassurance for areas where the general public spend the majority of their time (Figure 6). A total of 10.4 ha were monitored during the survey and no radioactive finds were detected.

There were two alpha rich particles recovered from Drigg beach when the annual vehicle strandline monitoring was completed in January 2016, resulting in an increase in find rate when compared to previous years. However, the small number of finds, combined with a small amount of area monitored results in highly variable find rates which are not representative of wide area averages. Similar variations in find rates over small areas have been recorded in previous years.

Find numbers recovered each year will vary according to the area monitored so find rate per hectare values are often a more useful measure than the absolute find numbers. An assessment of find rates is therefore included later in this report (Section 4.2).

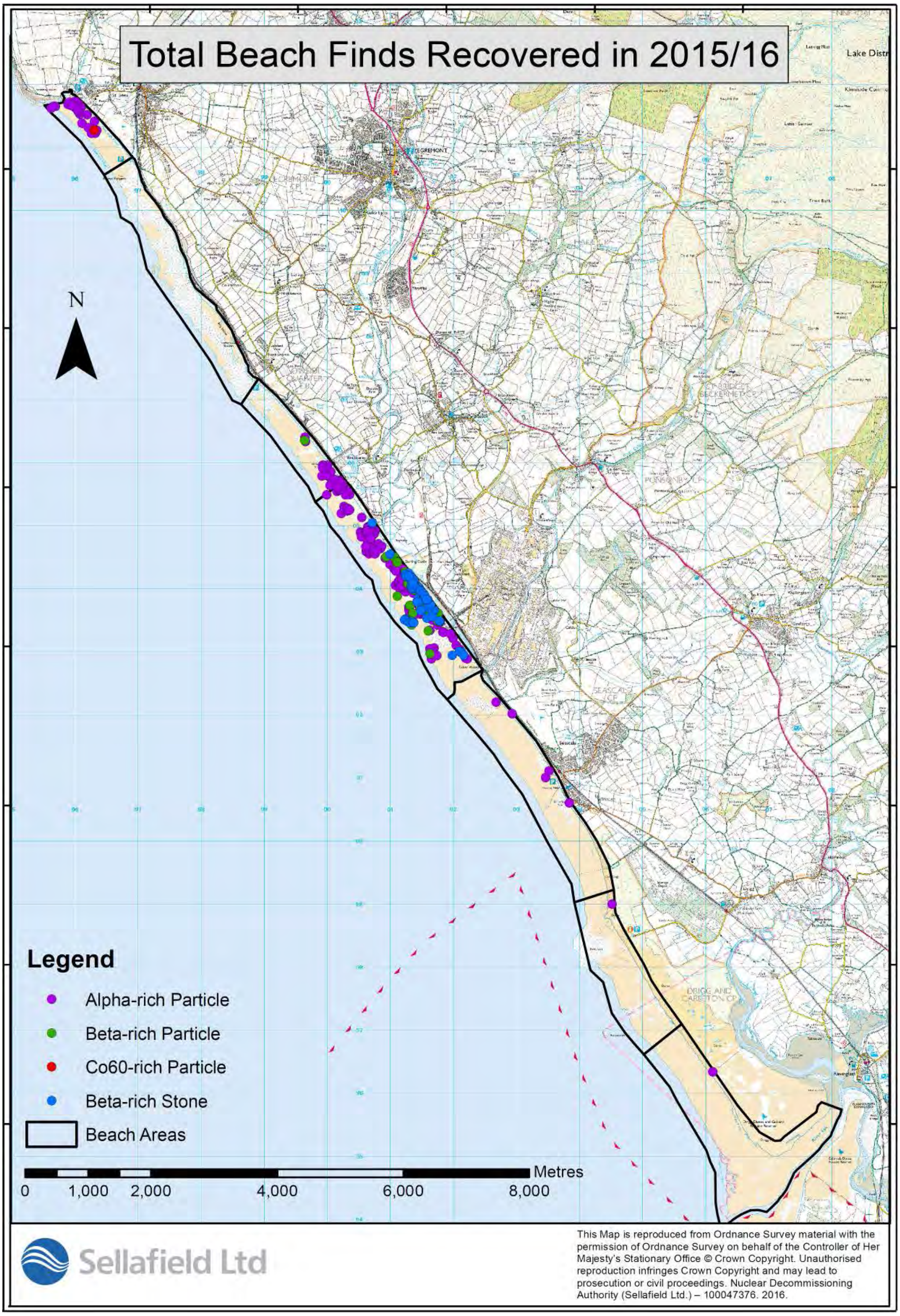


Figure 7: Particle and stone finds recovered during 2015/16 adjacent to Sellafield.

3.4 Types of Beach Finds Detected During 2015/16

The key radionuclides detected by the Groundhog Synergy 2 monitoring are ^{137}Cs and ^{241}Am and to a lesser extent ^{60}Co. Consequently, initial characterisation of each find recovered via the monitoring programme concentrates on these isotopes.

For positive analytical results:

- Finds with ^{241}Am activity greater than ^{137}Cs activity are classified as alpha rich.
- Finds with ^{137}Cs activity greater than ^{241}Am activity are classified as beta rich.
- Finds with positive ^{60}Co activity greater than the ^{137}Cs activity are classified as cobalt-rich.
- Finds with a contact beta gamma dose rate in nSv/hr greater than 15 times the ^{137}Cs activity in Bq and not alpha rich and not cobalt-rich are classified as excess beta (*e.g.* a pure beta emitter such as ^{90}Sr may be present).

Over 75 % of all finds recovered in 2015/16 were classified as alpha rich (Table 5). There were 85 finds classified as beta rich in 2015/16, with 84 of the 85 beta rich finds recovered from Sellafield, the remaining find being recovered from Braystones. Due to the limited finds recovered from Braystones beach, it was not possible to assess whether the find types recovered at Braystones were affected by monitoring Sellafield beach.

In total, 289 finds were recovered from Sellafield beach (Table 6). Of these, 204 were classified as alpha rich, 84 as beta rich and a stone (defined as an object with a length greater than 2 mm) containing ^{226}Ra. As in previous years, stones were mainly found on Sellafield beach (Table 7). The number of stones recovered from Sellafield beach during 2015/16 increased compared to 2015/16 (59 versus 35). Excluding the ^{226}Ra stone, all the remaining stones were classified as beta rich.

A ^{60}Co-rich particle (defined as an object with a length less than 2 mm) was detected during a routine vehicle survey of St. Bees beach in March 2016 (Table 6). This is discussed in detail in Section 3.5.3.

Table 5: Numbers of finds by type and classification since 2006.

Classification	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	Total
Alpha rich Stones	0	2	0	2	2	0	0	0	0	0	6
Alpha rich Particles	1	28	24	140	320	225	197	101	307	262	1605
Alpha rich Finds	1	30	24	142	322	225	197	101	307	262	1611
Beta rich Stones	5	213	146	48	33	13	19	8	36	58	580
Beta rich Particles	6	104	72	46	27	27	30	8	40	27	387
Beta rich finds	11	317	218	94	60	40	49	16	76	85	967
Cobalt (wire)	0	1	0	0	0	0	0	0	0	0	1
Cobalt rich Particle	0	4	2	5	1	2	2	0	0	1	17
Cobalt rich Finds	0	5	2	5	1	2	2	0	0	0	18
All	12	352	244	241	383	267	248	117	383	348	2595

Note 1: the single find recovered by seabed grab sampling (April 2012) is **not** included in the totals for 2012/13.
Note 2: two ^{226}Ra stones, one from each of 2007/08 and 2015/16 are not included in totals.

Table 6: Find numbers by type recovered during 2015/16.

Monitoring area	Alpha rich	Beta rich	Cobalt rich	Total in 2015/16
Allonby	0	0	0	0
St. Bees	33	0	1	34
Braystones	18	1	0	19
Sellafield stones	0	58	0	58
Sellafield Particles	204	26	0	230
Sellafield Finds	204	84	0	288
Seascale	5	0	0	5
Drigg	2	0	0	2
Total	262	85	1	348

Note: ^{226}Ra stone not included in 2015/16 totals

Table 7: Find numbers by type recovered since 2006/07.

Monitoring area	Alpha rich	Beta rich	Cobalt rich	Total
Allonby particles	13	2	0	15
Harrington particles	4	0	0	4
Workington stones	0	1	0	1
Workington particles	5	1	0	6
Workington finds	5	2	0	7
Whitehaven particles	8	1	0	9
St. Bees particles	217	15	2	234
Braystones particles	377	35	4	416
Sellafield stones	6	575	0	581
Sellafield (wire)	0	0	1	1
Sellafield particles	897	307	9	1213
Sellafield finds	903	882	10	1795
Seascale stones	0	3	0	3
Seascale particles	61	23	1	85
Seascale finds	61	26	1	88
Drigg particles	23	3	1	27
Total finds	1611	966	18	2595

Note 1: the single find recovered by seabed grab sampling (April 2012) is not included in the totals for 2012/13.
Note 2: two ^{226}Ra stones, one from each of 2007/08 and 2015/16 are not included in totals.

3.5 Unusual Finds Detected During 2015/16

As part of the surveillance of the beach monitoring programme the EA require that Sellafield Ltd notify them of any unusual finds that are detected (EA, 2016). The following sections detail the unusual finds detected during 2015/16.

3.5.1 High activity beta rich particle (S1516)

A particle find was detected on 2nd June 2015 on Sellafield beach during a routine vehicle survey that had a ^{137}Cs activity of 1.7E+05 Bq (Table 8). This particle had the second highest ^{137}Cs activity of any beta rich particle recorded to date. Despite the high ^{137}Cs activity the measured contact dose rate was unremarkable when compared to the previous measurements. As this find was above 1E+05 Bq of ^{137}Cs it has been scheduled for further analysis as detailed in Section 4.6.

Table 8: Comparison between S1516 with all beta rich particles.

	Activity (Bq) or Contact Dose (nSv/hr)					
		All beta rich particle finds				
Sample	**S1516**	**Min**	**Max**	**Average**	**Percentile**	**Rank**
^{60}Co	<1.6E+01	0.0E+00	2.4E+02	<1.6E+01	61.5%	148
^{137}Cs	1.7E+05	4.8E+02	2.9E+05	1.9E+04	99.7%	2
^{241}Am	<2.4E+02	0.0E+00	1.6E+03	<2.1E+02	71.3%	110
Contact dose	5.0E+04	0.0E+00	1.0E+06	5.5E+04	69.0%	109

3.5.2 High activity beta rich stone (S1643)

A stone find was detected on 2nd November 2015 on Sellafield beach during a routine vehicle survey that had a ^{137}Cs activity of 3.7E+06 Bq (Table 9). This find had the highest ^{137}Cs activity of any beta rich stone recorded to date. The contact dose rate was also high at 1.2 mSv/hr and ranks the stone as the 2nd highest contact dose rate of any beta rich stone recorded to date.

In order to assess the risk from this find it was important to account for its physical size. The stone had a length of 62.5 mm and was therefore the 18th largest stone found to date. PHE have previously used a dose conversion factor of 0.86 mGy/hr/kBq/cm^2 which allowed the estimation of a skin dose of 110 mSv/hr based on the area of the stone that could contact the skin (30 cm^2) and its ^{137}Cs activity.

The PHE risk assessment (Brown & Etherington, 2011) considered the skin dose from a beta rich stone with a ^{137}Cs activity of 8.75E+05 Bq (4 times lower than S1643) although with an area of 9.4 cm^2 (3 times lower than S1643). As the skin dose is related to the activity and the surface area then it is reasonable to conclude that the skin dose from S1643 would be comparable to that of the stone evaluated by PHE which had a lower activity but distributed over a smaller surface area. PHE concluded that the exposure time required to reach the threshold [10 Gy] for deterministic effects on the skin would be approximately 50 hours and that it is extremely unlikely that stones could remain in contact with the skin for such lengths of time. PHE further stated that it can be reasonably concluded that skin dose thresholds could not be exceeded by objects with these activities.

Table 9: Comparison between S1643 with all beta rich stones.

	Activity (Bq) or Contact Dose (nSv/hr)					
		All beta rich stone finds				
Sample	**S1643/SEL**	**Min**	**Max**	**Average**	**Percentile**	**Rank**
^{137}Cs	3.7E+06	2.0E+03	3.7E+06	5.4E+04	100.0%	1
^{241}Am	2.0E+03	0.0E+00	5.3E+03	<3.3E+02	98.0%	12
Contact dose	1.2E+06	0.0E+00	2.5E+06	4.7E+04	99.8%	2

3.5.3 ^{60}Co–rich particle (S1750)

A radioactive object was detected during a routine vehicle survey within the intertidal zone of St. Bees beach on 17th March 2016. Radioactivity was associated with a particle that was located within a sandy area of beach at a depth of 2 cm. The radio-analytical results demonstrated that it was categorised as a ^{60}Co rich find.

The last ^{60}Co rich find was recovered on the 22/02/2013 on Sellafield beach and since the programme began in 2006 a total of 18 ^{60}Co rich finds have been recovered to date. Of these, 17 are particles with the remaining find being a piece of wire.

A comparison between the measured activity of S1750 and that of the 17 finds recovered previously is shown in Table 10. The radioisotope signatures for the current find are well within the range of the previously recorded ^{60}Co rich finds.

A comparison between S1750 and the only previous ^{60}Co rich find recovered at St. Bees beach (2009/07/02/01/STB, July 2009) is included in Table 11. This demonstrates that the current find is comparable with the previous find in most respects (in particular the field measurement made in contact with the particle) though it has a slightly higher ^{60}Co activity and a higher limit of detection value for ^{137}Cs.

A total of 9 of the previous ^{60}Co rich particle finds have been subject to detailed analysis by external laboratories. These analyses identified the particles as steel (4 particles), iron and iron oxide (4 particles) and silicate (1 particle). The previous ^{60}Co rich particle from St. Bees beach was categorised as "Steel" and was subject to detailed analysis by gamma scan, alpha spectroscopy and ^{90}Sr analysis however no other radioisotope was detected above the analytical limit of detection.

In summary, particle S1750 was identified as unusual as ^{60}Co rich finds are relatively rare, however this particle is well within the range of previous measurements and therefore is comparable to the particles considered by PHE in the Health Risk Assessment (Brown & Etherington, 2011; Etherington *et al*., 2012).

Table 10: Comparison between S1750 with all ^{60}Co rich particles.

	Activity (Bq) or Contact Dose (nSv/hr)					
		All ^{60}Co rich particle finds				
Sample	**S1750**	**Min**	**Max**	**Average**	**Percentile**	**Rank**
^{60}Co	1.1E+04	2.5E+03	2.4E+04	1.1E+04	62.5%	7
^{137}Cs	<1.4E+02	<1.8E+01	<1.4E+02	<8.8E+01	93.7%	2
^{241}Am	<6.5E+01	<8.9E+00	4.5E+03	3.9E+02	25.0%	13
Contact dose	2.0E+03	1.0E+03	1.3E+05	1.8E+04	18.7%	11

Table 11: Comparison between S1750 with the previous measured ^{60}Co rich particle at St. Bees beach.

	Measurement		Change (%)
Date /Time	**17/03/2016 10:21**	**02/07/2009 14:05**	
Sample	**S1750**	**2009/07/02/01/STB**	
Analytical results			
^{60}Co (Bq)	1.1E+04	8.4E+03	+31
^{137}Cs (Bq)	<1.4E+02	<7.7E+01	+82
^{241}Am (Bq)	<6.5E+01	<1.4E+02	-54
Field measurements in contact with particle			
DP6 (cps b/g)	250	285	-12
DP6 (cps a)	0	0	0
44B (cps g)	1000	1000	0
IonC (b/g micro-Sv/hr)	2	2	0
IonC (g micro-Sv/hr)	2	2	0

4 Data Analysis Review

4.1 Spatial Analysis of Beach Finds

To investigate if there is any correlation between find characteristics and the find location, the beach monitoring GIS has been used to generate find rate maps along the coast between St. Bees and Drigg point. This was achieved by dividing the coast up into 100 m grid cell (note that the area of each cell equals 1 ha) the total area monitored within each cell and the total number of finds (accounting separately for alpha rich particles, beta rich particles and beta rich stones). It should be noted that ^{60}Co rich finds could not be analysed statistically due to the low number recovered. In order to account for the differences between monitoring technology the data were separated into Synergy and Synergy 2 subsets. Find rates were also found to be highly uncertain when they related to small amounts of monitoring within a cell hence data were filtered so that find rates are only presented when more than 1 ha of monitoring occurred in a grid cell.

Find rate maps for Synergy and Synergy 2 are shown in Figure 8 and Figure 9 respectively and are summarised in Figure 10. These maps illustrate that the areas monitored for Synergy and Synergy 2 were similar, although with a larger total area and a greater area monitored at Drigg by Synergy. The summary of the find rate maps shown in Figure 10 illustrate that alpha rich particles finds are predominantly recovered to the north of the Sellafield discharge pipeline with a peak to the north (at around 1-2 km) and a gradual decay with distance. There is a discontinuity in Figure 10 as monitoring cannot be conducted between the northerly edge of Braystones beach and the southerly edge of St. Bees beach due to the nature of the beach. Beta rich particles and stones were found to be more tightly clustered, with again a peak to the north of the pipeline (although only several hundred metres). It is interesting to note that the data from Synergy 2 seems to show that beta rich particles and stones are more tightly clustered than was found for the Synergy monitoring. This could suggest that the areas north of the pipeline are being stripped of particles by the monitoring programme at a rate that is greater than the mixing rate of material along the beach.

The trends in find activities with distance along the coast were also evaluated using the position of the Sellafield pipeline as a datum point. Figure 11 presents the data on activity with distance along the coast for alpha rich particles, beta rich particles and beta rich stones. The activity of alpha rich and beta rich particles can be seen to show some evidence of a reduction with distance from the pipeline. If it is assumed that the distance along the coast (for a particular type of material) is related to time since discharge then this indicates that material loses activity over time as would be expected from erosion processes. Beta rich stones show a more complex picture with the highest activity occurring at 1300 m north of the pipeline.

The spatial distributions of find rates and activities of beta rich particles and stones are similar, with the majority of finds located within 1000 m of the discharge pipelines. However, the distribution for alpha rich particles is clearly different.

It is not clear why alpha rich particles would appear to be more evenly distributed across the beaches than beta rich finds, although there are a number of possible explanations, including: (i) alpha rich particles are more mobile in a beach environment and therefore have travelled further; or (ii) alpha rich particles were released into the environment much earlier than the beta rich finds and have therefore had more time to be more widely distributed.

Work is scheduled for 2016/17 on coastal geomorphology and sediment transport to further investigate the transport of material along the coast.

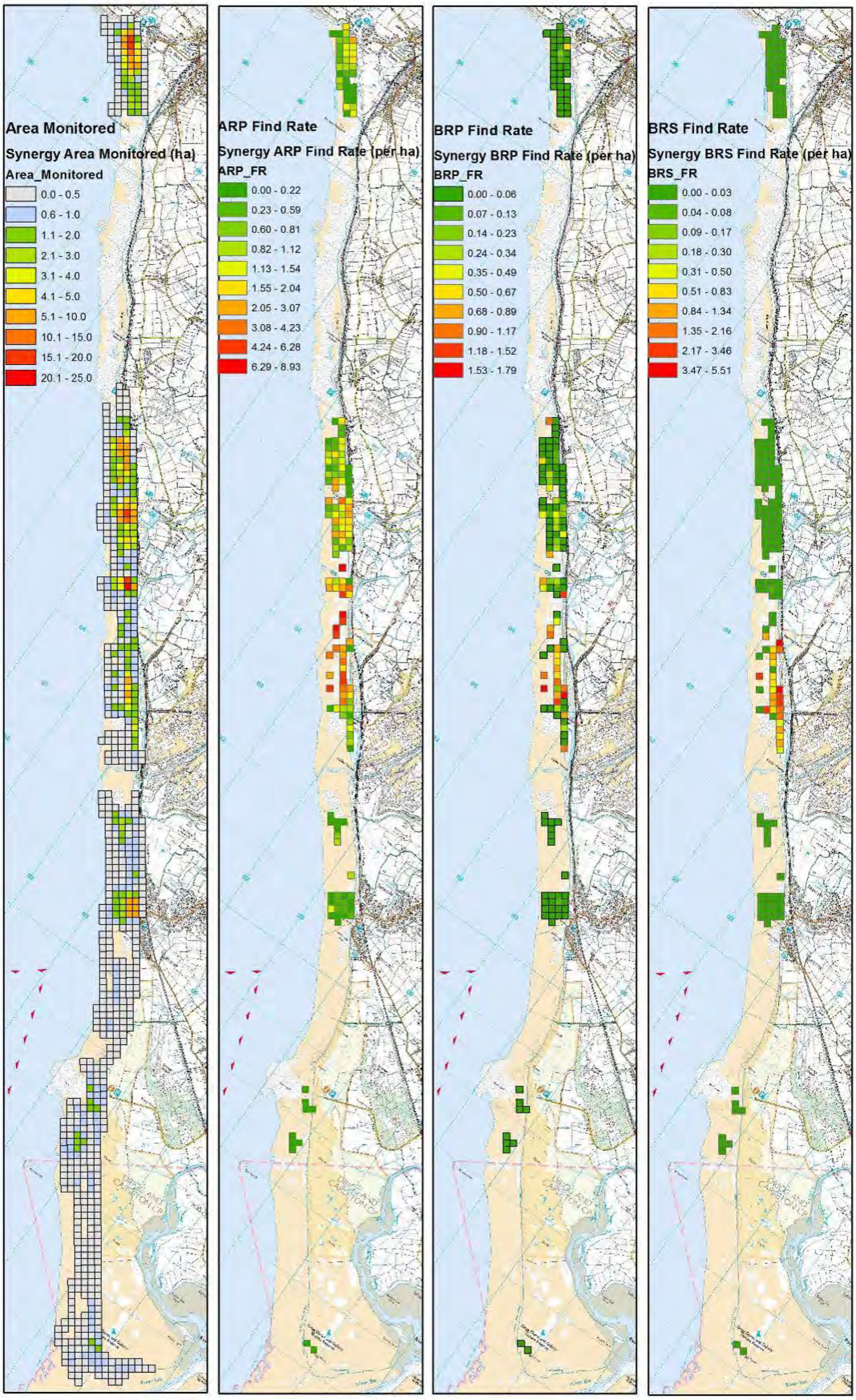


Figure 8: Find rate map for the Synergy monitoring period subdivided into the area monitored (ha), alpha rich particle find rate (ha^{-1}), beta rich particle find rate (ha^{-1}) and beta rich stones find rate (ha^{-1}).

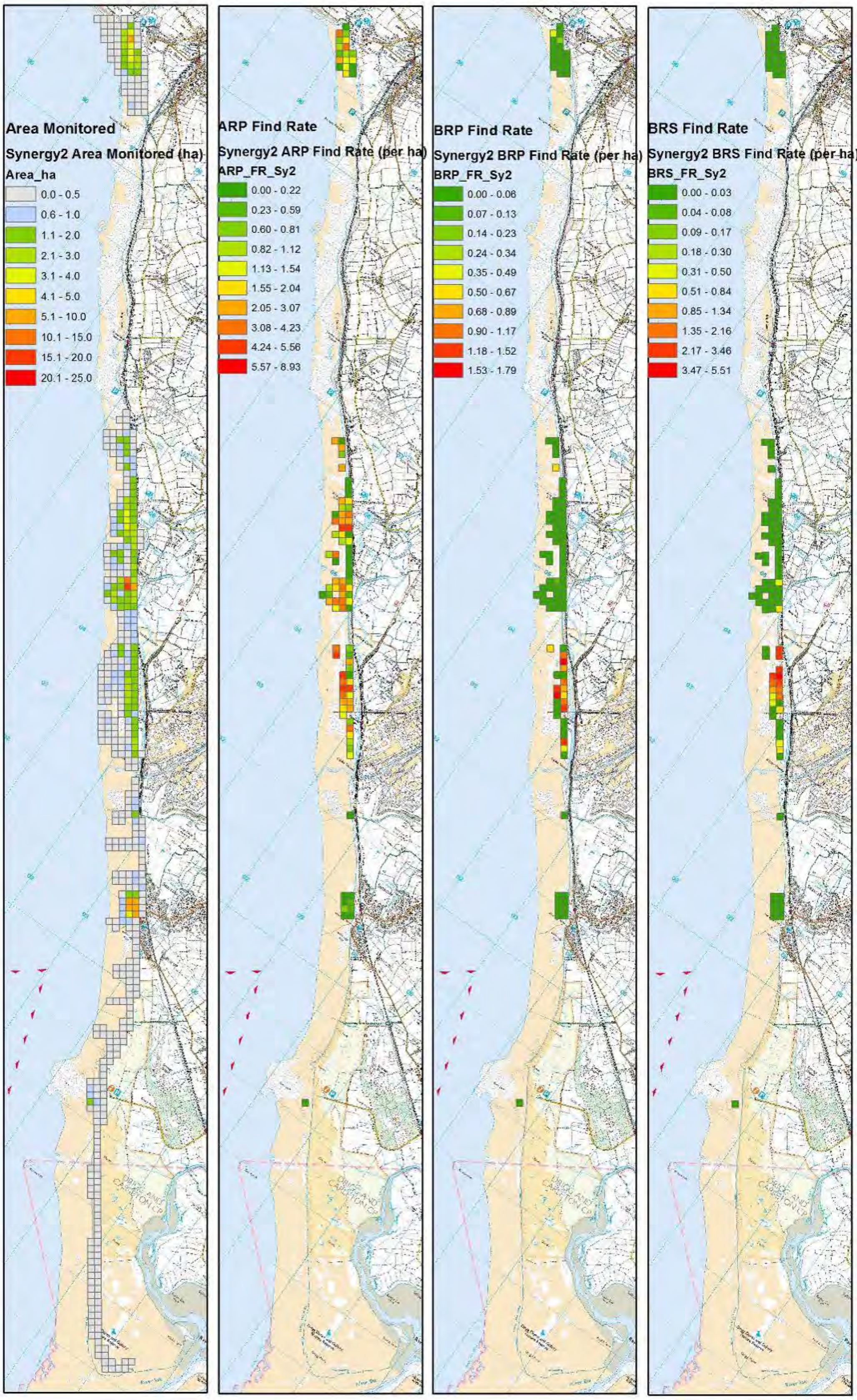


Figure 9: Find rate map for the Synergy 2 monitoring period subdivided into the area monitored (ha), alpha rich particle find rate (ha^{-1}), beta rich particle find rate (ha^{-1}) and beta rich stones find rate (ha^{-1}).

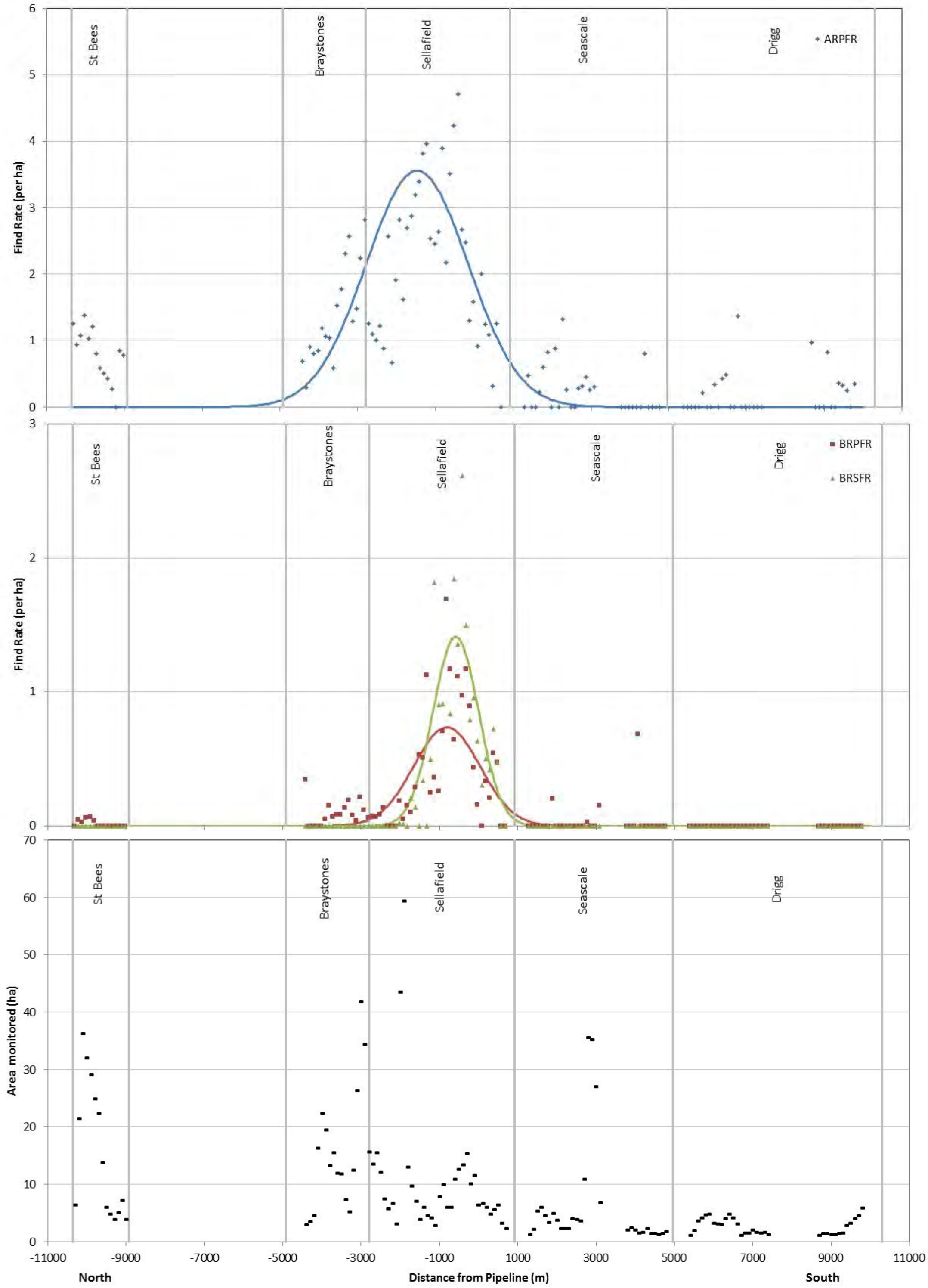


Figure 10: Spatial distribution of find rates for alpha rich particle (blue), beta rich particles (red), beta rich stones (green) and the monitoring areas (black) along the beaches (for Synergy and Synergy 2 data combined).

ARPFR - Alpha Rich Particle Find Rate, BRPFR - Beta Rich Particle Find Rate, BRSFR - Beta Rich Stone Find Rate.

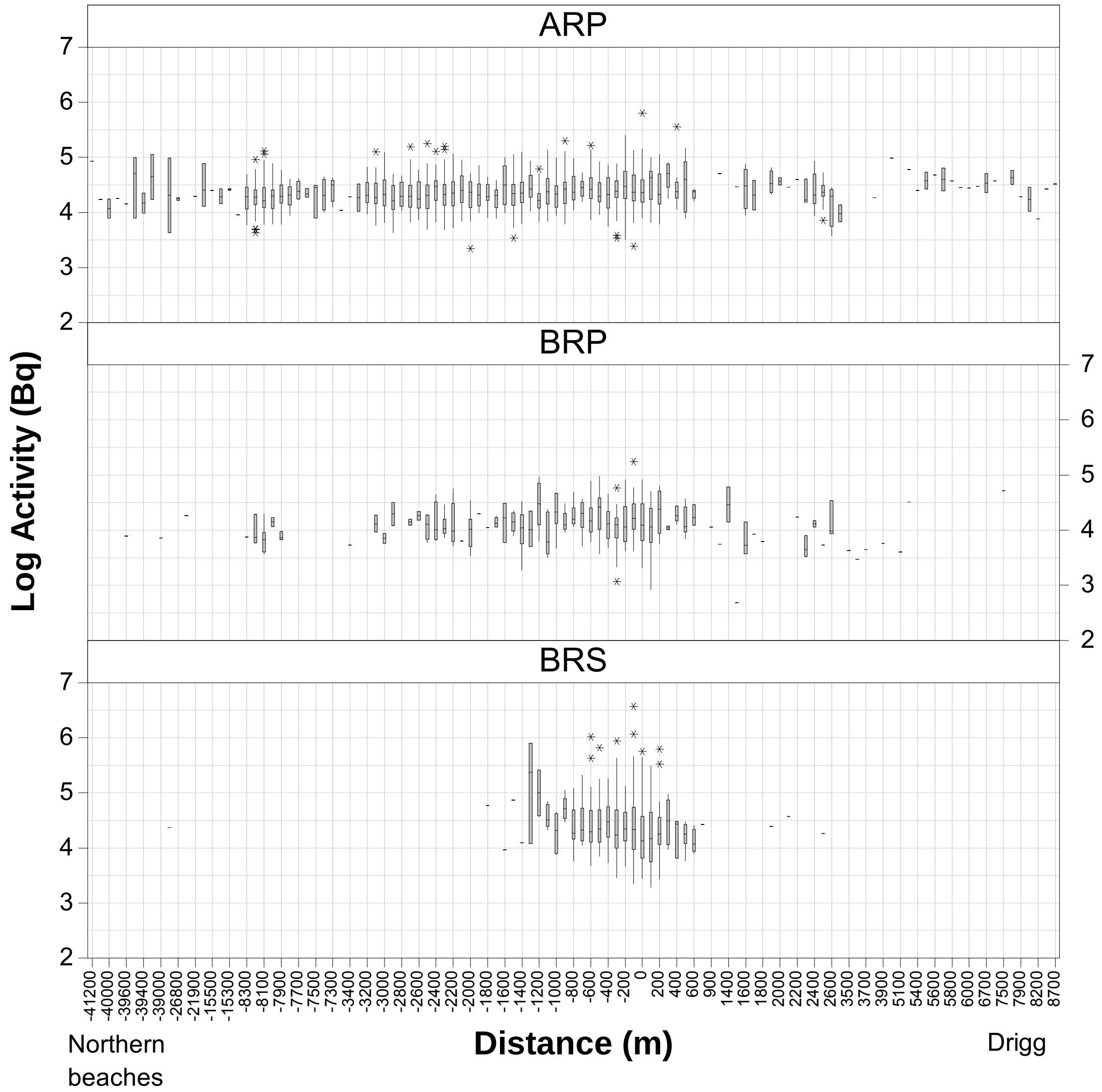


Figure 11: Relationship between find activity and distance from the Sellafield pipeline (for all data recorded to date).

ARP - Alpha Rich Particle, BRP - Beta Rich Particle, BRS - Beta Rich Stone.

4.2 Find Rates per Hectare

4.2.1 Find rate trend analysis

The analysis of the spatial distribution of find rates shown in Figure 10 illustrate that find rates are not consistent spatially and that the peaks of the distributions of alpha rich particles, beta rich particles and beta rich stones all occur on Sellafield beach. However, it is also clear that the shapes of these distributions differ between the three types of finds, with alpha rich particles being the most dispersed, with the most northerly peak and beta rich stones being the least dispersed, with a peak closest to the point the sealines cross the beach. The consequence of this is that trends in peak find rates can only be compared for fixed locations. This is clearly much less of an issue for beaches distant from Sellafield beach (*i.e.* St. Bees and Seascale).

The geographic locations of the spatial peaks in find rate were determined along with their Standard Deviations and these were used to define fixed locations to allow the comparison of find rates over time. Find rate data were found to show considerable variability when they were averaged over small areas. Hence, find rates were averaged over fixed areas of 10 ha (or approximately 2-3 weeks of monitoring effort) which was found to be suitable to allow trending. The resulting graphs are shown in Figure 12 and illustrate that:

- Alpha rich particle find rates increased significantly when the Synergy monitoring system was introduced due to its increased sensitivity to ^{241}Am. Since then find rates have been reasonably constant, with the increase recorded when Synergy 2 was introduced being found to be temporary, with find rates quickly declining to levels that were within the range of data recorded by the previous Synergy system.
- Beta rich particle and stone find rates reduced quickly when monitoring began with the Evolution System in 2006. Since then they have remained reasonably constant.

These data illustrate that the peaks in find rate referred to in the Particles Annual report for 2014/15 (Sellafield Ltd, 2015) were short term increases, although somewhat higher than those that are periodically observed on the beaches. They were, to some extent, due to monitoring for the initial period of Synergy 2 deployment focussing on the areas that are now understood to represent spatial peaks in find rates. There was no evidence that the alpha rich particle finds recovered during the initial period of Synergy 2 monitoring differed from the subsequent finds in terms of activity or depth of recovery.

Monitoring for 2016/17 is to continue to focus on these peak areas to determine whether a concerted monitoring effort can deplete find rates and, potentially, determine the rate of repopulation or mixing of material on the beach.

A comparison was also made between the alpha rich particle find rate at Sellafield beach and those recorded in the adjacent monitoring period at Braystones beach. Data for both the whole beach and for the repeat areas showed that these paired data were correlated, with higher find rates on Sellafield beach being associated with higher find rates on Braystones beach. This suggests that there may be a common factor between these beaches that controls find rates. This could be an environmental factor, such as storm events, and Section 8.2 details the further analysis that will be conducted in 2016/17.

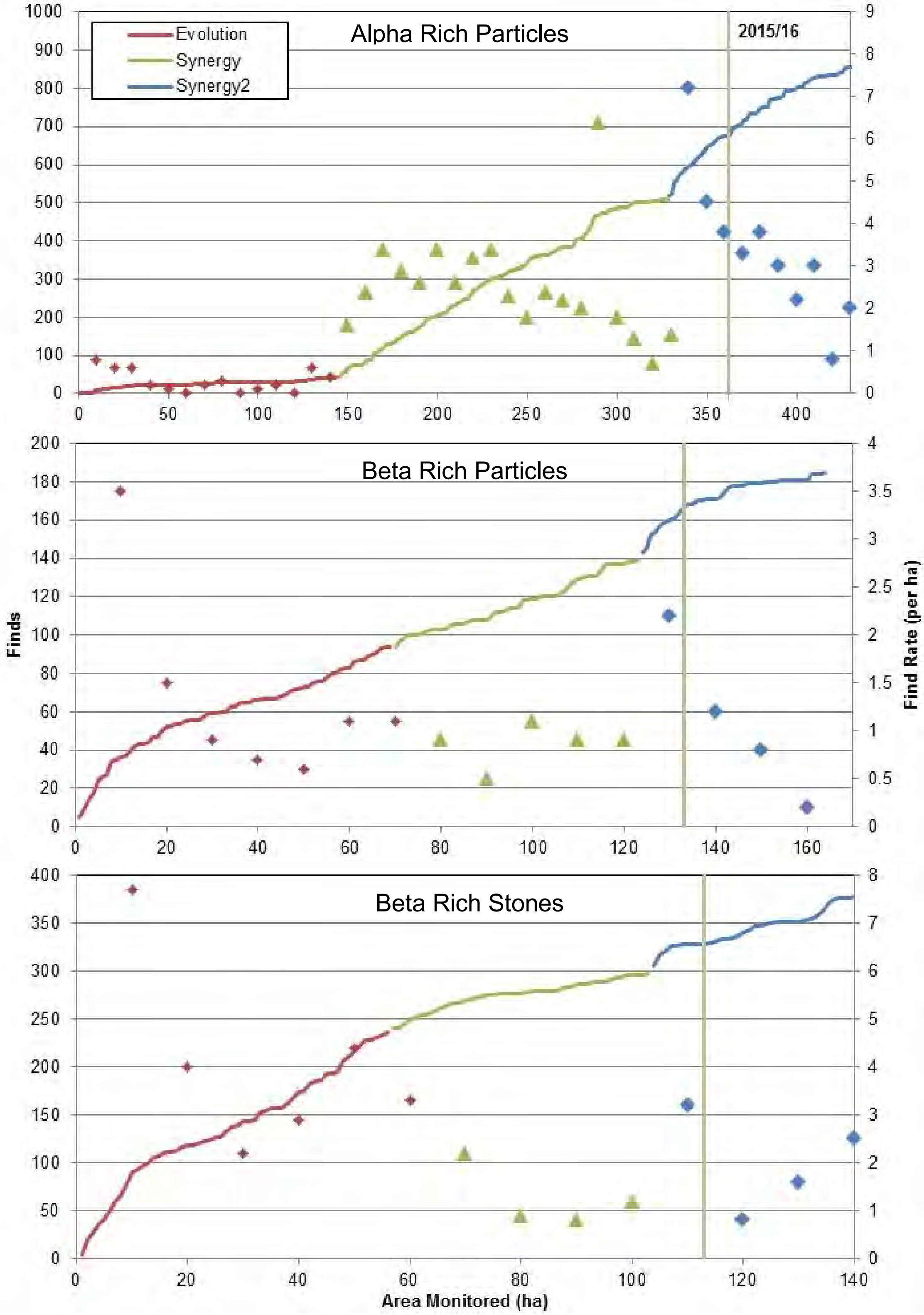


Figure 12: Trends in alpha rich particle, beta rich particle and beta rich stone finds with area monitored at the spatial peaks (+/- 1 standard deviation). Points show find rates averaged over 10 ha areas, vertical lines show the start of the 2015/16 monitoring data. Data are from Sellafield beach.

4.2.2 Annual find rates

The annual find rates for each of the beaches that are monitored in West Cumbria are shown in Table 12. Table A2.4 in Appendix A show the breakdown of finds by find types. These data illustrate that find rates during 2015/16 were within the typical ranges previously observed for all beaches, with the exception of the find rate on Drigg beach which was three times greater than that observed in 2014/15. It is important when examining changes in find rates to consider the area monitored and for Drigg beach only 1.08 ha was monitored with 2 particles being found. As noted in the previous section, find rates averaged over areas of less than 10 ha are highly variable and finding two particles in 1 ha of monitoring area has been observed eight times in the past from monitoring conducted at Drigg.

Table 12: Annual find rates for the last five years (finds per hectare).

Monitoring area	2011/12	2012/13	2013/14	2014/15	2015/16
Allonby	0.08	0.30	0.25	0.61	0.00
Workington Stones	–	0.00	0.00	0.23	–
Workington Particles	–	0.31	0.17	0.67	–
Workington	–	0.31	0.17	0.90	–
Harrington	0.39	1.03	0.00	0.00	–
Parton	–	–	–	–	–
Whitehaven	0.00	–	–	–	–
St. Bees	1.62	0.30	0.82	1.19	1.59
Nethertown	–	–	0.00	–	–
Braystones	1.29	1.55	0.80	3.00	0.78
Sellafield Stones	0.30	0.43	0.20	0.92	0.72
Sellafield Particles	3.37	3.29	0.95	5.47	2.79
Sellafield Finds	3.67	3.72	1.15	6.38	3.50
Seascale Stones	0.00	0.00	0.00	0.00	0.00
Seascale Particles	0.13	0.50	0.54	0.52	0.18
Seascale Finds	0.13	0.50	0.54	0.52	0.18
Drigg	0.34	0.00	0.00	0.60	1.85
Silecroft	–	–	–	–	–
All	1.72	1.65	0.77	2.39	2.09

'–'indicates that no monitoring was carried out.

The annualised alpha rich and beta rich particle find rates following the introduction of the Groundhog Synergy system in August 2009 for the main beaches are shown in Figure 13. This figure shows relatively stable find rates, with a peak in alpha rich particles at Sellafield and Braystones and beta rich particles at Sellafield coinciding with the introduction of Synergy 2 in May 2014. Find rates at both beaches declined in 2015/16 back to levels typical of those observed before Synergy 2 was introduced. The majority of the beta rich particles detected in 2015/16 were located on Sellafield beach as shown in Figure 10.

Beta rich stone find rates since monitoring began in 2006 are displayed in Figure 14. The number of stones recovered during 2015/16 reduced when compared with 2014/15, with all stones being recovered from Sellafield. Figure 14 illustrates that the annual stone find rates at Sellafield Beach have generally declined over time as also shown in Figure 12.

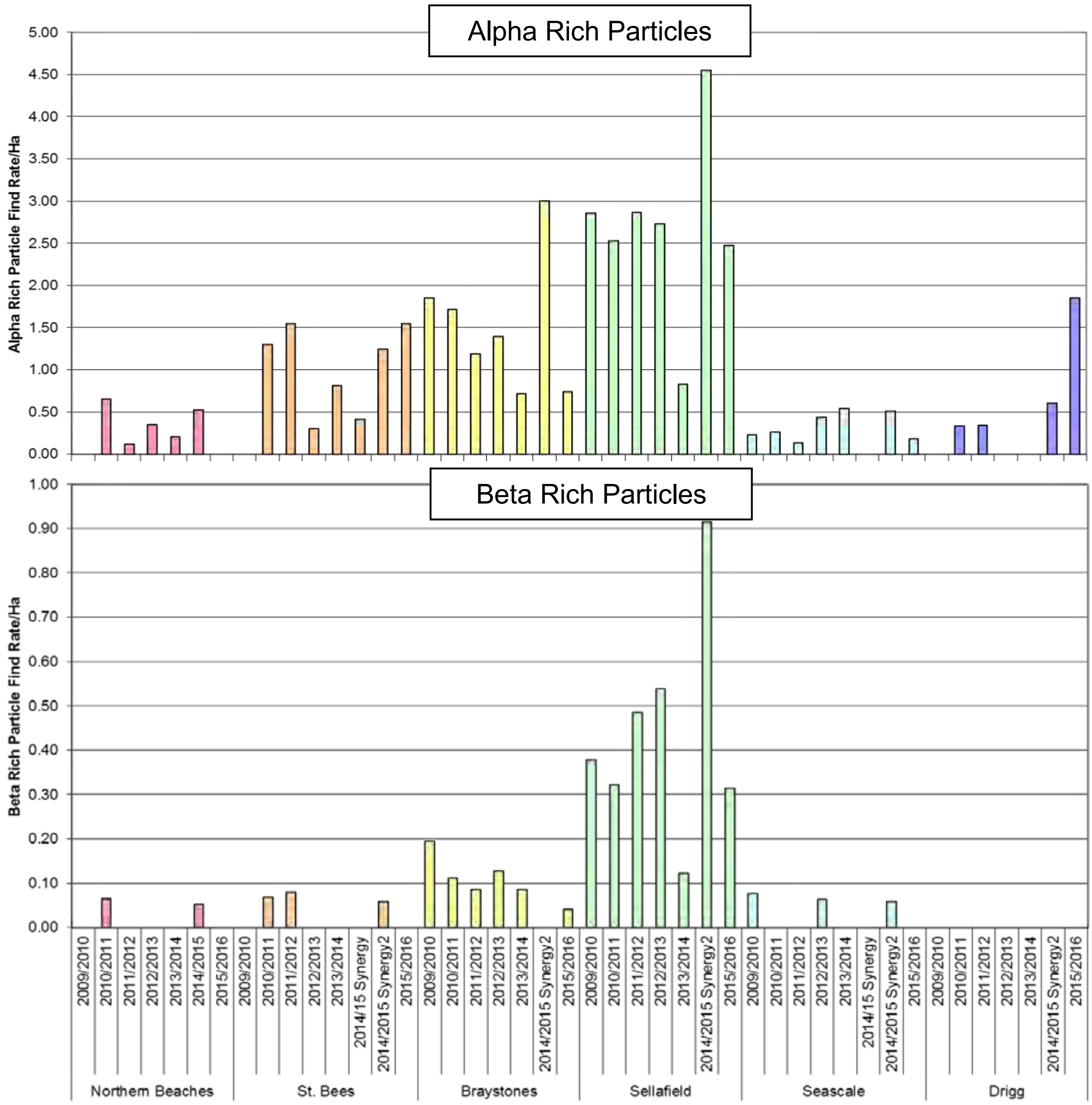


Figure 13: Alpha rich particle and beta rich particle find rates since the introduction of Synergy.

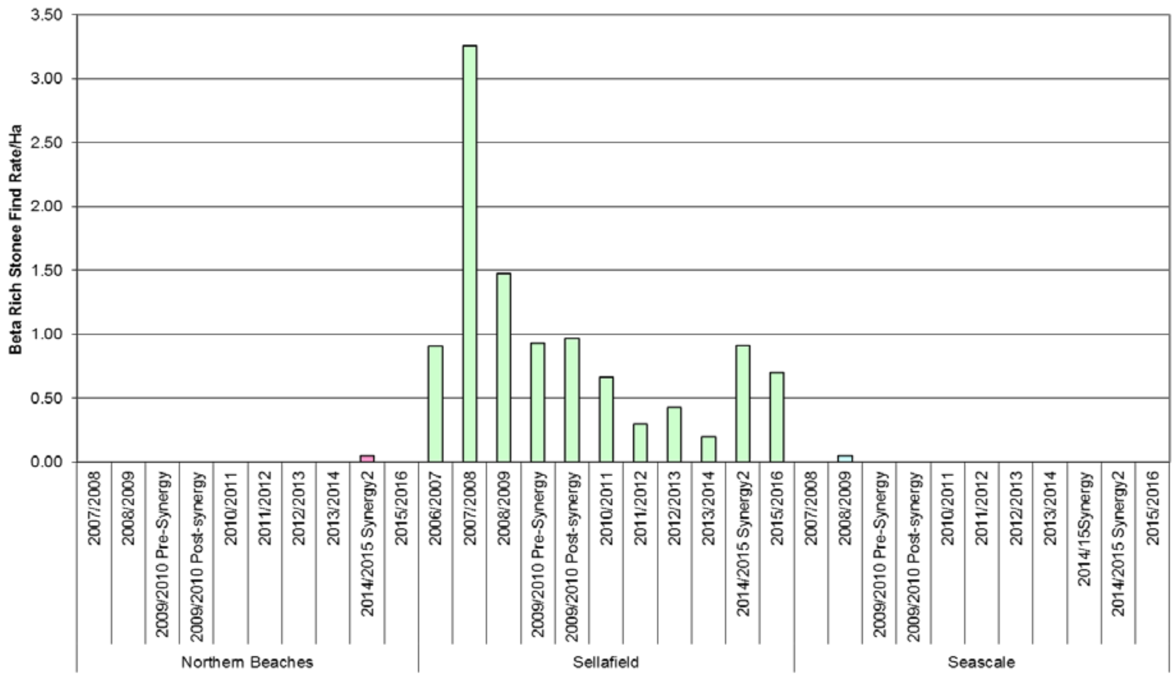


Figure 14: Beta rich stone find rates between 2006/07 and 2015/16.

4.3 Investigation Monitoring

4.3.1 Repeat area monitoring and analysis

Following their introduction in 2011/12, repeat areas continued to be monitored during visits to Sellafield, Braystones, St. Bees and Seascale beaches (7, 3, 5 and 5 times respectively) during the 2015/16 programme. The purpose of this monitoring is to provide reassurance that the find rates and find characteristics on beaches with the highest historic find rates and highest public occupancy are not changing significantly. At Sellafield, Braystones and St. Bees all the available beach area inside the designated repeat areas was monitored inside one tidal cycle, giving a footprint of that area of beach. At Seascale the repeat area is much larger (> 3 ha) and as a consequence is unable to be monitored in one tidal cycle. The data from previous repeat area monitoring trials has demonstrated that repopulation or mixing of material can occur in as little as two tidal cycles.

The overall find rate in 2015/16 was similar to that of the previous year (383 finds in 160.3 ha in 2014/15 compared to 349 finds in 166.76 ha in 2015/16). Table 13 shows that the find rates within the repeat areas at St. Bees, Braystones and Sellafield were relatively constant between 2015/16 and 2014/15 although a reduction in the find rate at Seascale was observed with results being more consistent with measurement made in 2011/12 than those of the previous three years. Comparing find rates from monitoring inside and outside the repeat areas (Table 13) for Sellafield and Braystones beaches is complicated by the spatial distribution of finds shown in Figure 10. The higher find rates in the repeat area at Braystones beach is partially due to the repeat area being located at the southerly limit of the beach, closest to Sellafield beach and the spatial peak in find rates shown in Figure 10. However, an important conclusion from Table 13 is that despite repeat monitoring since 2011/12 there is no evidence of any substantial depletion of find rates within the repeat areas. Hence, the data confirm that the beaches are well mixed which was also a conclusion of the conceptual site model report (Rankine and Jackson, 2014).

Table 13: Find rates for all find types within and outside designated repeat areas.

Beach	Area	Find rate in area monitored				
		2011/12	2012/13	2013/14	2014/15	2015/16
St. Bees	Inside Repeat Area	0.94	0.40	1.02	2.24	2.13
	Outside Repeat Area	1.77	0.28	0.79	0.98	1.42
Braystones	Inside Repeat Area	1.69	3.02	0.60	6.02	4.68
	Outside Repeat Area	1.24	0.90	0.86	2.24	0.73
Sellafield	Inside Repeat Area	3.27	3.38	1.88	6.69	5.09
	Outside Repeat Area	3.78	3.78	0.86	6.31	3.39
Seascale	Inside Repeat Area	0.15	0.50	0.56	0.54	0.12
	Outside Repeat Area	0.00	0.52	0.00	0.51	0.09

Note: Repeat area monitoring introduced in 2011/12.

4.4 Find Characterisation

4.4.1 Mixed alpha and beta rich finds

In general, particle finds contain either ^{137}Cs or ^{241}Am at detectable levels, with the other radionuclides being reported as being below the analytical limit of detection. Of the 1606 alpha rich particle finds recovered up to the end of March 2016 only 28 contained measurable levels of ^{137}Cs activity. This is approximately 2 *%* of the total number of alpha rich finds. Similarly for beta rich particle finds, of the 387 recovered up to the end of March 2016, 44 (or 11 *%)* contained measurable levels of ^{241}Am activity (Table 14).

Aside from the unusual find recovered from Seascale in June 2014, which had a ^{137}Cs activity of 7.38E+03 Bq, the activity of ^{137}Cs in alpha rich finds is generally relatively low, with the maximum being only 6.09E+01 Bq. For the beta rich finds, the maximum ^{241}Am activity is somewhat higher at 1.63E+03 Bq, which is just below the activity of finds recovered by detection of ^{241}Am. The relative activities are shown graphically in Figure 15 and it can be seen there is no clear relationship between the relative activities is present.

Figure 16 shows the ^{241}Am activity in beta rich particle finds. This illustrates that there is no correlation between ^{241}Am and ^{137}Cs activities.

Relatively few alpha rich stones have been found, with only six recovered to date. Of these, three also contained detectable levels of ^{137}Cs. Of the 580 beta rich stones, 93 also contained detectable levels of ^{241}Am. The relative activities of all the stone finds with both ^{137}Cs and ^{241}Am are shown in Figure 17.

Table 14: Find classifications since 2006/07.

	Alpha rich			Beta rich		
	Pre-Synergy	Synergy	Synergy 2	Pre-Synergy	Synergy	Synergy 2
Total number	62	983	567	599	206	161
No. of particles	59	980	567	210	110	67
No. of stones	3	3	0	389	96	94
Particle mean ^{241}Am (Bq)	7.82E+04	3.00E+04	2.49E+04	3.68E+02	4.87E+02	2.13E+02
Particle max. ^{241}Am (Bq)	6.34E+05	2.52E+05	1.46E+05	1.15E+03	1.63E+03	7.17E+02
Number of particles containing ^{241}Am	59	980	567	18	13	13
Stone mean ^{241}Am (Bq)	1.74E+04	2.40E+05	0.00E+00	7.70E+02	4.56E+02	7.49E+02
Stone max. ^{241}Am (Bq)	3.54E+04	6.18E+05	0.00E+00	4.99E+03	1.17E+03	5.27E+03
Number of stones containing ^{241}Am	3	3	0	58	12	23
Particle mean ^{137}Cs (Bq)	4.09E+01	1.99E+01	3.95E+02	1.62E+04	2.05E+04	2.75E+04
Particle max. ^{137}Cs (Bq)	6.09E+01	3.36E+01	7.38E+03	7.19E+04	2.92E+05	1.74E+05
Number of particles containing ^{137}Cs	2	7	19	210	110	67
Stone mean ^{137}Cs (Bq)	7.04E+03	5.46E+01	0.00E+00	4.01E+04	5.97E+04	1.07E+05
Stone max. ^{137}Cs (Bq)	7.20E+03	5.46E+01	0.00E+00	8.75E+05	1.04E+06	3.73E+06
Number of stones containing ^{137}Cs	2	1	0	389	96	94

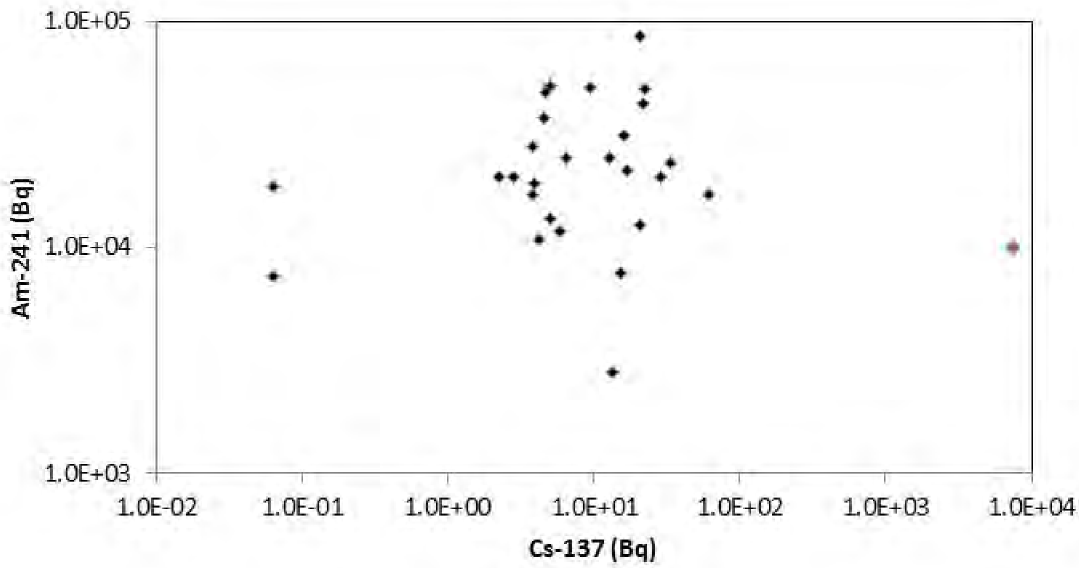


Figure 15: ^{137}Cs activity in alpha rich particle finds (the unusual find at Seascale is marked in red).

Note Unusual Seascale find (S1164) included in chart. S1164 had ^{137}Cs activity of 7.38E+03 Bq and ^{241}Am activity of 1.01E+04 Bq.

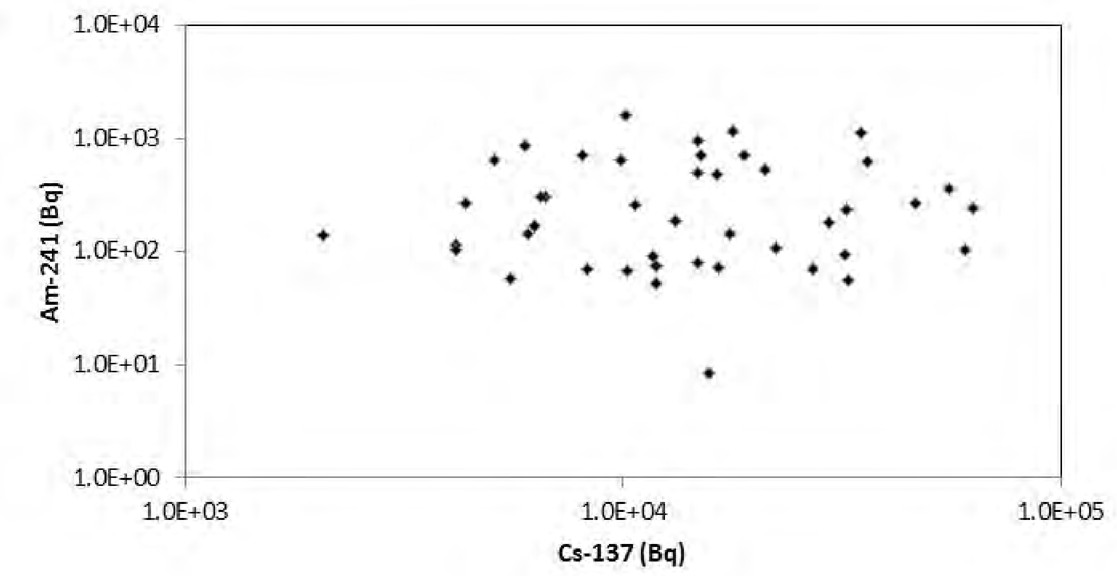


Figure 16: ^{241}Am activity in beta rich particle finds.

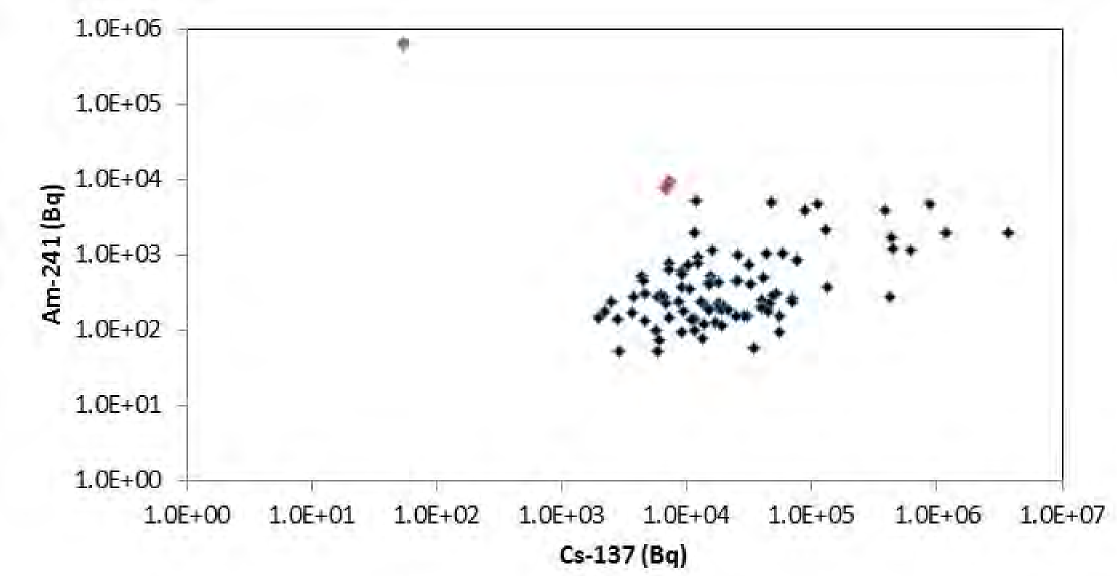


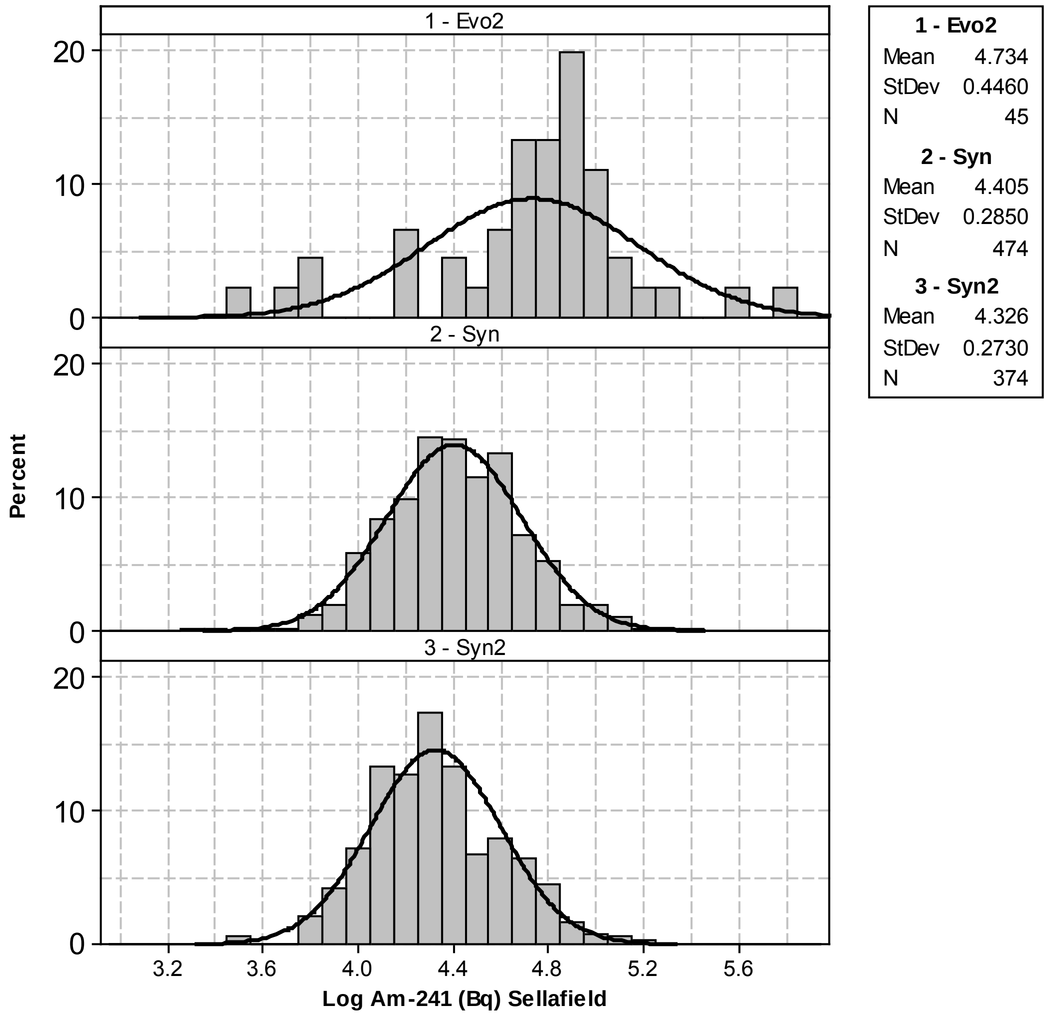
Figure 17: ^{137}Cs and ^{241}Am activity in stone finds (alpha rich in red).

4.5 Activity Distribution for ^{137}Cs and ^{214}Am

The introduction of Synergy 2 appears to have impacted on the types of material being recovered, with a noticeable increase in the detection of both lower activity ^{241}Am particles and higher activity ^{137}Cs particles. Data have been analysed for vehicle surveys of Sellafield beach and compared between Evolution (used to August 2009), Synergy (used to May 2014) and Synergy 2.

Figure 18 shows that the distribution of detected ^{241}Am activity on particle finds reduced with the introduction of Synergy. This was expected as the Synergy system was designed to have an improved detection capability as is evidenced by the substantial increase in alpha rich finds detected (45 with Evolution and 474 with Synergy). The introduction of Synergy 2 can be seen to have shifted the activity distribution towards lower activity alpha rich particles (as shown by the reduction in mean from 2.5E+04 Bq to 2.1E+04 Bq). However, the standard deviation also was found to reduce, with a lower rate of alpha rich particle finds with activities higher than 5.0E+04 Bq (equivalent to Log 4.7 in Figure 18), with 14% and 11% of the Synergy and Synergy 2 data, respectively being above this threshold. The reduction in the detection of high activity alpha rich particles could suggest that the population of these highly detectable finds may be being depleted by the monitoring programme. Detection at the lower limits of the distribution also changed between Synergy and Synergy 2, with 6.8% of the Synergy alpha rich particles being lower than 1.0E+04 Bq (Log 4.0) compared to 9.9% of the equivalent Synergy 2 data. As noted previously, this would be consistent with the improvement in detection efficiency of Synergy 2.

Figure 19 shows that there was a slight change in the distribution of ^{137}Cs activity detected when the system was changed from Evolution to Synergy, although in this case the total number of finds detected reduced (from 168 to 75). It is also noticeable that fewer very low activity beta rich particles (less than 6.3E+03 Bq, or Log 3.8) were detected with Synergy, with 23.8 % and 13.3 % of finds being lower than this threshold when monitored using Evolution and Synergy respectively. The detection of higher activity beta rich particles also changed going from Evolution to Synergy, with 13.1 % and 16.0 % of finds being above 3.16E+04 Bq respectively.

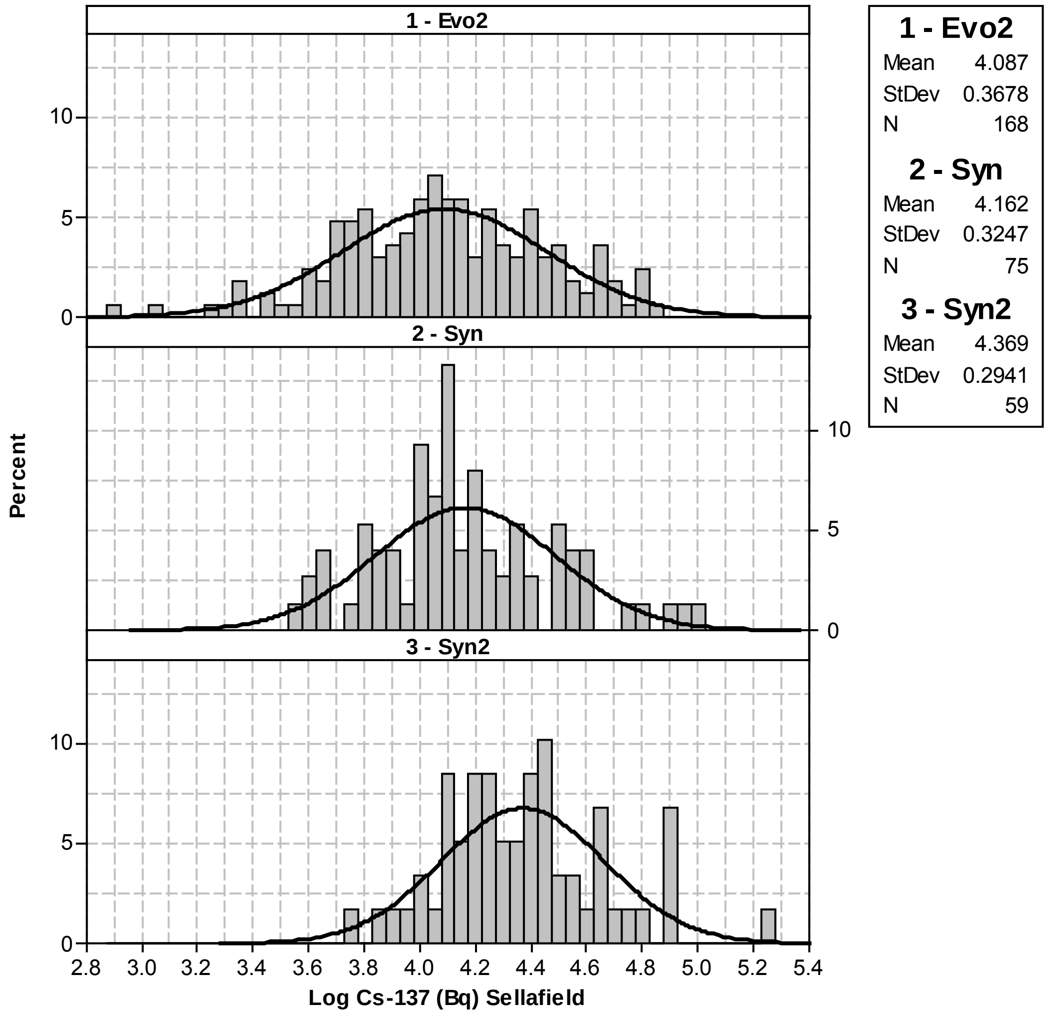


Note: Log scales have been used hence, Log 3 = 1,000 (1E+03); Log 4 = 10,000 (1E+04) and Log 5 = 100,000 (1E+05).

Figure 18: Distribution of ^{241}Am activity of alpha rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.

It is also noticeable that the mean ^{137}Cs activity detected increased when going from Synergy to Synergy 2, with 1.7 % of finds being less than 6.31E+03 Bq (compared to 13.3 % detected with Synergy) and 28.8 % of finds being above 3.16E+4 Bq (compared to 16.0 % detected with Synergy). This was not predicted by the instrumentation designers and further investigations are underway to determine the cause of this change.

The distribution of ^{137}Cs and ^{241}Am activities shown in Figure 18 and Figure 19 since Synergy 2 was introduced remain within previously observed ranges, providing reassurance that they are part of the same general population. This provides confidence that the PHE advice remains valid. It is now over six years since the most active beta rich particle find was recovered (from Whitehaven beach) and over nine years for the most active alpha rich particle find (from Sellafield beach).



Note: Log scales have been used hence, Log 3 = 1,000 (1E+03); Log 4 = 10,000 (1E+04) and Log 5 = 100,000 (1E+05).

Figure 19: Distribution of ^{137}Cs activity of beta rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.

4.6 Further Analysis of Beta Rich Particle Finds

4.6.1 Analytical approach

Laboratory analyses were performed on a selection of beta rich finds to provide information on the activity concentrations of ^{90}Sr and other alpha and beta emitting radionuclides and skin doses. Discussions of these data are given below. These discussions complement those given in the 2014/15 annual report (Sellafield, 2015).

The inventory of beach finds submitted for physical and radiochemical analyses to Golder Associates (UK) Ltd (Golder) for further analysis since August 2013 consists of:

Tranche 1	20 samples	August 2013
Tranche 2	7 samples	March 2014
Tranche 3	10 samples	July 2014
Tranche 4	10 samples	October 2015

These particles encompassed a range of beta-gamma contact dose rates with the exception of one particle which was the alpha rich high contact dose rate particle recovered from Seascale beach in June 2014. The analysis of these 47 finds was performed in project 'ESR 162'. Reference to 'ESR 162' is used here as an identifier of this work in relation to the previous analytical investigations presented in Sellafield (2015).

Golder has co-ordinated beta rich find analytical investigations through the use of several companies and organisations as shown in Table 15.

Table 15: Analysis conducted through the ESR 162 contract in 2015/16.

	Public Health England (PHE)	**British Geological Survey (BGS)**	**Amec Foster Wheeler (AMEC) and Public Health England (PHE)**
Non destructive	Particle isolation; Dose rate measurements; High resolution gamma spectrometry; Dose rate measurements using small volume ion chambers, Gafchromic film and Thermoluminescence Devices (TLD).	Scanning Electron Microscopy (SEM) imaging; Energy Dispersive X-ray (EDX) analysis.	
Destructive	Total dissolution – mineral acids, microwave digestion; Metal analysis by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and ICP Mass Spectrometry (ICP-MS);		Radiochemical analyses on selected digested particle solutions*.

* Radiochemical analysis will be used to determine: ^{90}Sr; ^{234,235,238}U; ^{238,239,240}Pu; ^{241}Pu; and ^{241}Am + Cm.

The specific types of physical and radiochemical analyses that have been and are being undertaken on the selected beta rich finds are described in the list below. More analytical details can be found in Sellafield (2015).

1. **Separation of high activity particles** from the beach find as delivered;
2. **High Resolution Gamma Spectrometry (HRGS)** on the beach find as delivered, the separated particle from within the beach find, the residual of the beach find, the washed (de-ionised water) particle and on an aliquot of the dissolution liquid (particle dissolved in acid);
3. **Optical particle imaging** using a binocular stereo photo-microscope;
4. **Scanning Electron Microscopy (SEM) particle imaging** for the purpose of detailed petrographical analysis using high-resolution secondary electron (SE) imaging;
5. **Energy-Dispersive X-ray microanalysis (EDXA)** for phase identification and characterisation of alteration products by simultaneous observation of spectra during SEM observation;
6. **Metals analysis** by inductively coupled plasma mass spectrometry (ICP-MS);
7. **Beta analysis (as ^{90}Sr) and ^{90}Sr content analysis** on an aliquot of the dissolution liquid (particle dissolved in mineral acid);
8. **Radiochemical analysis of ^{234,235,238}U, ^{238,239,240}Pu, ^{241}Pu and ^{241}Am + Cm** on an aliquot of the dissolution liquid (particle dissolved in mineral acid); and,
9. **Dose rate measurement using small volume ion chambers** on selected beach finds (Tanner, 2015).

The following criteria were used to select the ten beach finds submitted in October 2015:

- Any particle with ^{137}Cs activity greater than 1E+05 Bq to be analysed. Prior to 2 June 2015, all particles satisfying these criteria had been analysed. During 2015/16, one particle, found on 2 June 2015, was included in the list;
- Select four particles that have the highest ^{137}Cs activities that have not been analysed yet; and,
- Regarding beta/gamma dose rate, select five particles that give the highest dose rate that have not been analysed to date.

All of these beach finds had ^{137}Cs activities between 1.9E+04 to 1.7E+05 Bq and ^{241}Am activity < 8.2E+02 Bq.

During 2015/16, contact dose measurements and HRGS were performed on all 47 beach finds. The majority of finds (40 in total) have been dissolved in mineral acids and have undergone radiochemical analysis for ^{90}Sr, gross alpha and beta, U, Pu and Am/Cm activity by AMEC and PHE. The remaining seven finds, retained by Public Health England to have refined dose rate measurements made using small volume ion chambers (0.2, 6.0 and 350 cm^3) have now been released for further analysis. One of these samples was radiochemically analysed during 2015/16.

4.6.2 Petrographic results and conclusions

Example results from the petrographic analysis performed for a batch of 10 samples during 2015/16 are shown for a zirconium-rich beach find, in Figure 20, and a graphite-rich beach find, in Figure 21. Based on SEM and EDXA analysis of the likely source materials from which particles have originated, the 10 particles have been grouped in to 4 categories, as listed below. The first two categories contain eight particles and comprise natural mineral materials originating from rocks and sediments; the next 2 categories contain one particle each and comprise materials of anthropogenic origin - zirconium-rich and graphite.

4.6.2.1 Naturally occurring rock fragments (5 particles)

These particles are all pebbles of low porosity silicate rock fragments. Rock types identified include altered igneous (two types), sandstones (again two types, one a red sandstone, the other a grey muddy sandstone) and a mudstone (red). The varied lithologies of these pebbles mean that they have differing risks of fragmentation. The sedimentary types (sandstone, muddy sandstone and mudstone) are generally considered to have a higher risk of fragmentation than are the igneous types because of their granular structures and / or high content of relatively soft clay minerals. Overall the risk of fragmentation of the rock fragments is considered to be moderate.

4.6.2.2 Naturally occurring Biotite mica (3 particles)

Biotite mica is a naturally occurring mineral, found in many rock types. All three of these particles have similar and somewhat atypical (for biotite) physical appearances. Several have Fe-rich deposits on their surfaces which could contain adsorbed radioactive species. Alternatively, micas represent potential sites for Cs fixation by virtually irreversible cation-exchange for K. All finds are micro-fractured and one is present as five fragments, showing that breakage in addition to the detachment of cleavage plane flakes are characteristics that mean this group of particles carry a significant risk of further fragmentation.

4.6.2.3 Anthropogenic Graphite (1 particle)

The graphite particle hosts micro-particles (typically <5 μm) of Pu-rich material variably scattered on its surface. There are rare particles containing Zr and U also present. Graphite is a very soft material, so dispersal in the environment is possible through contact transfer; a strongly developed cleavage suggests fragmentation is also a high risk.

4.6.2.4 Anthropogenic Zirconium-rich (1 particle)

This particle comprises a core of material rich in Zr with discrete uranium rich inclusions; both elements are most likely present as oxides. The Zr-based constituent defines a network (or ‘chicken-wire’) texture which itself is microporous. An Fe-rich material, probably of oxide / oxyhydroxide, infills the Zr-defined fabric. Trace Cs is locally detected associated with the uranium rich inclusions. The angular form of the particle and its fine structure suggest that it represents a high risk for further fragmentation.

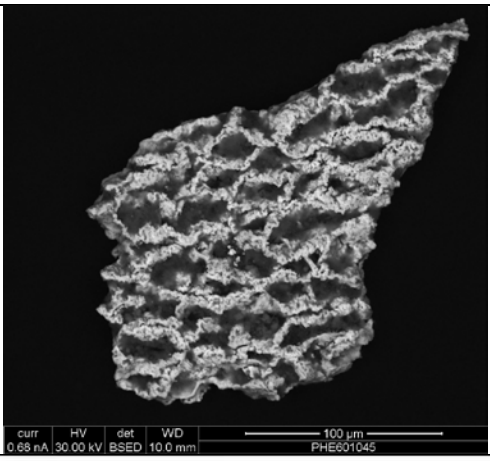
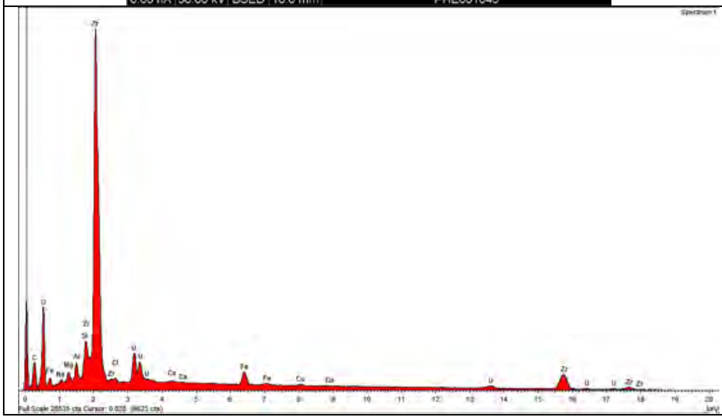
The particle shown below was identified as the only source of significant radioactivity through the use of a collimated monitor combined with selective shielding by a lead sheet. The active particle is a very thin tabular angular particle comprising a network substrate of material rich in Zr that contains U-rich inclusions both most likely as oxides. In detail, the Zr-rich substrate has a finely feathered texture. An Fe-rich phase, probably of oxide / oxyhydroxide, infills the network. Trace Cs is identifiable associated with the U-rich inclusions.	
	**BSEM image, 30 kV, 0.15 Torr of H2O** Image showing the whole particle, which comprises a high backscatter coefficient substrate with a network structure. The gaps in this structure are filled by a relatively low backscatter coefficient phase that has an Fe-rich detectable composition.
	**0-20 keV portion of EDXA spectrum; SOI5, 30 kV, 0.15 Torr of H2O** EDXA spectrum from the surface of the particle. This is from a high backscatter coefficient inclusion and shows significant U as well as the dominant Zr. Cs is detectable as a trace constituent. Fe is at least in part from the adjacent coating phase, as are the Si, Al, Mg, Na and Cl.

Figure 20: Example Petrographic analysis results for a zirconium rich beach find (particle 1198035).

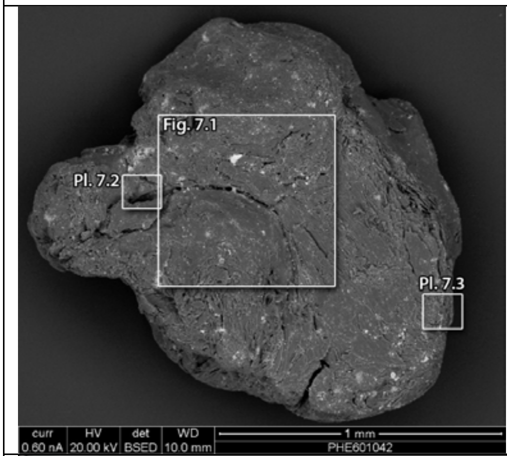
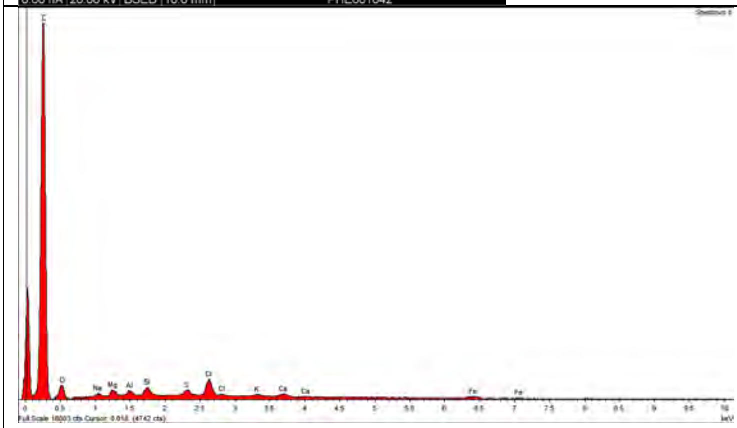
A particle which has a subrounded form and a deformed platy internal texture. Its texture, characteristic lustre and C-based composition suggest that it is graphite. NaCl is present as a widespread fine surface precipitate and there are common fines at the particle surface typically embedded in cleavage planes. These include scattered very fine (micron scale) discrete Pu-bearing particles and rare Zr-U particles. Graphite is a very soft material, so dispersal in the environment is possible through contact transfer; common fractures and a strongly developed cleavage suggests fragmentation is also a risk.	
	**BSEM image, 20 kV, 0.15 Torr of H2O** Image showing the whole particle. It has a brightness similar to that of the C-based adhesive mounting tab, consistent with it comprising graphite. Brighter patches are other phases on and at its surface. Note the common fractures and deformed cleavage planes.
	**0-10 keV portion of EDXA spectrum; SOI9, 30 kV, 0.15 Torr of H2O** Portion of an EDXA spectrum from an area site on the surface of the particle. This is dominated by C, with minor to trace amounts of O, Cl, Si, Al, Mg, Na, S, K, Ca and Fe. The lesser elements come from the common surface deposits that include precipitates of NaCl and probable gypsum as well as various silicates, Fe oxide / oxyhydroxide and steel.

Figure 21: Example Petrographic analysis results for a graphite rich find (particle LSN: 1150055).

4.6.3 Radionuclide activity in ESR 162 finds

Details of the radionuclide activities are given in Table 16. The table has been arranged in descending order of total beta values. As expected, the activities of the beta emitters present, principally ^{137}Cs and ^{90}Sr with a smaller contribution from ^{241}Pu, are significantly greater than the alpha-emitting radionuclides reported (^{234,238}U, ^{238,239,240}Pu, ^{241}Am).

The highest total beta and ^{137}Cs activities (1.53E+05 and 1.71E+05 Bq respectively) were associated with a ‘Rock fragment’ particle from the Sellafield beach whereas the highest ^{90}Sr activity (1.49E+04 Bq) and ^{241}Pu activity (3.9E+02 Bq) was associated with a ‘Graphite’ particle from St. Bees beach. This ‘Graphite’ particle also contained 1.93E+04 Bq of ^{137}Cs.

The highest activity of ^{238}Pu (2.70E+02 Bq) was found in a 'Metal and metal corroded' particle from the Sellafield beach. This particle also contained 2.3E+03 Bq of ^{90}Sr and 3.40E+04 Bq of ^{137}Cs. The highest activities of ^{239,240} Pu (5.50E+02 Bq) and ^{241}Am (1.60E+03 Bq) were found in a 'Zirconium and Uranium rich' particle from the Sellafield beach.

The five highest total beta and ^{137}Cs activities are actually associated with stones (first five entries of Table 16). This observation was only confirmed once the find had been isolated in the laboratory. The units in Table 16 are Bq per find rather than Bq per unit mass hence the observation that relatively large stones can contain higher levels of activity than relatively smaller particles. All these five stones were very small, ranging from 4.5 to 15 mm.

Ignoring the stone data in Table 16, the highest total beta and ^{137}Cs activities would be 5.09E+04 and 5.82E+04 Bq respectively. These activities were associated with a 'Metal and corroded metal' particle from the Sellafield beach.

Table 16: Radiochemical analysis of beta rich finds (Bq per find).

Sample Code No.	Area	Petrographic Category	Total Beta	Sr-90	Cs-137	Pu-241	Total Alpha	U-234	U-238	Pu-238	Pu-239/240	Am-241
2073255	Sellafield	Rock fragment (N)	153000	286	171000	18	14	<0.11	<0.07	1	2.7	18
1339124	Sellafield	Rock fragment (N)	76800	28	87500	25	66	<0.09	<0.08	3.4	14	20
1319938	Sellafield	Rock fragment (N)	61200	76.4	84900	15	34	<0.06	<0.04	2.1	8.2	11
2017716	Sellafield	Rock fragment (N)	57400	20.9	79400	51	77	<0.08	<0.05	4.3	21	49
1343752	Sellafield	Rock fragment (N)	51400	8.3	74600	60	110	<0.06	<0.04	6.2	27	170
1148626	Sellafield	Metal and corroded metal (A)	50900	<41	58200	1.0	<150	4.33	0.98	18	10	6.6
1148627	Sellafield	Zr-based (A)	46900	113	48500	63	69	NA	NA	4.4	25	15
1210775	Seascale	Metal and corroded metal (A)	42900	29	54500	NA	<32	NA	NA	NA	NA	NA
1196033	Sellafield	Si rich (N)	39100	50	46700	NA	<82	NA	NA	NA	NA	NA
1329902	St. Bees	Graphite (A)	38300	14900	19300	390	NA	<0.02	<0.02	7.2	77	74
1171400	Sellafield	Metal and corroded metal (A)	38100	2320	34000	<0.4	1700	<0.25	<0.4	270	240	1200
1196991	Sellafield	Rock fragment (N)	33600	<16	30100	NA	<62	0.06	0.05	NA	NA	NA
1428187	Sellafield	Rock fragment (N)	31500	25	32900	220	110	0.12	0.11	7.5	38	42
1150055	Sellafield	Graphite (A)	30700	8650	11700	5.7	20	<0.12	<0.07	1.4	1.8	2.4
1198034	Sellafield	Graphite (A)	27300	10600	15400	290	NA	<0.02	<0.03	6.7	110	67
1134897	Sellafield	Zr-based (A)	26400	1800	26400	370	92	<0.1	<0.17	23	21	61
1291248	Sellafield	Biotite mica (N)	23000	22	24200	NA	<47	NA	NA	NA	NA	NA
1172960	Sellafield	Biotite mica (N)	21800	13.6	23400	4.5	11	<0.08	<0.04	0.6	2.1	5.4
1254478	Sellafield	Biotite mica (N)	18000	<11	21600	NA	<36	NA	NA	NA	NA	NA
1233243	Sellafield	Biotite (chloritised, fragmented)	17300	193	18500	4.2	26	<0.08	<0.05	0.8	3.3	5.1
1171174	Braystones	Biotite mica (N)	16000	<12	18900	NA	<49	NA	NA	NA	NA	NA
1459607	Sellafield	Rock fragment (N)	13900	19	12400	0.03	90	0.04	0.03	3.3	17	92
1122193	Sellafield	Layered iron and silicon rich (A)	13800	<6	18300	NA	<19	NA	NA	NA	NA	NA
1381345	St. Bees	Graphite (A)	13700	138	7800	130	68	<0.03	<0.02	2.8	37	28
2014703	Sellafield	Biotite mica (N)	13500	27.7	12900	<20	27	<0.03	<0.03	0.2	1.4	18
1146360	Sellafield	Rock fragment (N)	12500	<12	14400	0.01	<30	<0.01	0.01	0.1	0.6	19
1159552	St. Bees	Biotite mica (N)	12400	14.8	14000	5.5	24	<0.07	<0.05	1.1	4.3	5.3
2006881	Sellafield	Si-based (N)	12200	<7	13200	NA	<22	NA	NA	NA	NA	NA
2001825	Sellafield	Zr U rich (A)	11900	537	10200	<14	2100	<12	<8.8	110	550	1600
1160739	Seascale	Zr-based (A)	10200	46.3	10300	25	<37	NA	NA	4.1	3.7	2.5
1121835	Sellafield	Biotite mica (N)	9100	5.9	10200	NA	<43	NA	NA	NA	NA	NA
1173970	Sellafield	Rock fragment (N)	8300	<6	8980	39	<39	NA	NA	1.2	6.8	7.8
1249081	Seascale	Graphite (A)	7400	3040	3840	71	NA	<0.03	<0.03	1.4	10	11.4
1132336	Sellafield	Metal and corroded metal (A)	6600	677	5820	NA	<8	0.01	<0.01	NA	NA	NA
1153626	Sellafield	Zr-based (A)	6500	246	8110	29	14	<0.02	<0.03	0.5	2.8	4.9
1319396	Sellafield	Biotite mica (N)	4100	<2	3910	NA	<7	NA	NA	NA	NA	NA
1188601	Braystones	Biotite mica (N)	3900	1.6	4020	NA	<19	NA	NA	NA	NA	NA
1197896	Sellafield	Biotite mica (N)	3300	<2	4110	NA	<19	NA	NA	NA	NA	NA
1224273	Sellafield	Zr-based (A)	3200	39.5	3240	77	22	0.005	<0.01	1.2	3.9	16
1198035	Sellafield	Zr-based (A)	2700	67.7	3130	2	<10	<0.07	<0.04	0.2	1.1	2.4
1103077	Sellafield	Metal (U)	700	210	280	35	23	0.07	0.01	0.6	8.3	7.6

(A) – Anthropogenic; (N) – Natural; (U) – Unknown; (NA) - Not Analysed.

4.6.4 ^{137}Cs/^{90}Sr ratios in ESR 162 finds

Knowing what the ^{137}Cs/^{90}Sr activity ratio is of a beach find is an important parameter for calculating radiological doses. Caesium-137 can be determined relatively easily and non-destructively via HRGS whereas determination of ^{90}Sr activity is more resource demanding and time consuming. If a reliable relationship can be determined between ^{137}Cs and ^{90}Sr then assumptions can be made of the ^{90}Sr activity of a find from the ^{137}Cs activity.

The lowest ^{137}Cs/^{90}Sr activity ratio measured in the finds analysed between 2013 and 2016 was 1.3 (Table 17). This is higher than the ^{137}Cs/^{90}Sr activity ratio of 0.61 adopted by Brown & Etherington (2011) in their risk assessment of beach finds and would suggest that the risk assessment predicted higher doses than would be determined from the current measurement data.

Plotting ^{90}Sr against ^{137}Cs activities (Figure 22) reveals no obvious relationship between these two radionuclides in this dataset. However, in considering data points where ^{90}Sr activities are greater than 3000 Bq then a relationship between ^{137}Cs and ^{90}Sr can be derived.

Table 17: ^{137}Cs/^{90}Sr activity ratios of beta rich particles.

Sellafield LSN	Area	Cs-137 / Sr-90 Ratio
1249081	Seascale	1.3
1329902	St Bees	1.3
1103077	Sellafield	1.3
1150055	Sellafield	1.4
1198034	Sellafield	1.5
1132336	Sellafield	8.6
1171400	Sellafield	15
1134897	Sellafield	15
2001825	Sellafield	19
1153626	Sellafield	33
1198035	Sellafield	46
1381345	St Bees	57
1224273	Sellafield	82
1233243	Sellafield	96
1160739	Seascale	220
1148627	Sellafield	430
2014703	Sellafield	470
2073255	Sellafield	600
1459607	Sellafield	650
1196033	Sellafield	930
1159552	St Bees	950
1291248	Sellafield	1100
1319938	Sellafield	1100
1428187	Sellafield	1300
1172960	Sellafield	1700
1121835	Sellafield	1700
1210775	Seascale	1900
1188601	Braystones	2500
1339124	Sellafield	3100
2017716	Sellafield	3800
1343752	Sellafield	9000

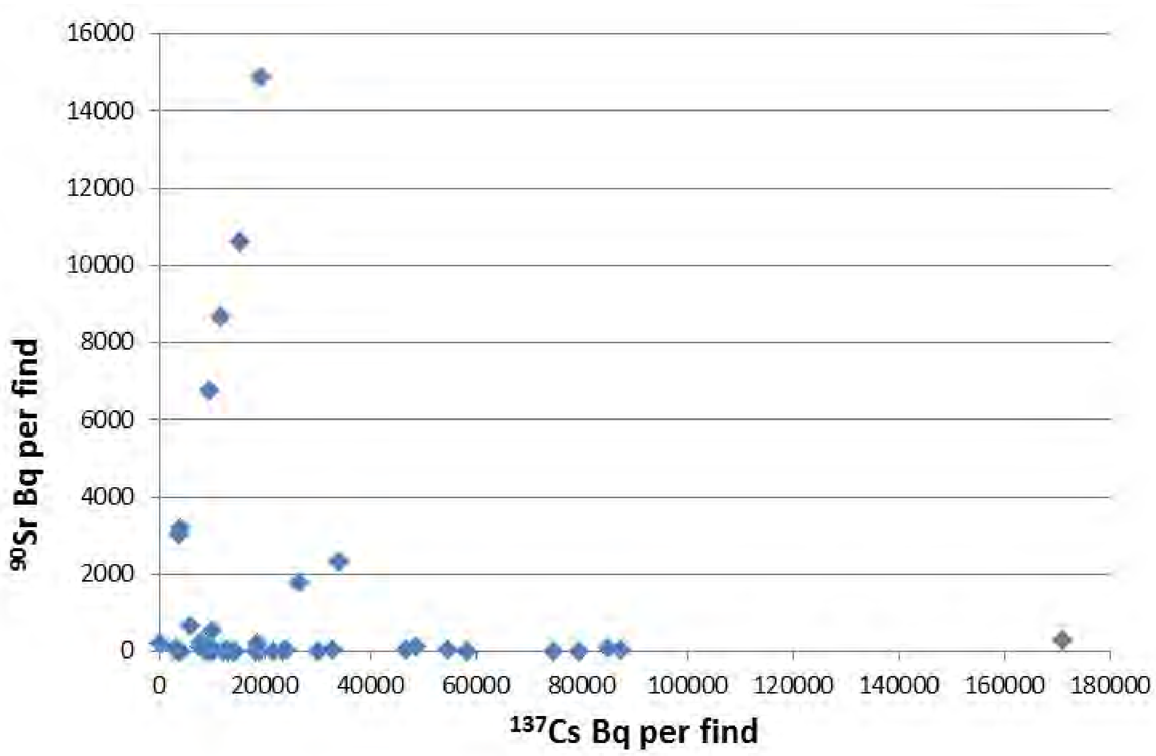


Figure 22: Correlation between ^{137}Cs and ^{90}Sr in further analysed beta rich beach finds.

Figure 23 shows the linear relationship between ^{90}Sr activities over 3000 Bq and their corresponding ^{137}Cs activities. These data points are also related to relatively low ^{137}Cs/^{90}Sr activity ratios (1.3 – 1.5), have similar dimension (around 1 mm) and all are graphitic in nature.

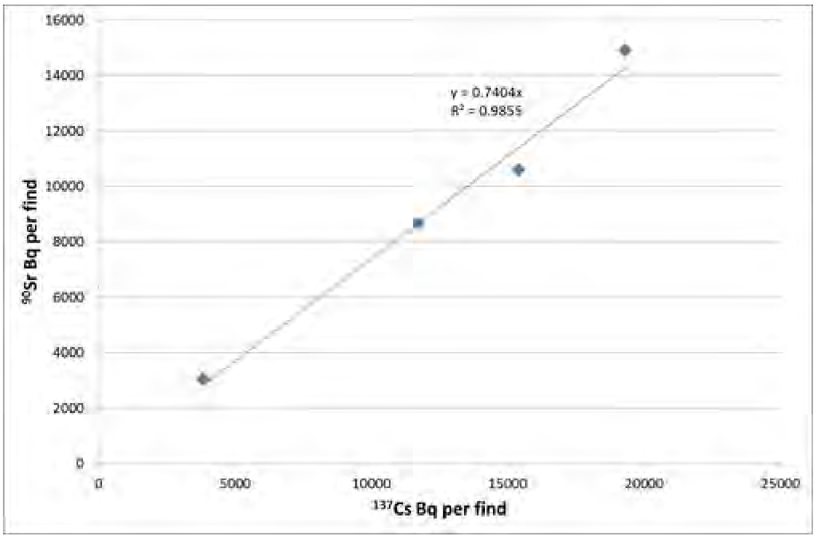


Figure 23: Correlation between ^{90}Sr and ^{137}Cs activities in further analysed beta rich beach finds for ^{90}Sr activities greater than 3000 Bq per find.

4.6.5 Correlation between total beta and ^{137}Cs + ^{90}Sr

The total beta activities have been compared to the sum of the ^{90}Sr and ^{137}Cs activities in beach finds (Figure 24). The clear linear relationship shown in Figure 24 confirms that the significant contributors towards the total beta activity of the find are accounted by ^{90}Sr and ^{137}Cs and that there are no other major beta-emitting radionuclides to consider.

It is therefore possible that a non-destructive estimate of ^{90}Sr activity could be made from total beta and ^{137}Cs activity measurements with a total beta:^{137}Cs ratio of >1.7 predicting that the find will contain >3000 Bq of ^{90}Sr. This relationship is based on 6 measurements from a pool of 41 ^{90}Sr determinations and will be reviewed as more total beta, ^{137}Cs and ^{90}Sr measurements are available.

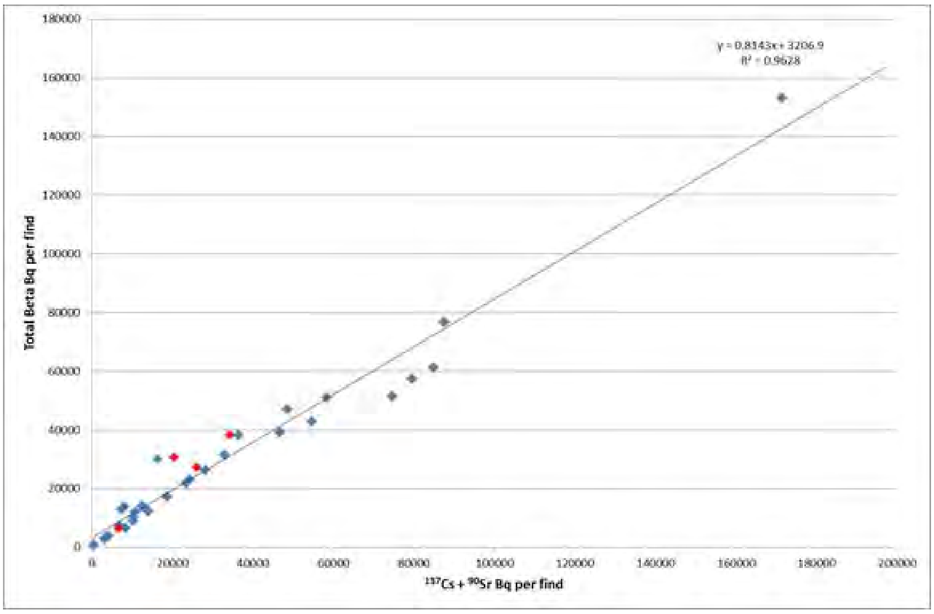


Figure 24: Correlation between total beta and ^{90}Sr + ^{137}Cs in further analysed beta rich beach finds. Red data points are ^{90}Sr > 3 kBq detailed in Figure 23.

4.6.6 Dosimetric calculations based on ^{90}Sr and ^{137}Cs analytical data.

Measurements of the contact beta-gamma dose rate were used to screen beta rich finds that could contain the radioisotope ^{90}Sr. Work conducted by the University of Birmingham (Serco, 2011) calculated skin dose per unit activity factors (Table 18). It should be noted that an absorbed dose of 1 Gy is the same as an equivalent (tissue) dose of 1 Sv when considering beta radiation; hence the units of Gy and Sv are interchangeable in this context.

The calculated skin doses are shown in Table 19 based on the dose conversion factors from Table 18 and the activity concentrations of ^{90}Sr and ^{137}Cs from Table 16. The maximum beta dose calculated from these particles was 105 mGy hr^{-1} and was entirely due to ^{137}Cs (sample LSN1148626). The highest calculated ^{90}Sr dose contribution was 69 mGy hr^{-1} resulting in a total beta dose of 103 mGy hr^{-1} (35 mGy hr^{-1} due to ^{137}Cs, sample LSN1329902). These maxima doses are well below the guideline dose level of 300 mGy hr^{-1} as set out by the PHE where a review of the particle monitoring programme is recommended (Brown & Etherington, 2011).

Table 18: ^{137}Cs and ^{90}Sr dose conversion factors (from Serco, 2011).

Skin dose per unit activity	^{137}Cs	^{90}Sr/^{90}Y	Units
	1.8	4.6	Gy hr^{-1} per MBq or Sv hr^{-1} per MBq

Table 19: ^{137}Cs and ^{90}Sr skin dose rates determined using Table 18.

Sample Code No.	Area	Dose (mGy/hr)			% Sr contribution to dose	Cs/Sr dose ratio
		Cs-137	Sr-90	Total		
1148626	Sellafield	1.05E+02	LOD	1.05E+02	LOD	LOD
1329902	St. Bees	3.47E+01	6.85E+01	1.03E+02	6.64E+01	5.07E-01
1210775	Seascale	9.81E+01	1.33E-01	9.82E+01	1.36E-01	7.35E+02
1148627	Sellafield	8.73E+01	5.20E-01	8.78E+01	5.92E-01	1.68E+02
1196033	Sellafield	8.41E+01	2.30E-01	8.43E+01	2.73E-01	3.65E+02
1198034	Sellafield	2.77E+01	4.88E+01	7.65E+01	6.38E+01	5.68E-01
1171400	Sellafield	6.12E+01	1.07E+01	7.19E+01	1.48E+01	5.73E+00
1150055	Sellafield	2.11E+01	3.98E+01	6.09E+01	6.54E+01	5.29E-01
1428187	Sellafield	5.92E+01	1.15E-01	5.93E+01	1.94E-01	5.15E+02
1134897	Sellafield	4.75E+01	8.28E+00	5.58E+01	1.48E+01	5.74E+00
1196991	Sellafield	5.42E+01	LOD	5.42E+01	LOD	LOD
1291248	Sellafield	4.36E+01	1.01E-01	4.37E+01	2.32E-01	4.30E+02
1172960	Sellafield	4.21E+01	6.26E-02	4.22E+01	1.48E-01	6.73E+02
1254478	Sellafield	3.89E+01	LOD	3.89E+01	LOD	LOD
1233243	Sellafield	3.33E+01	8.88E-01	3.42E+01	2.60E+00	3.75E+01
1171174	Braystones	3.40E+01	LOD	3.40E+01	0.00E+00	LOD
1122193	Sellafield	3.29E+01	LOD	3.29E+01	LOD	LOD
1146360	Sellafield	2.59E+01	LOD	2.59E+01	LOD	LOD
1159552	St. Bees	2.52E+01	6.81E-02	2.53E+01	2.69E-01	3.70E+02
2006881	Sellafield	2.38E+01	LOD	2.38E+01	LOD	LOD
2014703	Sellafield	2.32E+01	1.27E-01	2.33E+01	5.46E-01	1.82E+02
1459607	Sellafield	2.23E+01	8.74E-02	2.24E+01	3.90E-01	2.55E+02
1249081	Seascale	6.91E+00	1.40E+01	2.09E+01	6.69E+01	4.94E-01
2001825	Sellafield	1.84E+01	2.47E+00	2.08E+01	1.19E+01	7.43E+00
1160739	Seascale	1.85E+01	2.13E-01	1.88E+01	1.14E+00	8.71E+01
1121835	Sellafield	1.84E+01	2.71E-02	1.84E+01	1.48E-01	6.76E+02
1173970	Sellafield	1.62E+01	LOD	1.62E+01	LOD	LOD
1153626	Sellafield	1.46E+01	1.13E+00	1.57E+01	7.19E+00	1.29E+01
1381345	St. Bees	1.40E+01	6.35E-01	1.47E+01	4.33E+00	2.21E+01
1132336	Sellafield	1.05E+01	3.11E+00	1.36E+01	2.29E+01	3.36E+00
1197896	Sellafield	7.40E+00	LOD	7.40E+00	LOD	LOD
1188601	Braystones	7.24E+00	7.36E-03	7.24E+00	1.02E-01	9.83E+02
1319396	Sellafield	7.04E+00	LOD	7.04E+00	LOD	LOD
1224273	Sellafield	5.83E+00	1.82E-01	6.01E+00	3.02E+00	3.21E+01
1198035	Sellafield	5.63E+00	3.11E-01	5.95E+00	5.24E+00	1.81E+01
1103077	Sellafield	5.04E-01	9.66E-01	1.47E+00	6.57E+01	5.22E-01

LOD - Limit of Detection.

4.6.7 Seascale beach particle find S1164/SEA

A particle was recovered in June 2014 from Seascale beach which was unusual in that its activity was predominantly from ^{90}Sr (Table 20). PHE performed detailed dose rate measurements on this find which were reported by Tanner (2015) and included in the annual report for 2014/15 (see Sellafield, 2015). The study used three separate measurement techniques – radiochromic dye film, extremity thermoluminescence dosemeter and small ion chamber units. From these investigations a skin dose rate (1 cm^2, 70 μm) range of 500 – 800 mGy h^{-1} for the particle was derived.

Stationary skin contact with such a particle would exceed the 2 Gy threshold for localised ulceration after about 3 hours. The measurements made by PHE indicated that the skin dose rate (1 cm^2, 70 μm) exceeded the criterion that it has recommended to EA should prompt a review of health risks to beach users, 300 mGy per hour skin dose rate (1 cm^2, 70 μm). PHE advised EA in September 2014 (Harrison, 2014) that '*While the retrieval of one particle cannot in itself be regarded as a substantial public health issue, this find should now lead to a* *reassessment of monitoring capabilities for particles with high content of strontium-90, along with any other measures that may be considered appropriate, to support a reappraisal of the potential health risks'*."

Details of the SEM/EDXA investigation of the find are given in Figure 25. The major constituents of the find were of anthropogenic origin consisting of Fe, Mg and Al oxides.

The radionuclide content of the Seascale particle (S1164/SEA) is given in Table 20. In comparing these data with the 190 beach finds that have been further analysed to date (dominated by beta rich finds), the Seascale particle possesses the highest total beta, ^{90}Sr, ^{152,154,155}Eu and ^{238}Pu Bq per find values. The total beta activity is four times greater than the next highest reported value (9.2E+04 Bq per find, LSN1129215, ESR78 Second Tranche) and the ^{90}Sr activity is 3.5 times greater than the next highest value (4.9E+04 Bq per find, LSN1129215, ESR11 First Tranche). The data below confirm the dominance of beta emitters in this particle as indicated by early contact beta/gamma dose rate measurements.

The ^{137}Cs/^{90}Sr ratio quoted below, 0.03, is the lowest reported to date for any beach find. Previously, the lowest reported ratio was 0.61. However, from Table 17, it is evident that the ^{137}Cs/^{90}Sr ratio in Table 20 is exceptional.

Table 20: Radionuclide content of the Seascale particle S1164/SEA.

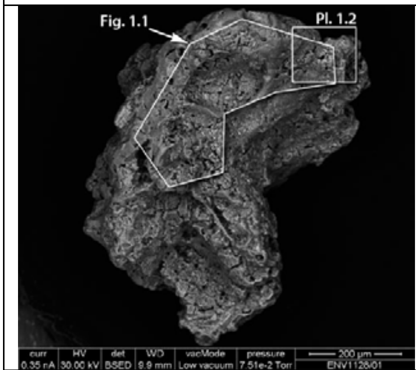
Analysis	Bq/find	±
Total Beta	4.24E+05	5.10E+04
^{90}Sr	1.71E+05	1.40E+04
^{137}Cs	4.77E+03	7.40E+02
^{241}Pu	1.96E+04	1.10E+04
^{137}Cs / ^{90}Sr Ratio	2.79E-02	
Total alpha	1.26E+04	2.20E+03
Pu alpha	5.67E+02	5.16E+01
Am+Cm	8.54E+03	8.41E+02
^{60}Co	1.00E+01	4.00E+00
^{152}Eu	5.50E+01	1.30E+01
^{154}Eu	1.44E+03	2.20E+02
^{155}Eu	1.35E+02	3.70E+01

The source of this particle is, at present, unknown. Investigations into identifying the source are ongoing. In considering europium activity ratios, the particle was not likely to have been produced from recent Magnox operations (within the last 15 years) and is likely to be related to legacy operations.

Application of the skin dose rate conversion factors given in Table 18 to the ^{90}Sr and ^{137}Cs values in Table 16 produce calculated skin dose rates of 787 mGy hr^{-1} and 8 mGy hr^{-1} respectively, giving a total of 795 mGy hr^{-1}. This calculated approach is in good agreement with the measured skin dose range of 500 – 800 mGy hr^{-1}.

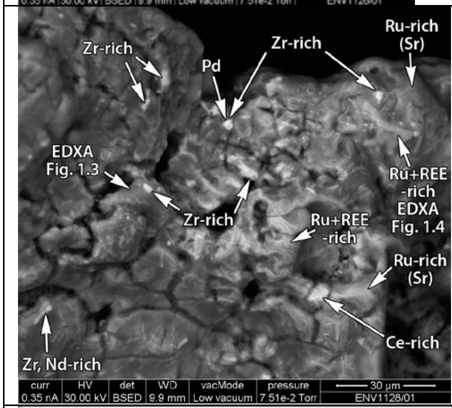
A dark grey subrounded particle with surface pits that are orange-brown in colour. Under BSEM imaging the particle displays a complex pattern of brightness variation reflecting compositional variation. EDXA shows that the surface chemistry is dominated by Fe, Mg, Al and O, suggesting the surface of the particle, at least, comprises mixed oxides. In detail there are two main compositionally distinct constituents that are intermixed on a fine (micron) scale. Whilst these constituents are too finely intermixed to obtain 'pure' compositional information from either, trends are fairly consistent and point to there being two main end-member types. The material with a low backscatter electron coefficient (darker under BSEM) contains the Fe, Mg, Al and O that dominates the whole particle composition. The material with a higher backscatter coefficient (brighter under BSEM) additionally contains a suite of light REEs, including Ce, Pr, Nd and Sm, in some cases with detectable La. Y is also detectable as a trace constituent. The U detected from this particle appears to be associated with the REE constituent. The REE-rich constituent locally displays a desiccation-like micro-fracture texture suggesting a potential for surface flaking.

There are scattered individual 'specks' of high backscatter coefficient material (bright under BSEM imaging); these mostly have Zr-rich compositions, some are also rich in Pd. Other elements detected as being present in the sample include Ru, Ca, P, Si, S, Cr, Ni, Cu, Zn, Sr and Pb; these do not show any consistent compositional relationships. However, Sr was only detected in sites with the highest Ru contents. Auto-fluorescent X-ray spectra show the presence of Np.

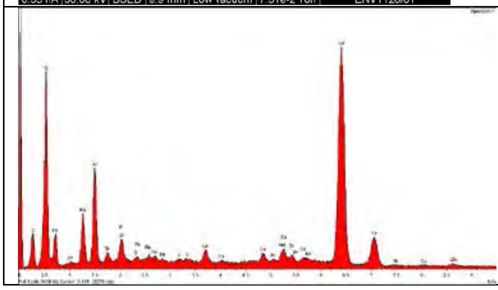


BSEM image, 30 kV, 0.08 Torr of H_2O
Image showing the whole particle. The boxed area is the site of the more detailed image shown below.

At this scale, the particle dominantly comprises material of intermediate backscatter electron brightness with fine speckles of higher brightness matter.



BSEM image, 30 kV, 0.08 Torr of H_2O
Detail of a portion of the particle surface. This shows that the particle has a heterogeneous composition and structure, with areas of differing brightness reflecting compositional variation, some features of which are labelled. Generally the higher brightness areas are rich in REE and / or Ru. Embedded discrete specks of high brightness are mostly Zr-rich, whilst some are also rich in Ru, Pd and REE. Widespread desiccation-like textures are apparent affecting the brighter REE-rich material; most are in-filled with the darker material



0-10 keV portion of EDXA spectrum; SOI7, 30 kV, 0.08 Torr of H_2O
Portion of an EDXA spectrum from the topographically high portion of the particle as shown above. The dominant peaks are attributable to Fe, Al, Mg and O. Other notable constituents are the REEs Ce and Nd, as well as Zr, Ru, Pd and U. Elements Si, P, S, Pb, Ca, Ni, Cu and Zn are also present.

Figure 25: Petrographic analysis results for Seascale beach particle S1164/SEA.

4.7 Stones Analysis Review

In the autumn of 2015 a review of the beach stones identified during the beach monitoring campaigns was performed. This work was presented to the Particles Working Group in February 2016 and the outcome of the review is summarised in the executive summary below (Golder, 2016). No further work on stones is planned.

The purpose of the review is to consider the need and requirements for further analysis of stone finds from beaches around Sellafield and identify relevant analytical techniques that could be applied to the stones, if required.

Previous work on the characterisation of beta rich stones (14 of natural origin, one of anthropogenic origin) by Serco and NPL between 2008 and 2010 revealed that the radionuclide content of these stones was dominated by the presence of ^{137}Cs. The other major beta-emitter contributor, ^{90}Sr, exhibited activities that were much lower, ranging between 0.04% and 1% of ^{137}Cs activities. Leaching studies (using mineral acids) showed that for the majority of stones, the ^{137}Cs activities were contained on the surface layer of the stones.

The total number of beta rich stones recovered as part of the Sellafield Ltd beach monitoring programme decreased from the period 2007/08 (214 stones) to 2014/15 (36 stones).

In 2011, Public Health England performed a health risk assessment of beach finds (including stones) from the Cumbrian coastal area, in 2011. In that assessment, PHE reported that the highest calculated lifetime risk of radiation-induced fatal cancer from the presence of beta rich objects on Sellafield beach was less than 10^{-11}. This level of risk is at least one hundred thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk (1 in a million) for members of the public and workers. The 2011 risk value considered various factors including the probability of encountering a beta rich stone and the risk of exposure to a beta rich stone. PHE have now considered information on stones collected between 2010 and 2015 to update the risk assessment findings of 2011. PHE confirm the probability of encountering a beta rich stone has been reduced by around an order of magnitude and that the risk of exposure has also been reduced by around an order of magnitude compared to 2011.

Given the reduced probability of encountering a beta rich stone of reasonably high activity that could potentially give rise to health risks, and the resulting low health risks calculated by PHE, then further analysis of stones is not justified. When considering the identified uncertainties that could be addressed through further analysis of stones, the benefits of completing this work do not match up to the relative costs of carrying out the various analyses.

4.8 Beach Monitoring Programme Conclusions

The 2015/16 beach monitoring programme was successfully completed to programme and time. A total of 166.75 hectares, between Allonby and Drigg point, was monitored and 349 radioactive finds recovered. The introduction of Synergy 2 in 2014 impacted on the number of finds and the associated find rates. The number of finds detected increased for most beaches when compared with the previous year, and peak find rates were observed at Sellafield, Braystones, Allonby, Workington and Drigg. The data collected during 2015/16 has shown that this increase was temporary and was likely to have been coincidental with the introduction of Synergy 2.

The programme for 2015/16 focused on monitoring at Sellafield beach (82.56 ha) to provide reassurance that the find rates and find characteristics on the beach with the highest historic find rates had not changed significantly. In addition, a further 72.74 ha of monitoring effort was split between the beaches at Braystones, St. Bees and Seascale, providing reassurance that find rates on beaches with high public occupancy remain low. The remaining monitoring effort (11.45 ha) was deployed on far-field beaches (in particular Allonby beach with 10.37 ha of monitoring).

The types of material being recovered during 2015/16 remained consistent with those retrieved since commencement of the monitoring programme. The distribution of ^{137}Cs and ^{241}Am activities of current particles remain within observed ranges of all particles to date, providing reassurance that they are part of the same general population. This provides further evidence that the conclusion of the PHE risk assessment in 2011 remains valid and are as follows.

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches." (Brown & Etherington, 2011)

5 Assessment of Best Available Technique (BAT)

5.1 Particles in the Environment BAT/ Optioneering

A large amount of work has been done over recent years to improve understanding of both the beach and the marine environments and the implications on transport and dispersion of radioactive particles. For sub-sea, limited modelling work, data gathering and interpretation (*e.g.* swath bathymetry and Aquadopp deployment reported in Sellafield Ltd, 2011) and desk-based options assessment have all contributed, but the information being gathered from the beach monitoring provides the richest data source on the particles issue. Each year the level of understanding on particles in the environment increases as beach monitoring continues to reveal information on find populations, locations, activity concentrations *etc*.

A BAT case was submitted to the EA at the end of May 2013 (Sellafield Ltd, 2013) and the EA responded in the form of a Radioactive Substance Compliance Assessment Report (RASCAR) at the end of August 2013. A revised BAT assessment was produced and submitted to the EA in 2014 (Sellafield Ltd, 2014b) that updated the previous work that was conducted. The EA provided a response to the updated BAT case in November 2014. The BAT case (Sellafield Limited 2014b) determined that the techniques shown in Table 21 could be deployed for detecting the types of radioactive materials found on West Cumbrian beaches with the NaI detectors that are currently used representing the optimal technique.

The detection of material on the seabed was also considered in the BAT case (Sellafield Ltd, 2014b) although no optimal technique could be identified that would meet the criteria of detecting and recovering both alpha rich and beta rich particles on the seabed, that would provide reasonable area coverage and would not be disproportionately costly. The study considered that grab sampling provided the best compromise between the above criteria and further sampling was conducted in 2014 and reported in Sellafield Ltd (2015). This work provided a considerable amount of data on the characteristics of the seabed and of bulk radionuclide concentrations. Although, from 1706 successful grab samples (retrieved between August 2011 and August 2014 from 6 extensive campaigns of sampling) an area of approximately 170.6 m^2 of seabed was monitored yielding a single particle (in April 2012).

A similar level of resource deployment to the areas of peak find rates on the beaches would have been likely to have detected several hundred particles and stones and therefore no further sub-sea work is planned, allowing the programme to concentrate on beach monitoring.

5.2 Progress in meeting the 2014 BAT recommendations

A list of the recommendations of the 2014 BAT case, the responses from the EA and the progress in addressing the recommendations is shown in Table 22. The evaluation of BAT is an ongoing process, as technologies are developed and evaluated that have the potential to be used for the detection of beach and/or seabed particles.

Work during 2015/16 has focussed on the following specific areas:

- Trials to evaluate the performance of Synergy 2
- Trials of plastic scintillator detectors.
- Development of a forward monitoring strategy through the Sellafield Particles Working Group (this work is reported in Section 8.4).
- Further laboratory analysis and characterisation of particle finds (this work is reported in Section 4.7).

Table 21: Techniques for detecting radioactive particles on the beaches.

Method		*Discussion Summary*
Alpha	*Detection of alpha emitters using X-Ray and low energy gamma radiation – NaI*	*Well established and practicable technique for low energy gamma/X-Ray detection. Good area coverage. Can be utilised within a vehicle or hand held assembly.*
	HpGe detectors for X-Ray emissions	*Well established and practicable technique for low energy gamma/X-Ray detection in the lab and successfully trialled on beach environment. This technique gives good area coverage and can now be mechanically chilled in the field.*
Beta	*Plastic Scintillation Detectors*	*Well understood, off the shelf technique requiring only minimal modification to enable practical use in the beach environment. Vehicle and hand-held use practicable.*
Gamma	*NaI Scintillation Detector*	*Current technique used for beach monitoring at Sellafield. Well established and versatile technique, good detection efficiency, good area coverage, tough and relatively simple to use. Can be utilised for hand held or vehicle use.*
	High Purity Germanium Detector (HpGe)	*Optimum energy resolution, well established technique, now mechanically chilled, but more expensive than NaI Scintillation Detectors.*

Table 22: Recommendations from the 2014 BAT case, responses from the EA and progress.

BAT Recommendation	EA Response	Progress
1. Continue the current beach monitoring approach as agreed with the Environment Agency	Agreed	Ongoing
2. Conduct a review of the performance of the Synergy 2 monitoring system after an appropriate period (anticipated to be 12 months). In particular this review should evaluate the performance of the system for the detection of ^{90}Sr.	Agreed	Ongoing
3. Continue seabed sediment grab sampling, as carried out in 2011, 2012, and 2013 although evaluate the use of a larger grab sampler and methods to improve the sampling efficiency to increase the number of samples collected per day. The seabed monitoring campaigns should also focus on areas that were indicated by the Conceptual Site Model to have higher potential find rates.	Should consider ways to delineate the area of offshore contamination.	Completed and reported in 2014/15.
4. Maintain a watching brief on monitoring methods for beach particles (in particular for ^{90}Sr) and for seabed particles (in particular crawler ROVs and the seabed detection of alpha rich material).	May need to include the development of alpha (americium) detection capability through lab trials of sodium iodide detectors.	Ongoing
5. Consider the feasibility of conducting further beach trials to evaluate the performance of Synergy 2 for detecting ^{90}Sr.	Should be to undertake laboratory trials and then develop a case for any beach trial following this.	Synergy 2 trials
6. Align the walked surveys of the coast so that the Nuvia team carrying the large volume NaI detector and the Sellafield team carrying the FIDLER probe cover the same area on the same days.	Agreed	Ongoing
7. Modify the beach sampling programme to redeploy 10 ha of monitoring effort from beaches with the lowest risk (Drigg and Northern beaches) to Braystones.	Agreed	Completed
8. Develop a forward monitoring strategy that included exit strategy options.	Should be through consultation with the Sellafield Particles Working Group, COMARE, WCSSG and Copeland Borough Council.	See Section 8.4
9. Continue ^{90}Sr analysis of objects with the selection of samples based on ^{137}Cs activity and contact dose rate.	Agreed	See Section 4.6.3
10. Continue statistical work to underpin the monitoring programmes and sampling arrangements for both the beach and sub-sea environments.	Agreed	Ongoing
11. Maintain a watching brief on marine modelling methods and the possibilities for adjacencies with the programmes for other infrastructure developments.	Should be guided by a review of the information needs for any modelling work. The forward programme should then consider an appropriate priority for the filling of each of these and ensure that maximum value is obtained from other work done such that the need for additional 'model input specific' work is limited.	Ongoing
12. Evaluate the influence of standing water on the detection efficiency of Groundhog Synergy 2.	Agreed	Synergy 2 trials
13. Develop a formal contingency plan to deal with issues including equipment failure or obsolescence and provide a basis for decision making that avoids the threat of failing to meet the agreed programme.	Agreed	Completed

5.2.1 Trials to evaluate the performance of Synergy 2

Trials of the Synergy 2 system were undertaken in a controlled environment using a model railway based system to simulate a source passing the Synergy 2 detector array (Figure 26). The trials are described in Davies (2016) and evaluated the performance of the system for detecting ^{60}Co, ^{137}Cs, ^{90}Sr and ^{241}Am for the following tests:

- Response of the various alarms.
- Velocity variations (0.8 m/s, 1.0 m/s and 1.2 m/s).
- Detector height variations.
- Horizontal geometry variations.
- Influence of changing background levels.
- Effects of surface water (recommendation 12 in Table 22).
- False alarm rates.
- Influence of different software versions.
- Response to mixed (^{241}Am, ^{90}Sr and ^{137}Cs) sources.

In addition laboratory based work was conducted on the detection of ^{90}Sr using beta scintillators.

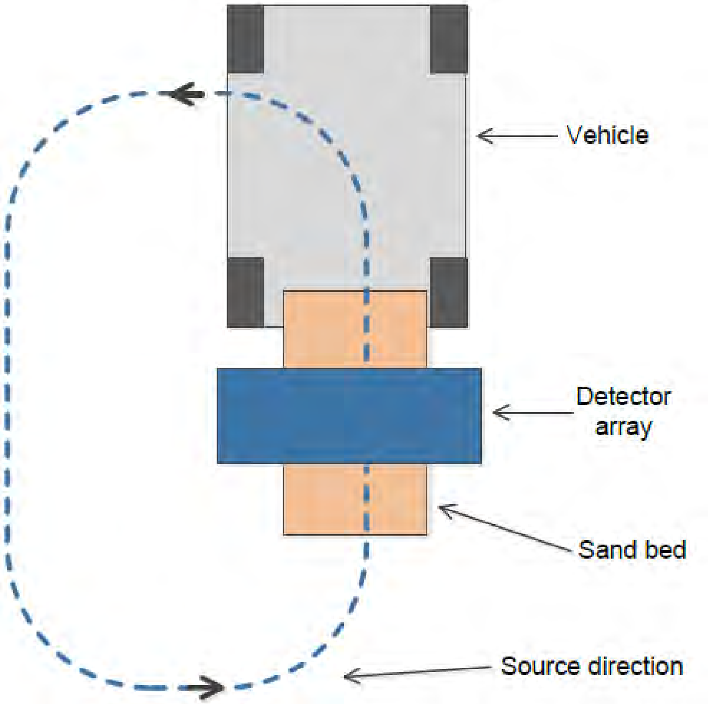


Figure 26: Equipment used for the evaluation of Synergy 2.

The conclusions from the trials work were:

- The trials methodology worked well and the use of the sources mounted on a track method should be applied in subsequent trials as it provided a good balance between realism and reproducibility whilst minimising risks to man and the environment.
- The results of the trials are likely to be somewhat pessimistic as the background that was applied was considerably higher than the backgrounds for West Cumbrian beaches. The influence of background level on detection was small for all trials with the exception of ^{60}Co at the surface. Any future trials should however apply a background level that is more representative of the beaches which would also remove the uncertainties associated with creating an elevated background.
- Synergy 2 provides the detection performance that was expected for wide area beach monitoring for near surface sources and sources at depth for ^{137}Cs.

- Detection of surface sources of ^{90}Sr and to a lesser extent ^{241}Am is better than expected.
- Detection of both ^{90}Sr and ^{241}Am at depth were in-line with expectations.
- Detection of ^{60}Co at depth was better than expected although only limited information were available for near surface sources. As ^{60}Co rich finds do not represent a significant issue to the risk assessment then there is no urgent need for revisiting the trials work.
- Detector performance varies across the array with decreases in detection occurring where a radioactive object is close the end of a large volume NaI detector or between two FIDLER probes. This supports the current use of overlap areas for the monitoring programme.
- The influence of velocity variations and detector height were broadly in line with expectations and no changes to the monitoring are required.
- Effectiveness of the alarms was evaluated and it was concluded that no detector/alarm could be changed or eliminated without affecting the particle detection performance of the system.
- Surface water was found to significantly affect the detection of ^{241}Am (and hence alpha rich particles). As these are of most concern for the Health Risk Assessment then the current practice of avoiding monitoring areas of standing water should be continued.
- No improvements to the detection performance were found to be associated with changes to the software used for Synergy 2. Therefore to preserve consistency in the monitoring programme the current software should be applied.
- Mixed source cases showed no evidence that alarms on Synergy could be defeated by combinations of radionuclides.
- Trials on the detection of ^{90}Sr demonstrated that Synergy 2 can detect a surface source at an activity of 4E+04 Bq with a probability of 91%. Plastic scintillators were found to potentially improve the detection limit by an order of magnitude.

5.2.2 Trials of plastic scintillator detectors

Trials of a hand-held plastic scintillator detector (Ludlum 44-142) were conducted in August 2015, March 2016 and April 2016 (McDowell, 2016). The aim of these trials was to determine whether a plastic scintillator detector with a higher sensitivity to ^{90}Sr than Synergy 2 would detect a population of ^{90}Sr rich particles on the beach. The hand held plastic scintillation was found to have a maximum missable activity (MMA) of approximately 5 kBq which is about ten times lower than the MMA for Synergy 2[2].

Controlled sources of ^{90}Sr were used in laboratory tests to establish the MMA of the hand held plastic scintillation detection. Measurements were made on Sellafield beach to determine whether any particles could be found. In order to establish whether any radioactive particles were present on the beach, measurements were also made using a hand held large volume NaI detector and a FIDLER probe. The beach was surveyed as shown in Figure 27 with the FIDLER probe and large volume NaI detector preceding the Plastic Scintillator.

The trials monitored a total area of 3.55 ha and recovered 11 radioactive finds. These comprised of 7 alpha rich particles, 2 beta rich particles, 1 beta rich stone and a stone containing naturally occurring radium (^{226}Ra) that was unrelated to releases from the Sellafield site (Table 23). None of the finds were detected primarily by the beta scintillation probe and only S1753/SEL was detectable *in-situ* by the probe, although the detector also responded to S1578/SEL once it had been recovered. It was also notable that none of the finds recovered were classified as "excess beta" and therefore were not likely to contain a high proportion of ^{90}Sr.

---

[2] The trials discussed in Section 5.2.1 reported a detection probability of 91%for a 41kBq source of ^{90}Sr on the surface of the sand.

The beta trials demonstrated that intensive hand-held monitoring of the beach, conducted over a total of 18 days) did not identify a population of ^{90}Sr rich finds that would have been missed by the Synergy 2 vehicle surveys. According to PHE (Brown *et al*., 2016) over 2.9 million ^{90}Sr finds (each with an activity of 1E+04 Bq) would need to be present per hectare to result in a lifetime risk to a young child beach user of 1 in a million (the *deminimis* level of risk used by the Health and Safety Executive). Risks from ^{90}Sr particles that would not be detected by Synergy 2 could therefore be concluded to be very low indeed and no further work using plastic scintillators is scheduled to be conducted.

Table 23: Summary of finds recovered from beta trials.

ID	Type	Date/Time	Activity (Bq)		
			^{137}Cs	^{226}Ra	^{241}Am
S1578/SEL	beta rich particle	10/08/2015 13:25	1.2E+04	-	-
S1579/SEL	alpha rich particle	11/08/2015 12:05	-	-	2.3E+04
S1580/SEL	radium stone	11/08/2015 13:30	2.1E+01	7.4E+03	6.0E+01
S1581/SEL	alpha rich particle	11/08/2015 14:40	-	-	4.2E+04
S1582/SEL	beta rich particle	11/08/2015 15:30	8.0E+03	-	-
S1583/SEL	alpha rich particle	13/08/2015 14:55	9.2E+00	-	5.1E+04
S1584/SEL	alpha rich particle	19/08/2015 09:30	-	-	1.9E+04
S1751/SEL	alpha rich particle	30/03/2016 10:30	-	-	2.5E+04
S1752/SEL	alpha rich particle	30/03/2016 11:54	-	-	1.8E+04
S1753/SEL	beta rich stone	06/04/2016 13:48	2.1E+04	-	2.8E+02
S1754/SEL	alpha rich particle	07/04/2016 09:10	-	-	2.1E+04

Figure 27: Trials of a plastic scintillator detector on Sellafield Beach.

6 Regulator and Stakeholder Engagement

Throughout all aspects of the work described in this report, Sellafield Ltd seeks to maintain open and effective communication with regulatory bodies and a wide range of other stakeholders. The methods of communication are varied and include general updates and availability of large amounts of information via the sellafieldsites.com website; through to attendance at specific meetings; and the production of detailed written documents such as this report.

The following provides further detail on the main processes for communication and engagement.

6.1 General Engagement with the Environment Agency

The EA specifies the following requirements on Sellafield Ltd for the particles in the environment work scope (EA, 2016):

Permit KP3690SX CEAR Issue 10 dated 01/03/2016

Requirement number 4.2.2 Part 2/v006

12. The Operator shall develop a programme of works, to be agreed with the Environment Agency, that:

- *Focuses on those radioactive particles in the environment that have arisen from Sellafield site operations that represent the greatest risks, so that these can be targeted and the risks to the public and the environment mitigated;*
- *Performs large area beach monitoring to detect and recover targeted radioactive particles, at locations and to a programme that is commensurate with particle numbers, distributions, environmental mobility and rates of encounter;*
- *Selects a proportionate number of recovered particles for detailed analysis, to reduce the uncertainty in the assessment of risk, to improve understanding of on-site sources and pathways, and to enable the further development of optimised detection and analytical methods;*
- *Develops a risk-based approach to assess and determine the best method(s) to detect and recover targeted radioactive particles in the environment;*
- *Develops techniques to characterise the transport and dispersion of Sellafield radioactive particles in the environment;*
- *Is supported by a suitable programme of research and development to ensure that the objectives of the programme continue to be met by the application of Best Practicable Means;*
- *Is supported by a schedule specifying the tasks to be undertaken in the programme and timescales for their completion, including routine reporting on progress, and undertaking periodic review and liaison with the Environment Agency and other relevant organisations;*
- *Establishes a basis on which the end point of the programme can be defined; and*
- *Uses techniques that are consistent with the application of BAT (BPM and BPEO) to achieve this end point.*

The Operator shall provide the Environment Agency with a copy of the programme by 31 March 2010, and thereafter annual updates of the programme by 30 June each subsequent year.

As part of managing the delivery of work against the above specification, Sellafield Ltd and the EA communicate regularly via telephone, email, letter and face-to-face meetings on the full range of aspects associated with this work. Face-to-face meetings are typically held quarterly throughout the year, providing an opportunity for general updates to be provided and for specific items to be discussed, with additional meetings as required. Where a decision point is reached that requires agreement or approval by the EA, Sellafield Ltd will make a formal written proposal before proceeding. In addition, any finds that are defined as unusual are formally reported to the EA (see Section 3.5).

Communications and engagement with the EA is not limited to one-to-one dialogue. Where specific items require (or benefit from) wider discussion and input from others, separate meetings or Working Groups have been held or established (for example the Multi-Agency Workshop and Sellafield Particles Working Group).

Sellafield Ltd is also required to prepare written submissions to the EA. This report forms the annual programme update submission that is referred to in the CEAR specification.

Sellafield Ltd regards the need for effective and constructive communications with the EA on this complex subject as essential and believes the processes employed to achieve this continue to be productive and ensure that good progress continues to be made.

6.2 COMARE

The inaugural meeting of the COMARE Contaminations Working Group was held on the 3rd July 2012. This group has combined the Dounreay and Sellafield working groups and extended its remit to cover wider 'particle' contamination issues, *e.g.* Dalgety Bay. A total of six meetings have now been held, with the latest in March 2016.

The EA routinely presents a paper on progress at Sellafield, which is well received and gives the committee members an opportunity to ask questions and to make suggestions on the forward work programme. The committee has noted that they were satisfied with the approach being taken by the EA and the progress being made by Sellafield Ltd. As with the previous Sellafield Working Group meetings, these meeting are constructive and provide an opportunity for Sellafield Ltd to listen to and discuss some the committee's questions at first hand.

6.3 Sellafield Particles Working Group

The Sellafield Particles Working Group was formed at the start of 2015 and replaces the Seabed Monitoring Working Group. The Group has focused on the risk assessment work that Public Health England (PHE) issued on the Groundhog Evolution2™ monitoring results (Brown & Etherington, 2011; Oatway, et al., 2011) and the update for the Groundhog Synergy™ monitoring results (Etherington, et al., 2012). In particular, work on reviewing the parameters for the seafood pathways has been carried out to derive realistic dose assessments and sensitivity analysis on the assumptions used in the assessments (Oatway and Brown, 2015).

Additionally, the Group has provided an opportunity to review the draft Sellafield particles forward programme and the Group will remain a key forum for taking this work forward through 2016/17. Further details of the work being carried out on the forward strategy are included in Section 8.4.

6.4 Local Stakeholders

Sellafield Ltd continues to communicate with local stakeholders on the work being done. This includes attendance and provision of information to various group meetings, including Parish Councils and the West Cumbria Sites Stakeholder Group and responding to questions raised by individuals. As requested by local stakeholders, Sellafield Ltd is continuing to schedule beach monitoring to avoid the busy tourist times of Easter and the summer school holidays.

Copies of the biannual updates and presentations made to the West Cumbria Sites Stakeholder Group, Environmental Health Sub-Committee are available from their web site as follows.

http://www.wcssg.co.uk/subcommittees/environmental-health-working-group/

7 Health Risk Assessment

The Health Protection Agency became part of Public Health England on 1st April 2013. Public Health England was established to bring together public health specialists from more than 70 organisations into a single public health service. It employs scientists, researchers and public health professionals and has 15 local centres and four regions (north of England, south of England, Midlands and east of England, and London). The headquarters of the 'Centre for Radiation, Chemical and Environmental Hazards' remains at Chilton in Oxfordshire. For the rest of this section the Health Protection Agency will be referenced as work was undertaken before the 1st April 2013.

In the 2010/11 Annual Report, Sellafield Ltd reproduced the Executive Summary from the Health Protection Agency risk assessment (Brown & Etherington, 2011), published in April 2011. That summary includes the following paragraph:

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches. The highest calculated lifetime risks of radiation induced fatal cancer are of the order of one hundred thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk (1 in a million) for members of the public and workers. It is also very unlikely that deterministic effects such as skin ulceration could occur from encountering an object. The likelihood of members of the public ingesting a radioactive particle from the consumption of seafood and the associated health risks have also been estimated using a conservative scoping approach in consultation with the Food Standards Agency. The risks to local consumers of seafood have again been found to be very low."

The EA asked the Health Protection Agency to review the data from the Synergy detection system and revise their advice accordingly, if needed. The Health Protection Agency completed their review of the Synergy data (Etherington, et al., 2012) in August 2012. They concluded that the statement above was still valid; an extract from the executive summary is given below.

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

As part of the work controlled by the Sellafield Particles Working Group, PHE have reviewed the risk assessment for consumption of seafood in the vicinity of Sellafield with respect to the potential for high specific activity particles to be present. The abstract of this report (Oatway and Brown, 2015b) is reproduced below.

"Since 2006 an intensive programme of monitoring for radioactive objects has been carried out on beaches in the vicinity of the Sellafield site in West Cumbria to help assess any potential impacts from on-site activities on the environment and people. These objects comprise particles with sizes smaller than or similar to grains of sand (less than 2 mm) and contaminated pebbles and stones. The health risk to people using the beaches along the Cumbrian coast from contaminated objects on those beaches was previously assessed by Public Health England (PHE), formerly the Health Protection Agency. As part of that assessment, the health risks from contaminated objects that may be ingested via the consumption of locally caught seafood were considered using the results of a conservative scoping study carried out in consultation with the Food Standards Agency.

The Environment Agency (EA) has a work programme to ensure that the overall programme of monitoring, both on the beaches and off-shore, addresses the remaining areas of uncertainty in a prioritised way as well as providing reassurance that the risks remain low. As part of that programme of work, EA commissioned PHE to provide a best estimate of the health risks to people from ingesting contaminated objects via locally caught seafood and the uncertainties associated with these estimates.

This report describes the approach used in the assessment, the assessed health risks from consumption of seafood and a discussion of the sensitivity of these health risks to the assumptions made in the assessment. Health risks to commercial fishermen have also been assessed. The overall health risks to both seafood consumers and commercial fishermen are very low. The highest risks of radiation-induced fatal cancer (97.5th percentile of the distribution) are of the order of ten thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk. The main uncertainties associated with the estimation of the health risks have also been identified."

The overall risks are shown in Table 24, illustrating that risks to adults and children using the beach and consuming seafoods are very low. In order to put these risks into context, a risk of between 1E-07 – 1E-08 per year is the annual risk of a fatal dog bite or insect sting (Brown & Etherington, 2011) and are therefore around 1000 times more likely than a radiation induced fatal cancer from exposure to radioactive particles in the environment.

Table 24: Risks of fatal cancer associated with encountering radioactive particles on the Cumbrian coast.

Find type	Beach user (risk yr^{-1})		Seafood consumer (risk yr^{-1})*	
	Adult	1 year old child	Adult	10 year old child
Alpha rich particle	2E-12	8E-12	6E-11	6E-12
Beta rich particle	9E-14$	3E-13$	5E-13	6E-14
Overall	2E-12	8E-12	6E-11	6E-12

*Based on probabilistic risk assessment (Oatway & Brown, 2015a)
$ Data are from Groundhog Evolution2 (Brown & Etherington, 2011) all other data are from Groundhog Synergy and Evolution2 (Etherington, et al., 2012; Oatway & Brown, 2015b).

8 Forward Programme

8.1 Proposed Beach Monitoring Programme for 2016/17

As in previous years, the beach monitoring programme is set to run from the start of April to the end of March, consistent with the financial year. A monitoring area of 160 ha is believed to be sufficient to meet the objectives of the beach monitoring programme.

The 2016/17 beach monitoring programme uses the same template as the 2015/16 programme, with the target areas and the order of scheduled surveys being almost identical (Figure 28 and Figure 29). Again the 160 ha is to be split into three programmes: a Sellafield programme (totalling 88 ha), a near field programme (totalling 62 ha) and a far field programme (totalling 10 ha). The near field programme will focus on the beaches at Seascale, Braystones and St. Bees, whereas the far field programme will focus on the beach at Allonby. The 2014/15 annual particles report (Sellafield Ltd, 2015) describes in detail the reasoning which underpins the current 2016/17 programme.

Using one monitoring vehicle, such as the Metrac H5, the maximum area that can be realistically achieved in a year is around 160 ha when taking into account the three periods of no monitoring (Easter, Summer and Christmas school holidays), the constraints of tides, restrictions of daylight hours and allowing time to conduct walked strandlines and occasional vehicle/equipment maintenance.

Sellafield Ltd believes the programme is commensurate with the programme objectives and is capable of providing reassurance that risks remain very low. The programme fits with Public Health England's advice for; *"Continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy, to provide continued reassurance that risks remain very low."* (Brown & Etherington, 2011; Etherington et al., 2012).

The proposal was discussed and agreed at the February 2016 meeting of the Sellafield Particles Working Group. Any changes to the programme, which may stem from interesting results, difficulties in accessing the proposed beaches or other operational issues, will be made in full consultation with the EA.

Figure 28: Comparison of 2014/15, 2015/16 and 2016/17 beach monitoring programmes.

Beach	Area monitored in year (ha)		
	2014/15	**2015/16**	**2016/17**
Sellafield	40	88	88
Braystones	30	22	22
St. Bees	40	20	20
Seascale	12	20	20
Northern Beaches	20	10*	10*
Drigg	8	0	0
Total	150	160	160

Notes: * Monitoring on Allonby beach only.

Figure 29: 2016/17 beach monitoring programme.

Quarter	Week Starting	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near-Field Programme: Target Area (ha)	Far-Field Programme: Target Area (ha)	Total available duration in week (5 days Mon-Fri)
Q1 2016/17	04-Apr	Easter Holidays				27:33
	11-Apr	St Bees (1)		4		31:21
	18-Apr	Seascale (1)		4		38:17
	25-Apr	Sellafield (1)	34			31:27
	02-May					31:23
	09-May					33:28
	16-May					40:58
	23-May					29:03
	30-May					34:22
	06-Jun					30:01
	13-Jun					42:42
	20-Jun					31:04
	27-Jun	Braystones (1)		8		42:48
Q2 2016/17	04-Jul					31:10
	11-Jul	St Bees (2)		4		42:32
	18-Jul	Seascale (2)		4		32:39
	25-Jul	Summer Holidays				40:50
	01-Aug					31:24
	08-Aug					39:18
	15-Aug					33:54
	22-Aug					37:08
	29-Aug					17:05
	05-Sep	St Bees (3)		4		33:25
	12-Sep	Seascale (3)		4		34:08
	19-Sep	Walking Strandline Monitoring				31:49
	26-Sep	Allonby (1)			10	30:21
Q3 2016/17	03-Oct					25:25
	10-Oct	Sellafield (2)	32			35:20
	17-Oct					25:24
	24-Oct					31:17
	31-Oct					19:27
	07-Nov					37:52
	14-Nov					17:15
	21-Nov					36:12
	28-Nov					15:13
	05-Dec	Braystones (2)		8		32:57
	12-Dec					17:01
	19-Dec	Maintenance Week				25:54
	26-Dec	No Monitoring (Christmas Holidays)				-
Q4 2016/17	02-Jan	St Bees (4)		4		22:20
	09-Jan					23:10
	16-Jan	Seascale (4) and Drigg Strandline Monitoring		4		27:23
	23-Jan	Sellafield (3)	22			27:26
	30-Jan					22:54
	06-Feb					33:17
	13-Feb					24:44
	20-Feb					38:05
	27-Feb	Braystones (3)		6		22:43
	06-Mar					40:29
	13-Mar	Walking Strandline Monitoring				22:46
	20-Mar	St Bees (5)		4		41:23
	27-Mar	Seascale (5)		4		24:40
		Cumulative Totals ==>	88 ha	62 ha	10 ha	
		OVERALL TOTAL ==>	160 ha			

8.2 Proposed Investigation Programme for 2016/17

Two items of further research are proposed for 2016/17, these are a review of coastal geomorphology and sediment transport and obtaining further information on storm events.

8.2.1 Review of coastal geomorphology and sediment transport.

Sellafield Ltd have contracted Golder Associates (working with CH2M Hill and Eden Nuclear and Environment) to provide a review of Coastal Geomorphology and Sediment Transport. This project is structured against the following milestones (A-G) and is due to report in Autumn 2016.

Task A Review sediment/ sand dynamics along the coast with a focus on interpreting the measured distribution of radioactive finds on the beaches. Working assumptions as to the likely release of 'finds' into the environment will be determined through the data analysis and with appropriate consultation. The review of the geomorphology of the coast will help determine the likelihood of radioactive objects being in areas other than those that have been routinely monitored (*e.g.* Dunes, Offshore Sandbars *etc.*). The review will evaluate the following topics:

(i) The general sediment transport mechanisms along the coast and how these correspond with finds from the beach monitoring programme.

(ii) Dispersion mechanisms, accounting for the physical differences between particles (< 2 mm) and stones (>2 mm).

(iii) The role of physical barriers (*e.g.*, headlands, outcrops) and sediment storage areas (*e.g.* estuaries, dunes) There is some uncertainty around the role of Ravenglass estuary complex as a potential sink for particle finds and, whilst some analysis of this area is required as part of the general understanding of bulk sediment transport processes, the project will concentrate on the coastal features in the regions of higher find rates (St. Bees to Drigg with a focus on Sellafield and Braystones beaches).

(iv) Influence of storm events.

The output from this task will include an evaluation of how well the current finds distributions and Conceptual Site Model (CSM) (Rankine and Jackson, 2014) fit to the distributions expected from a consideration of the underlying processes. In particular, the review will consider whether find rates on northern beaches (particularly Allonby, where 13 alpha rich particles and two beta rich particles have been found from 72 ha of monitoring) can be explained from an understanding of the physical processes involved and the likely sources of particles.

Task B Review the nature of rocky areas (including skears) of the foreshore (*e.g.* as seen at St. Bees). This will include assessing how transient these features are and stating whether there is potential for them to 'lock in' radioactive particles and stones.

The output from this task will be used to determine whether specific monitoring of rocky areas is required or whether the beach environment is sufficiently well mixed that such areas, and any particles contained therein, would be detected from monitoring the surrounding area of the beach.

Task C An assessment of the role of sediment sinks as potential stores, where radioactive particles and stones may have accumulated since being released into the environment. It is anticipated that this will focus on the dunes in the sections of beach where the highest particle find rates are (*i.e.* Sellafield and Braystones, see Figure 10). This will include a summary of the likely depth of finds in the dune depth profile and consideration of the circumstances required to liberate the radioactive objects back into the foreshore areas.

This task will be used to assess the need for more intensive monitoring of the upper beach. Information on the depth profile of material will be used to assess whether it is likely that the current equipment used for walked surveys would detect radioactive objects, noting that detection of alpha rich particles and beta rich particles beyond 5 cm and 20 cm depth respectively is rare due to the limitations of the detectors.

Task D To source and review available information from on-beach works (*e.g.* pipeline installations, loading ramps, works to create the Ehen spit *etc.*) to better understand the depth profile of the beach, the potential for the vertical transport of finds and the likely limits to burial of radioactive particles and stones.

Task E To review data on the concentrations of radioactivity in bulk sediments collected from the offshore grab sampling programme and assess the potential use of these data as tracers for evaluating offshore sediment dynamics as detailed in Topic A.

Task F Evaluate the usefulness of data on beach height collected from the beach monitoring programme in comparison with that obtained from remote sensing. Further information relating to topography of the Sellafield intertidal zone has been collected by the North West Strategic Coastal Monitoring Programme and these data along with consideration of other relevant data sources should be included.

Task G The LLWR Environmental Safety Case included modelling with the DAWN model developed by Halcrow. This task will consider whether such modelling packages could be readily applied to predict the future transport of particles in the environment from Sellafield using the monitored particle distribution data for calibration.

8.2.2 Analysis of storm events

A review of storm events that occurred over the past 10 years has been commissioned by Sellafield Ltd. The review of storm events will include a description of the synoptic scale meteorology of the storm, its progression across the UK and a brief summary of any impacts. The local effects measured at the meteorological station will be identified (wind direction, wind speed, gust speed, temperature, pressure and precipitation) as will the period of time that the storm affected the site along with information on tidal range and potentially wave height for the Cumbrian coast. It is anticipated that once this information has been gathered then a review of the beach finds data for the specific periods that storms affected the coast should enable any correlations between storm events and changes in find rates to be identified. It is anticipated that a preliminary analysis will be reported in the 2016/17 Particles Annual report.

8.3 Proposed Beach Find Analysis for 2016/17

8.3.1 Analysis for ^{137}Cs and ^{90}Sr Ratios of Beta rich Particle Finds

Particles with potentially high ^{90}Sr content will be analysed to address concerns expressed in the PHE risk assessment (Brown & Etherington, 2011). They recommended to the EA that beach finds with ^{137}Cs activity greater than 1E+05 Bq should be characterised in terms of size and chemical composition, and their ^{90}Sr content should be measured. The skin dose from such finds should be calculated or measured to assess if dose rates in excess of 300 mGy h^{-1} are possible.

The following analytical schedule is judged to provide the data required to answer the above concerns. However, to ensure that the most appropriate data is collected, contractors were asked to provide alternative schedules and/or techniques that they judged to be more appropriate. Justification of any alternatives was requested in a format and level suitable for discussion with the EA.

Current analytical schedule to gather required data:

1. High resolution gamma scan on ‘as received’ particle finds;
2. Sample dried and particle separated from residue;
3. High resolution gamma scan on separated particle and residue;
4. Particle washed to remove salt and other surface contaminants;
5. High resolution gamma scan on washed particle;
6. Skin dose assessment / measurement(s):
    a. Extremity thermoluminescence dosemeters (EXTRAD TLDs);
    b. Radiochromic dye film;
    c. Direct measurement using small ion chamber instruments;
7. Particle imaging using:
    a. Optical photography;
    b. Scanning Electron Microscopy imaging;
    c. Other imaging techniques;
8. Surface EDX measurements;
9. Total dissolution;
10. High resolution gamma scan on aliquot of total dissolution solution;
11. Radiochemical analysis on aliquot of total dissolution solution for total alpha (as ^{241}Am), total beta (as ^{90}Sr) and ^{90}Sr;
12. Radiochemical analysis of ^{234,235,238}U, ^{238,239,240}Pu, ^{241}Pu and ^{241}Am + Cm on an aliquot of the dissolution liquid (particle dissolved in mineral acid);
13. Metals analysis on aliquot of total dissolution solution using inductively coupled plasma mass spectrometry (ICP-MS);

A contract has been placed with Golder Associates (UK) Ltd for this work between 2016 and 2018 under the project "ESR 199". The analytical schedule described above will be performed by PHE (radioanalytical and dose measurements) and BGS (particle imaging, SEM and EDX analysis). To date, an initial batch of 10 finds have been sent for analysis. This complements the 190 finds that have been further analysed since 2009. As more beach finds are further analysed, the criteria for selection are adapted towards the remaining finds. The current criteria for selection of beta rich particles are:

1. Any finds exceeding the PHE threshold of 1E+05 Bq ^{137}Cs to be included.
2. Up to five finds with the highest ^{137}Cs activity that have not been analysed. Note the reported uncertainty of the ^{137}Cs activity is around 20 % so finds reported above 8E+04 Bq ^{137}Cs may potentially exceed the PHE threshold albeit at a low degree of confidence.
3. The five finds not selected using the above two criteria that have the highest reported contact beta/gamma dose rates.

These criteria are superseded on the retrieval of any unusual find, where the contact beta/gamma dose rate is high although the ^{137}Cs content is less than 1E+05 Bq (*e.g.* the Seascale particle, S1164/SEA).

Previously, any particle with a ^{137}Cs activity of greater than 1E+05 Bq has been included. To date, all particles with ^{137}Cs activity greater than 1E+05 Bq have now been analysed. Indeed, the ^{137}Cs activities of the remaining beach particles are 7.7 E+04 Bq per find or lower. The criterion of selecting particles for further analysis that have ^{137}Cs activity greater than 1E+05 Bq is now only applicable to future finds satisfying this condition.

8.4 Particles Programme Forward Strategy

A forward strategy for the particles programme has been developed in consultation with the Sellafield Particles working group (comprising of NDA, PHE, EA and FSA) and COMARE Contaminants working group.

8.4.1 Strategic aim

The aim of this strategy was agreed as follows:

"To optimise monitoring West Cumbrian beaches to a routine programme by 2018, in line with the principles of Best Available Techniques."

The strategy considered relevant guidance related to:

- Objectives and principles (EA, 2010a; EA, 2010b)
- Application of BAT (NICOP, 2010)
- Consistency with UK Discharges Strategy (DECC, 2009)

The application of the above guidance to the strategy implies that:

- Programme aims and objectives are being met.
- BAT applied for all elements of the programme.
- Defined closeout criteria are being worked towards.
- This strategy relates to the workplan for the next 3 years, following which a reduced programme could be implemented.

8.4.2 Considerations when developing the strategy

Based on the review of guidance detailed above, the following objectives and principles were identified as being applicable to the programme:

Programme Objectives

- Assess total representative persons dose.
- Assess total impact on wildlife (*e.g.* dose).
- Provide public and stakeholder reassurance.
- Assess long term trends (as an indicator).
- Understand / monitor behaviour of radionuclides in the environment

Specific Programme Objectives

- Provides reassurance that the conclusions of the PHE Health Risk Assessment remain valid.
- Monitor for abnormal radioactive material and remove in line with the principle of As Low As Reasonably Practicable (ALARP).
- Understand the behaviour of radionuclides in the environment.

Monitoring Principles

- Health and Safety.
- Benefits exceed impacts.
- Objective based.
- Proportionate.

- Satisfy stakeholder concerns.
- Based on authorisations.
- Optimised.
- Meet quality standards.
- Appropriate performance criteria.

BAT – Guiding principles

- Sustainability.
- Waste hierarchy and waste form.
- Precautionary principle.
- Proportionality.

Overall Exit Criteria

- Site continues not to release particles to the environment.
- Risks to people and the environment assessed as low.
- Monitoring demonstrates a sustained reduction in find rate and risk.
- Source – Pathway – Receptor relationships understood sufficiently to provide confidence that risks are less than one in a million.
- Uncertainties in the risk assessment are acceptably low and legitimate stakeholder concerns are addressed.

8.4.3 Screening of items in the workplan

An assessment was conducted through consultation with the Particles Working Group and COMARE Contaminant Working Group to screen each of the possible work packages that could be included in the workplan into the following categories.

- High Priority - enabling the close out of significant uncertainty or risk.
- Medium Priority - contributing to the close out of uncertainty or risk or essential to exit criteria.
- Low Priority - significantly contributing to exit criteria.

A decision tree used to screen items in the work plan is shown in Figure 30.

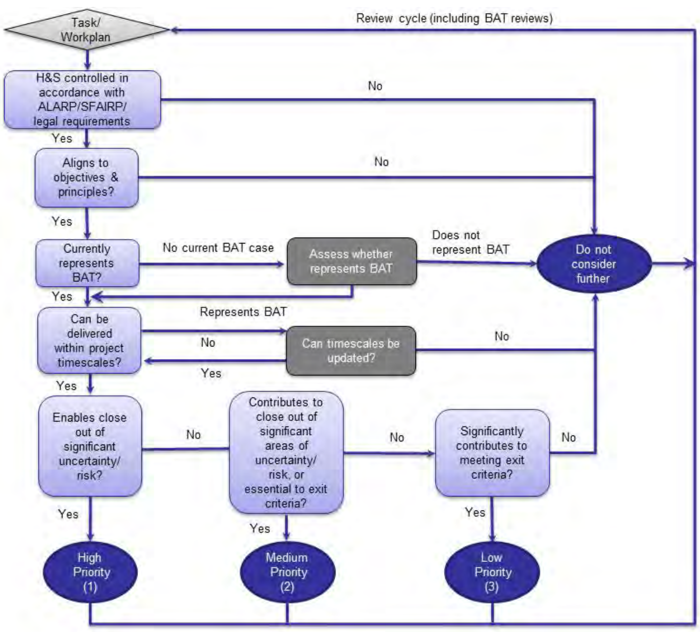


Figure 30: Flowchart used to prioritise items considered through the particles strategy.

8.4.4 Prioritised programme

The flowchart shown in Figure 30 was applied to screen items for inclusion in the current workplan, noting that the workplan itself will be periodically reviewed (by the Particles Working Group and others) and tasks that are currently screened out may reappear in future workplans. Overall 51 tasks were evaluated related to understanding the sources of beach particles, 20 tasks were evaluated related to understanding environmental pathways, 16 tasks were evaluated related to understanding the receptors for beach particles and 5 tasks were evaluated related to other aspects of the programme (including design and communications). Of these 92 tasks, 50 were identified as requiring further work and, of these, 11 were ranked as being high or medium priority and are shown in Table 25. It should be noted that the list in Table 25 has been optimised so some of the listed tasks meet several of the requirements detailed in the workplan.

Table 25: Tasks that were assessed as medium and high priority.

Tasks	Status
Synergy 2 trials and investigation into improved detection techniques (*e.g.* plastic phosphor scintillation detectors).	Completed
PHE to conduct a reappraisal of the Risk Assessment following the Synergy 2 trials (to be completed before 2018).	Not started
Evaluate the detection efficiency of Synergy 2 for buried particles.	Completed
Design of beach monitoring programme to focus on high find rate beaches.	Ongoing
Analysis of beach monitoring repeat areas to understand repopulation rates.	Ongoing
Conduct a geomorphology review to include existing knowledge of bulk sediment movement on the West Cumbrian coast and include analysis of beach height data from ongoing beach monitoring programme.	Started
Ongoing pro-active response to storm events.	Ongoing
SL to review photographic data including the use of drones.	Ongoing
PHE to reviewing the effective doses associated with the 2014 Seascale ^{90}Sr rich particle (S1164/SEA) and are to provide a letter response.	Completed
PHE conducting dose rate measurement work to advise on best techniques.	Completed
SL to develop staged proposals on optimising the sentinel monitoring programme.	Not started
Characterisation of finds from site (*e.g.* drainage finds containing [Hg]; ^{60}Co find on ground). Gully pot samples sent as part of characterisation. The RSR permit compliance requires SL to use BAT to avoid release in future and therefore there is an ongoing routine action on Plant to demonstrate compliance.	Ongoing

References

Brown J & Etherington G, 2011. *Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site,* Chilton: HPA-CRCE-018, Health Protection Agency.

Brown J, Oatway W & Cabianca T, 2016. *Health risks to beach users and seafood consumers from radioactive objects in the vicinity of the Sellafield site: Look-up Tables to assess the impact on the health risks of changes in information on object finds in the environment,* Chilton: CRCE-RAD-001-2016, Health Protection Agency.

Davies M, 2014. *Radionuclide specific alarms for ^{241}Am and ^{90}Sr/^{90}Y*. Warrington: 87257/TR/020, Nuvia Ltd.

Davies M, 2016. *Presentation of results of particle detection tests for Synergy 2 and initial interpretation*. Warrington: 72850/TR/007, Nuvia Ltd.

DECC, 2009. *UK Strategy for Radioactive Discharges*. Department of Energy & Climate Change, London.

EA, 2016. *Compilation of Environment Agency Requirements, Approvals,and Specifications,* Warrington: Environment Agency, EAR 4.2.2P2/V002 Condition 12, Issue 10, Permit KP3690SX.

EA, 2010a. *Regulatory Guidance Series, No RSR 1 - Radioactive Substances Regulation - Environmental Principles*. Environment Agency, Bristol, ea/br/s/std/v1.

EA, 2010b. *Radiological monitoring technical guidance note 2: environmental radiological monitoring*. Guidance published jointly by the EA, SEPA and FSA.

Etherington, G, Youngman, M D, Brown, J & Oatway, W, 2012. *Evaluation of the Groundhog Synergy Beach Monitoring System for Detection of Alpha-rich Objects and Implications for Health Risks to Beach Users,* Chilton: HPA-CRCE-038, Health Protection Agency.

Golder, 2016. *ESR162 Stones Analysis Review, Report Number 13514270153/510/A.0,* Nottingham: Golder Associates (UK).

Harrison J, 2014. *Letter from Public Health England to Environment Agency regarding the particle detected on Seascale beach on 24th June 2014*. Public Health England.

McDowell A, 2016. *Trial deployment of hand-held plastic scintillators and assessment of their performance in detecting ^{90}Sr/^{90}Y*. Warrington: 72850/TR/006, Nuvia Ltd.

NICOP, 2010. *Best Available Techniques (BAT) for the generation and disposal of radioactive waste*. Nuclear Industry Code of Practice.

Oatway W and Brown J, 2015a. *Supporting document: Parameter values for PHE assessment of health risks to seafood consumers. Note for environment agency,* Chilton, Didcot: Public Health England, CRCE-RA-2-2015.

Oatway W and Brown J, 2015b. *Health risk to seafood consumers from radioactive particlesin the marine environment near Sellafield,* Chilton, Didcot: Public Health England, PHE-CRCE-021.

Oatway W et al, 2011. Supporting Information for the Assessment of the Health Risks from radioactive Objects on beaches in the Vicinity of the Sellafield Site, HPA-CRCE-018 (supplement), April 2011.

Rankine A and Jackson D, 2014. *Review and update of conceptual site model for radioactive particles in the coastal area around Sellafield*. Eden Nuclear and Environment ENE-040G/01. June 2014.

Sellafield Ltd, 2011. *Particles in the Environment, Annual Report for 2010/11 and Forward Programme, June 2011, Sellafield Ltd,,* Whitehaven: Nuclear Decommissioning Authority.

Sellafield Ltd, 2013. BAT Assessment of monitoring for particles in the environment. SSEM/2013/19 Sellafield Limited. May 2013.

Sellafield Ltd, 2014a. *Particles in the Environment Annual Report for 2013/14 and Forward Programme,* Whitehaven: SSEM/2014/20 NDA.

Sellafield Ltd, 2014b BAT Assessment for Monitoring Particles in the Environment. June 2014, Sellafield Ltd, Whitehaven: SSEM/2014/22 *NDA.*

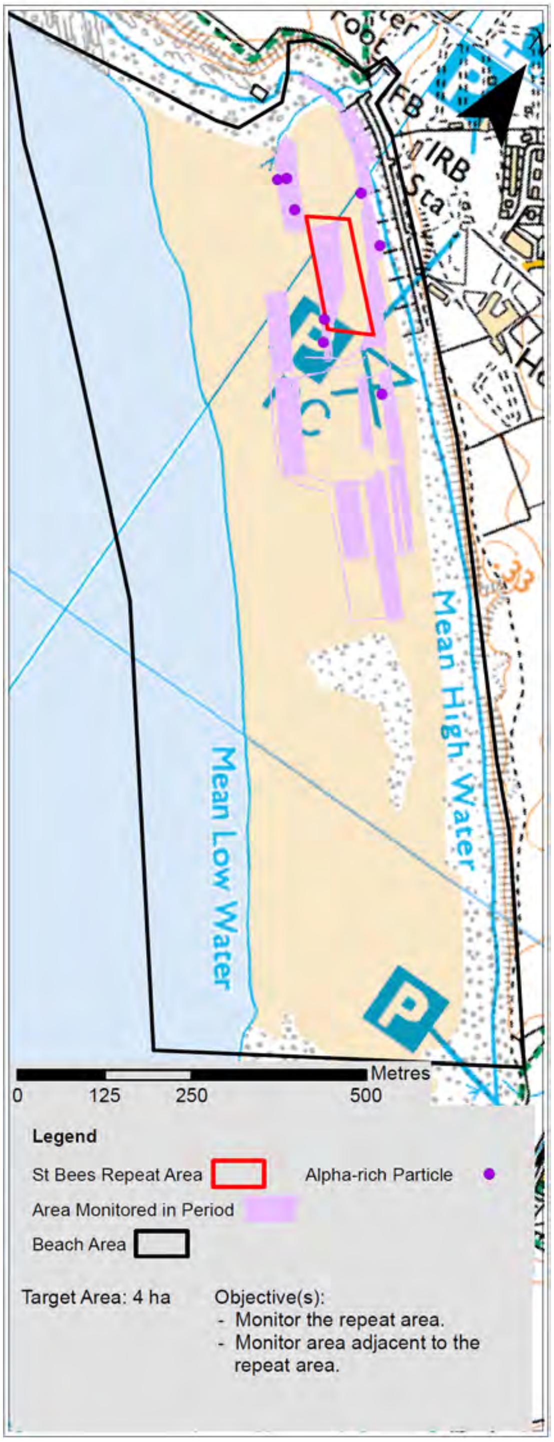
Sellafield Ltd, 2015. *Particles in the Environment, Annual Report for 2014/15 and Forward Programme, July 2015, Sellafield Ltd,,* Whitehaven: Nuclear Decommissioning Authority..

Serco, 2011. *Analysis of Beach Monitoring Finds – Third Tranche, ESR 107,* Warrington: SERCO/004820/001 Issue 01.

Tanner, R, 2015. *Measurements of dose rates to the skin made on Sellafield particle S1164/SEA,* Chilton: CRCE 2015 PHE.

Appendix 1: Beach Monitoring and Find Maps

St Bees (1) Area
Monitoring completed between
13th and 16th April 2015



Seascale (1) Area
Monitoring completed between
20th and 23th April 2015

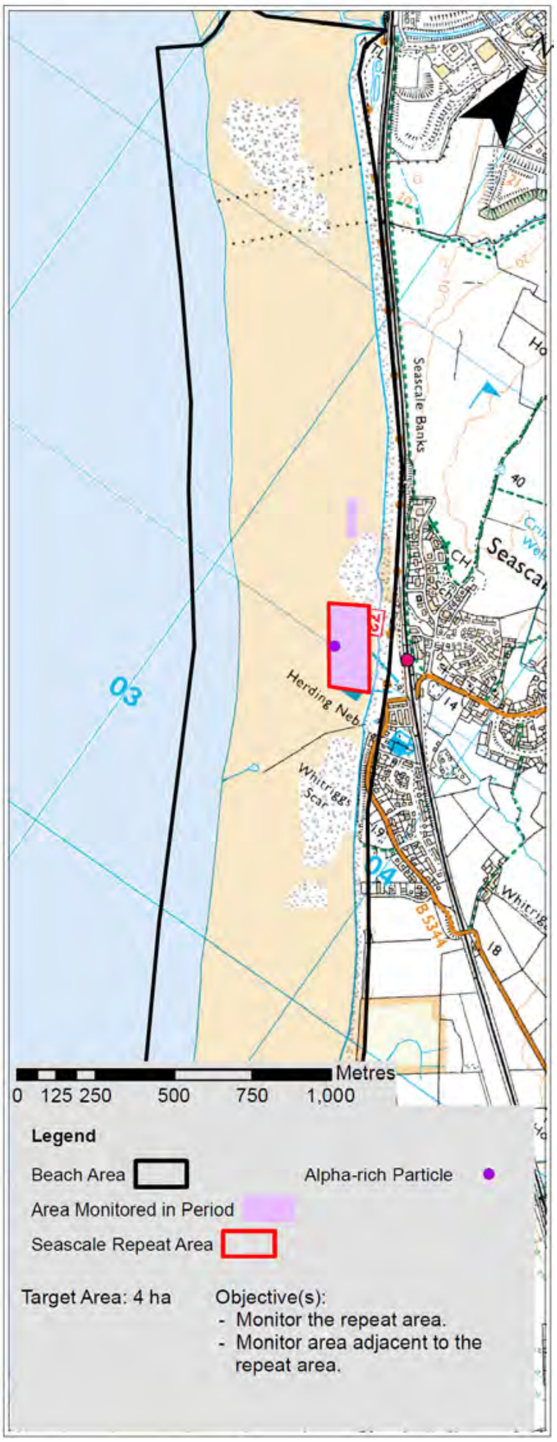


Figure A1.1 St. Bees and Seascale beach visits in April 2015.

Sellafield (1) Area - Monitoring completed between 27th April and 19th June 2015

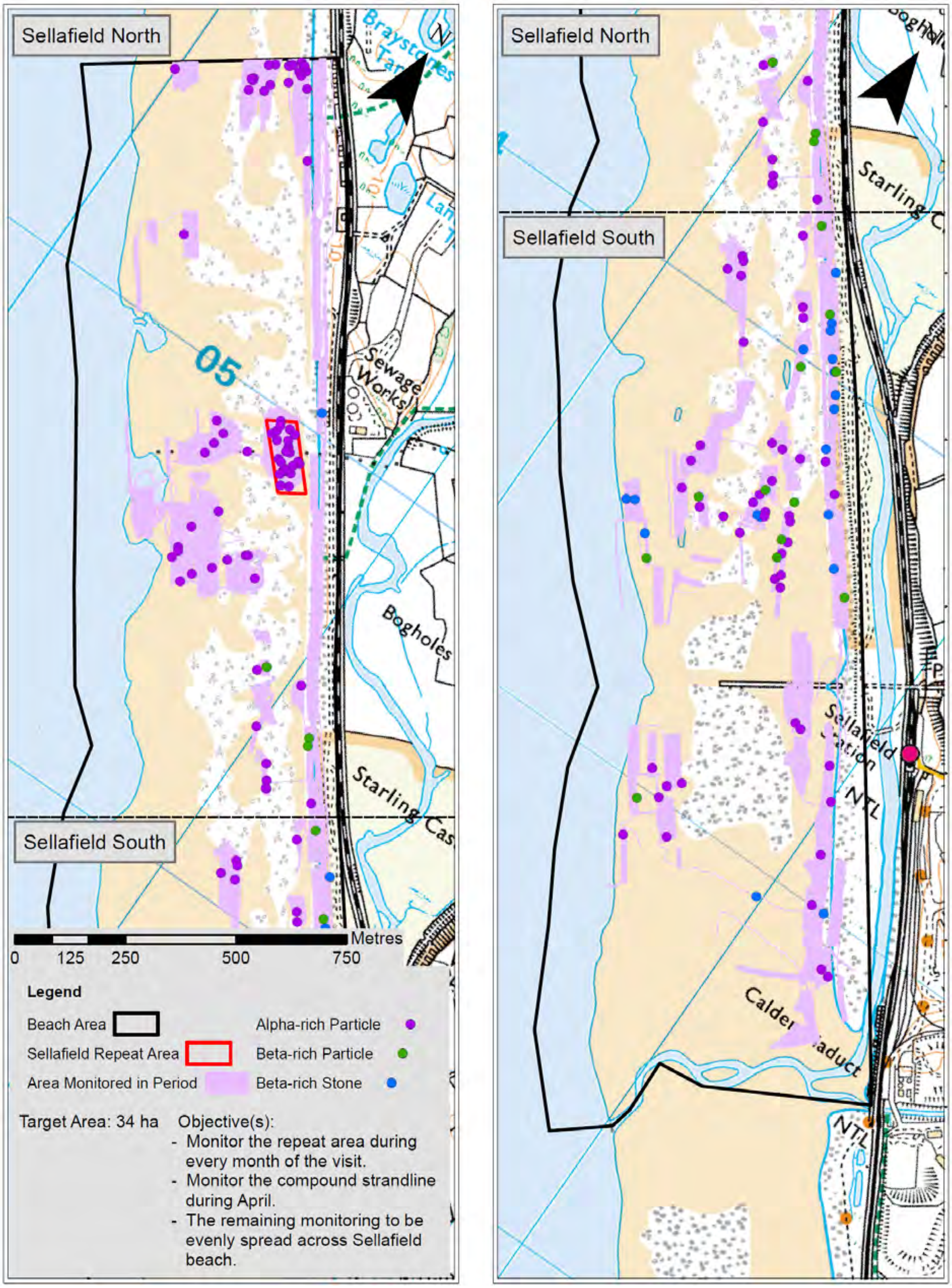


Figure A1.2 Sellafield beach visits in April, May and June 2015.

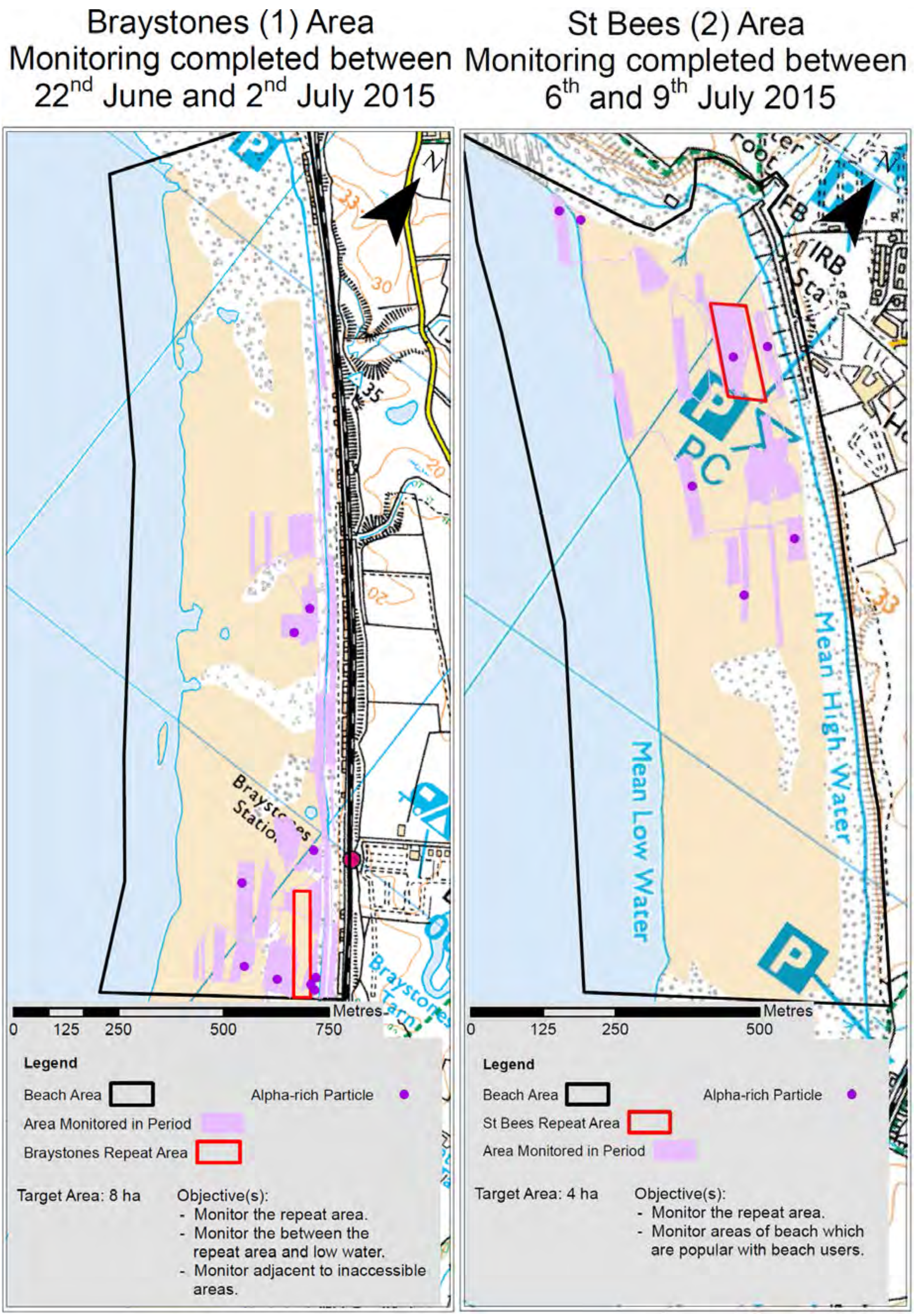


Figure A1.3 Braystones and St. Bees beach visits in June and July 2015.

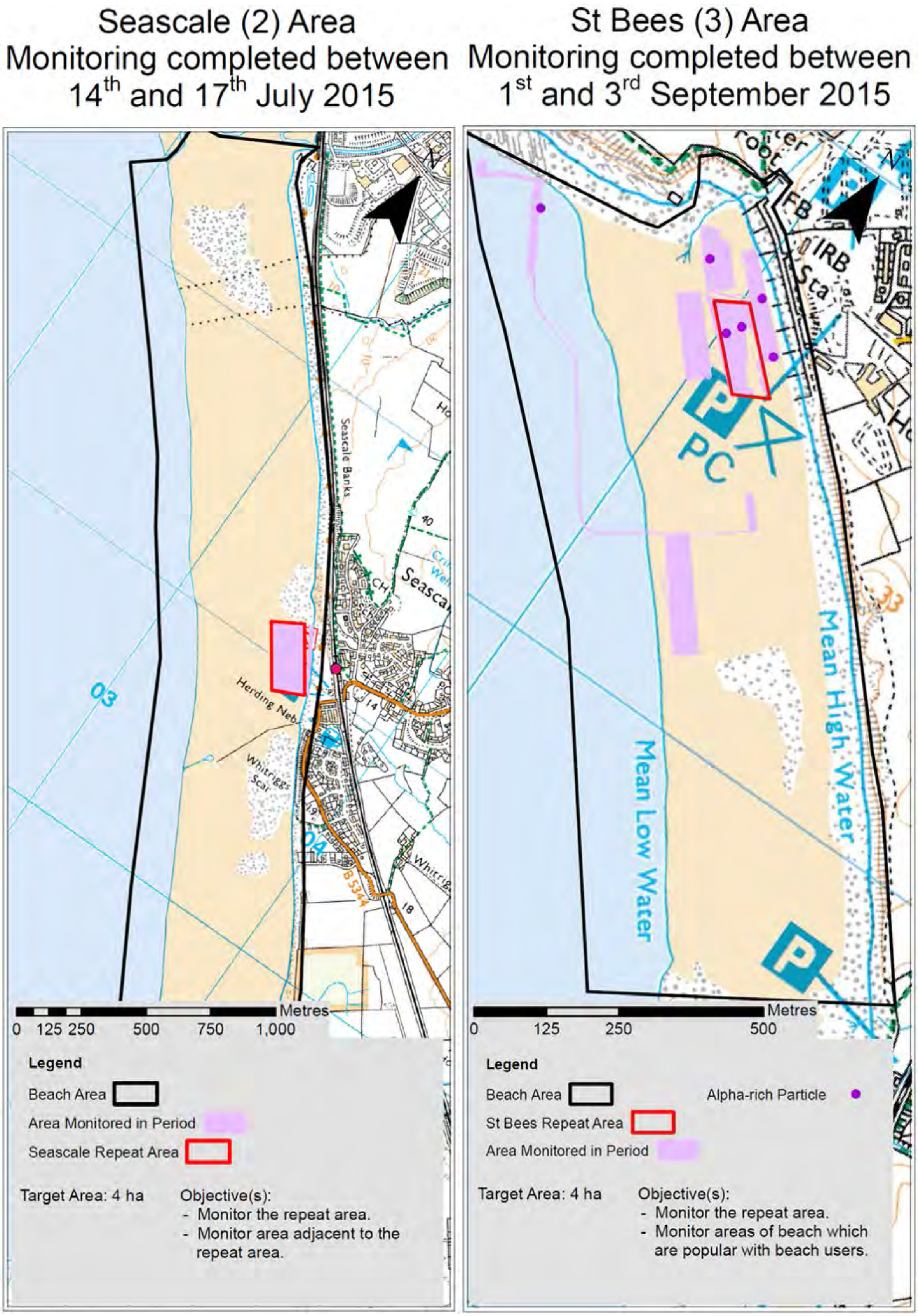


Figure A1.4 Seascale and St. Bees beach visits in July and September 2015.

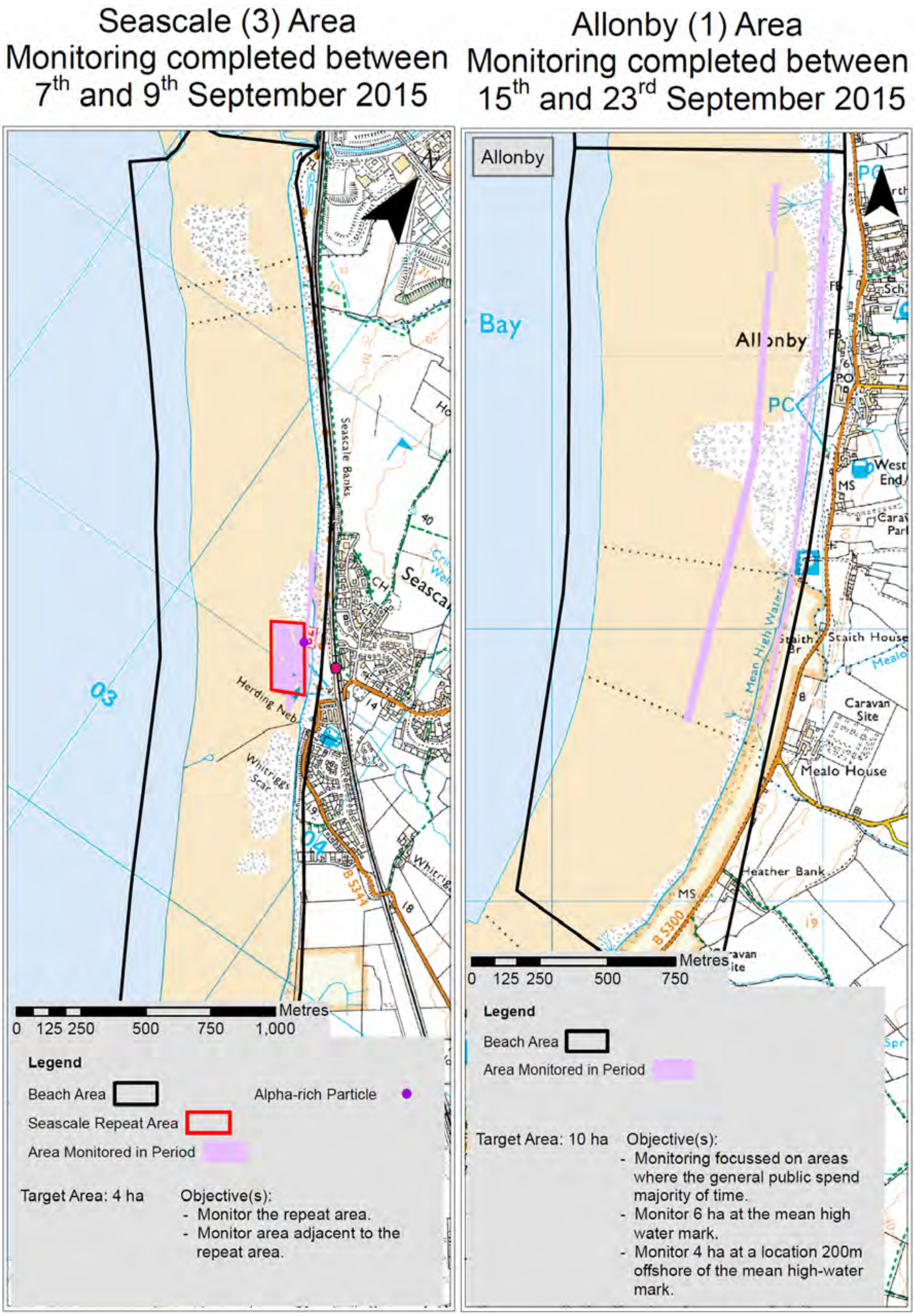


Figure A1.5 Seascale and Allonby beach visits in September 2015.

Sellafield (2) Area - Monitoring completed between 5th October and 25th November 2015

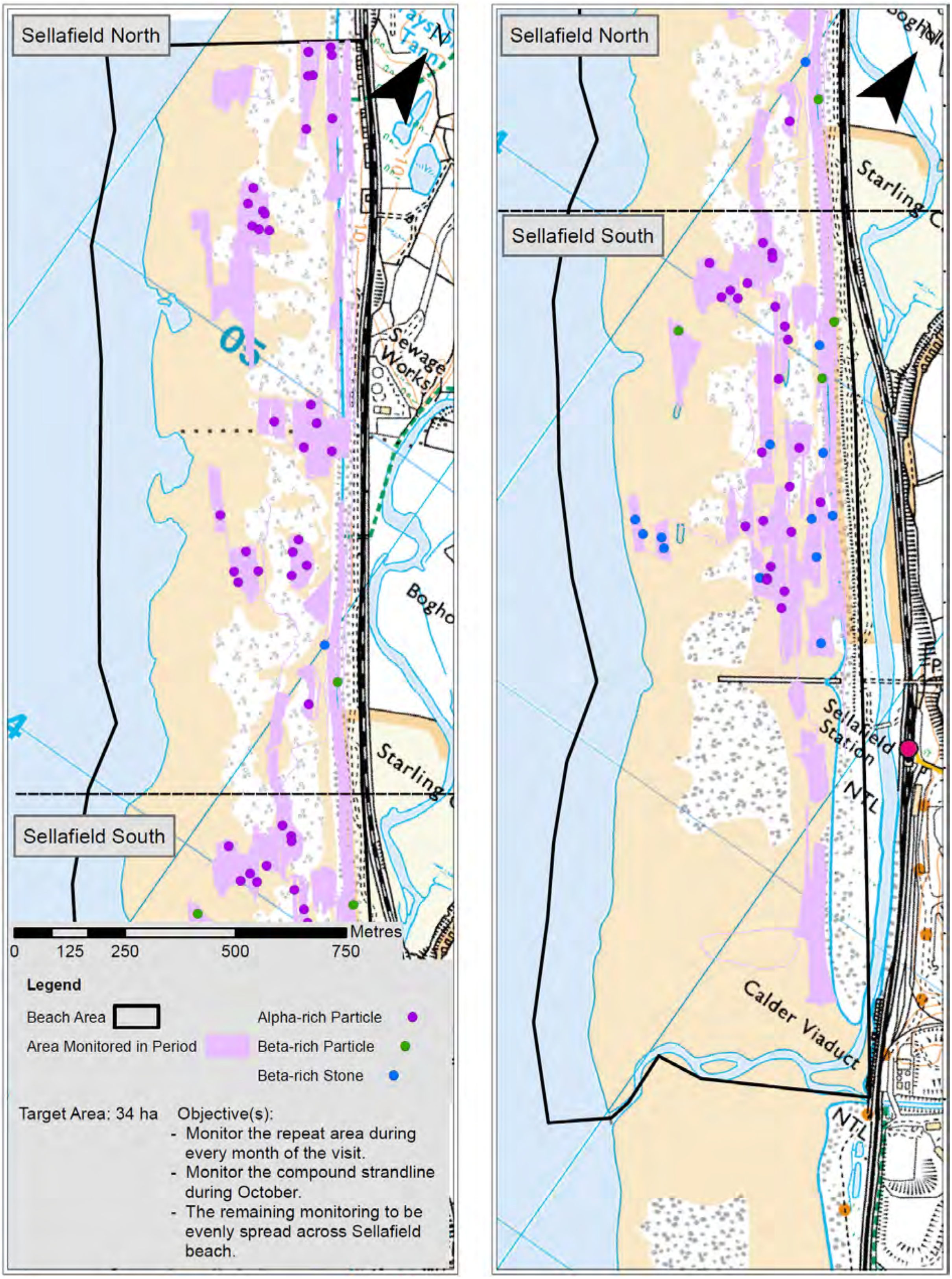
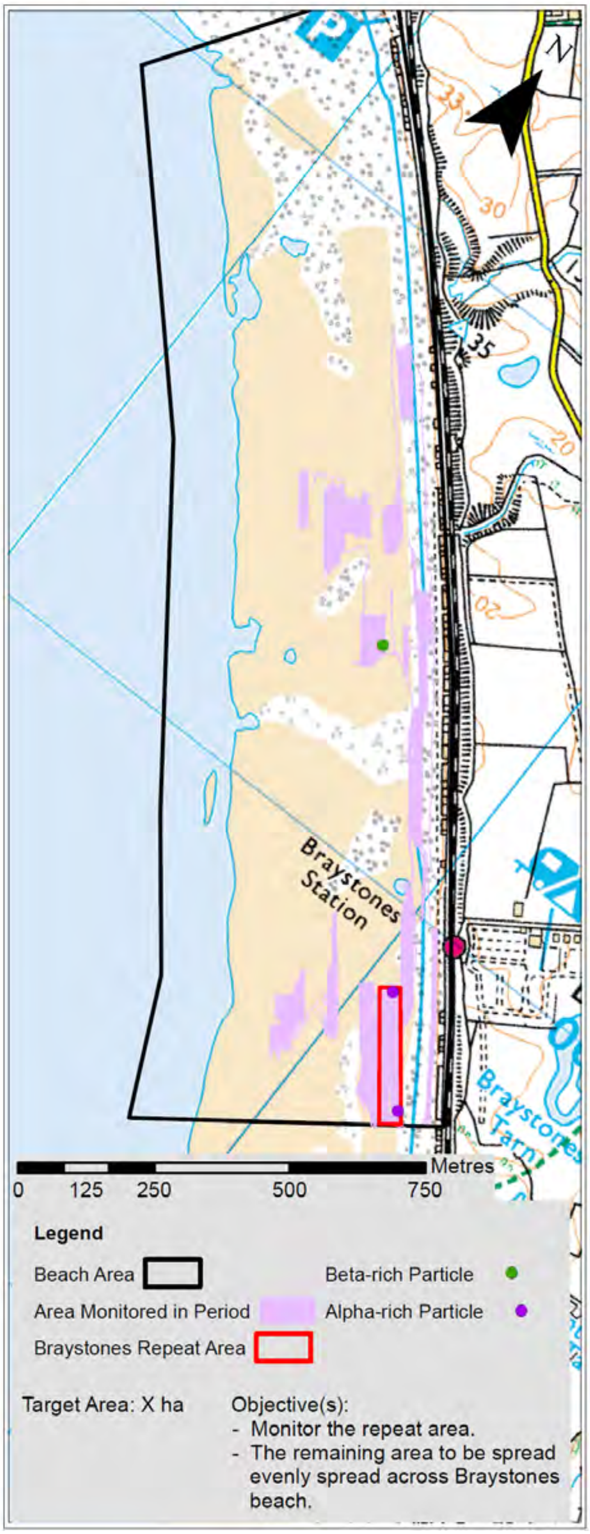


Figure A1.6 Sellafield beach visits in October and November 2015.

Braystones (2) Area
Monitoring completed between
30th Nov and 14th Dec 2015



St Bees (4) Area
Monitoring completed between
5th and 8th January 2016

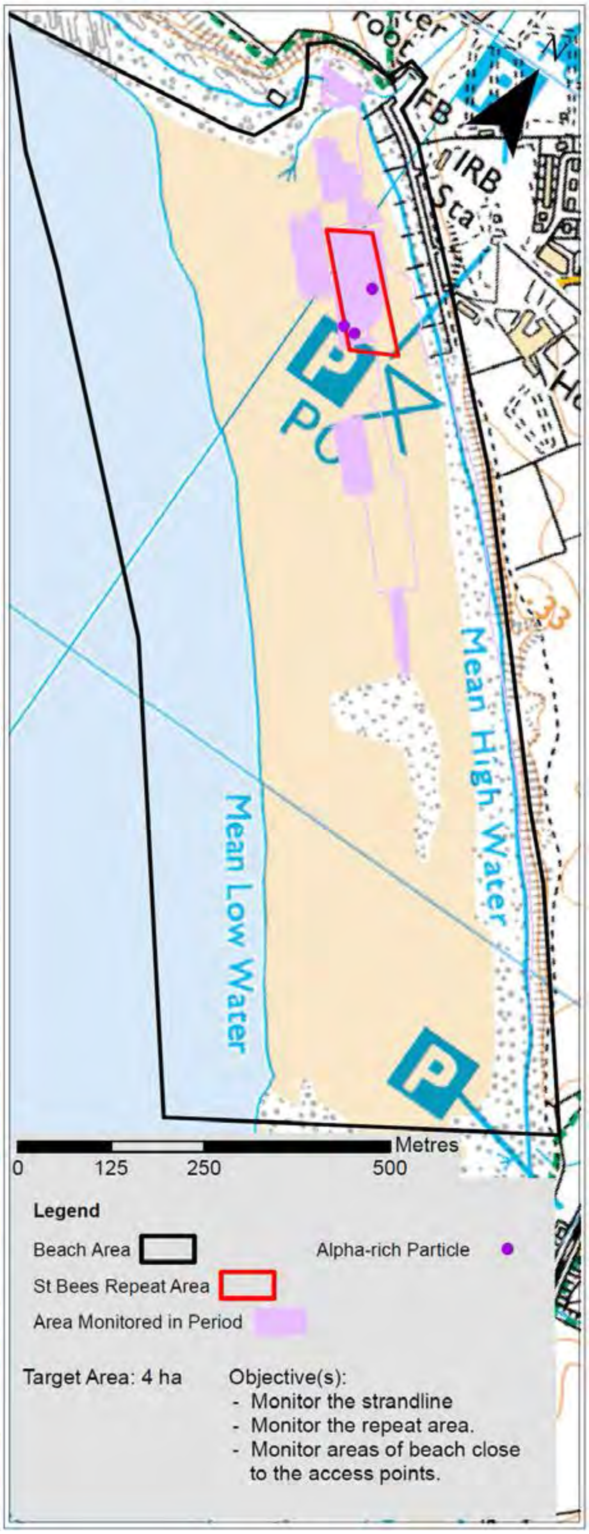


Figure A1.7 Braystones and St. Bees beach visits in November and December 2015 and January 2016.

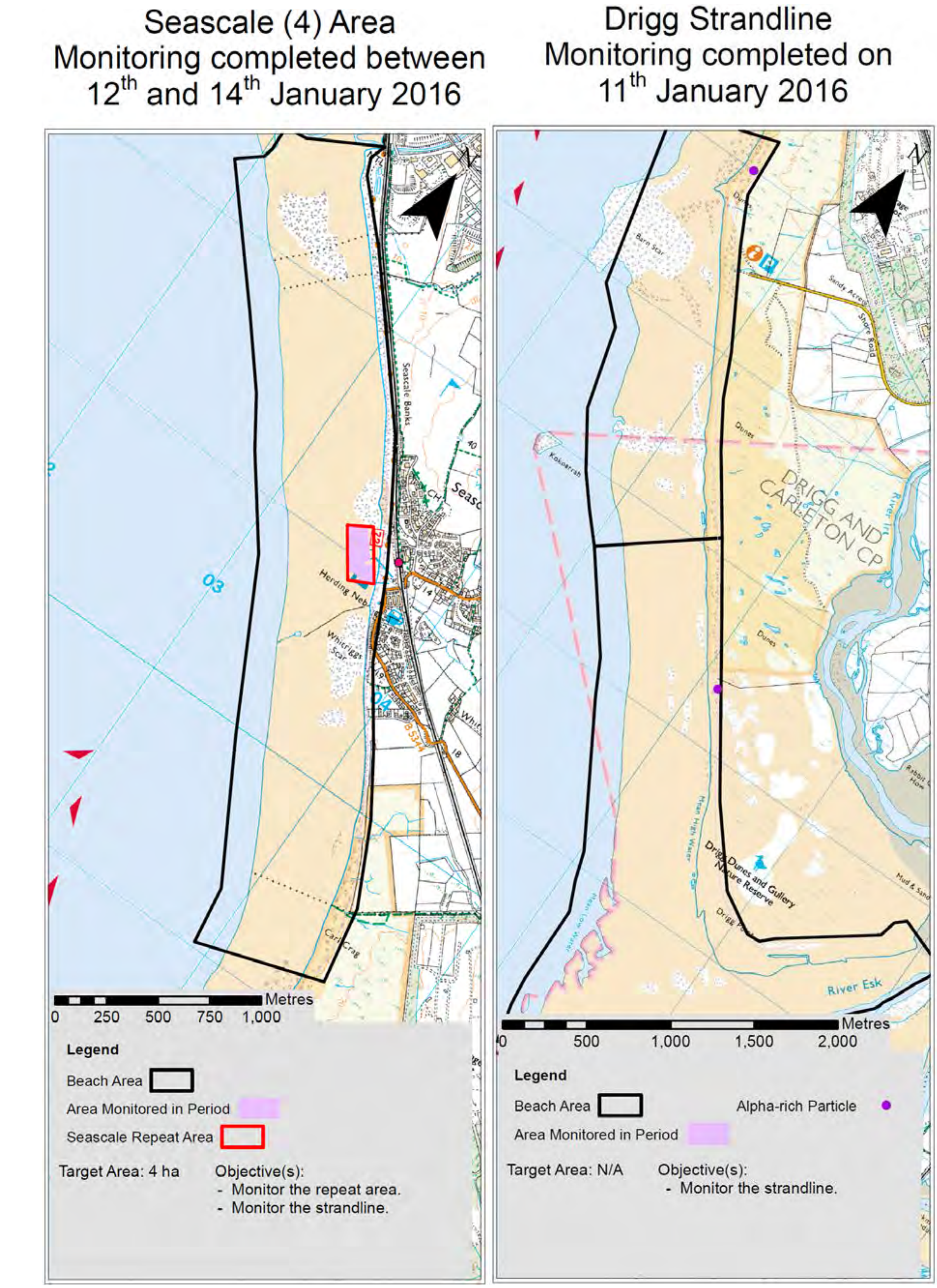


Figure A1.8 Seascale and Drigg beach visits in January 2016.

Seascale (5) Area
Monitoring completed between 3rd and 8th February 2016

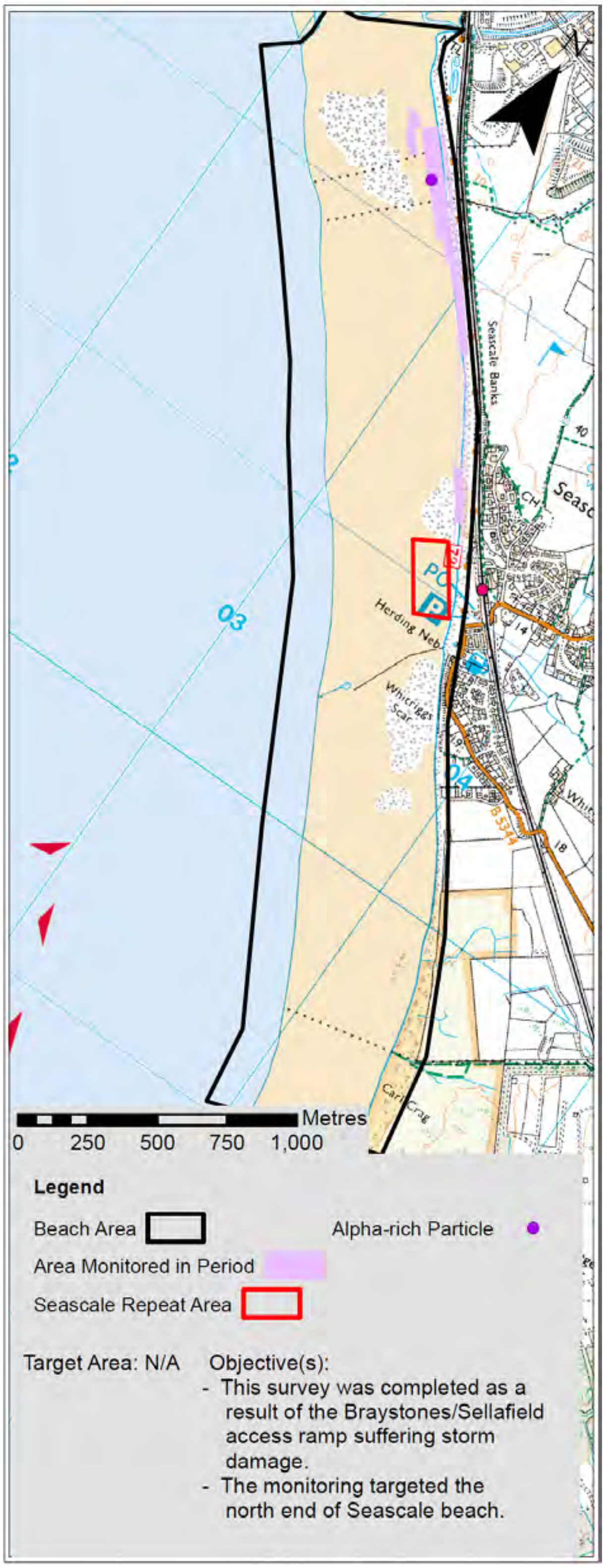


Figure A1.9 Seascale beach visit in February 2016.

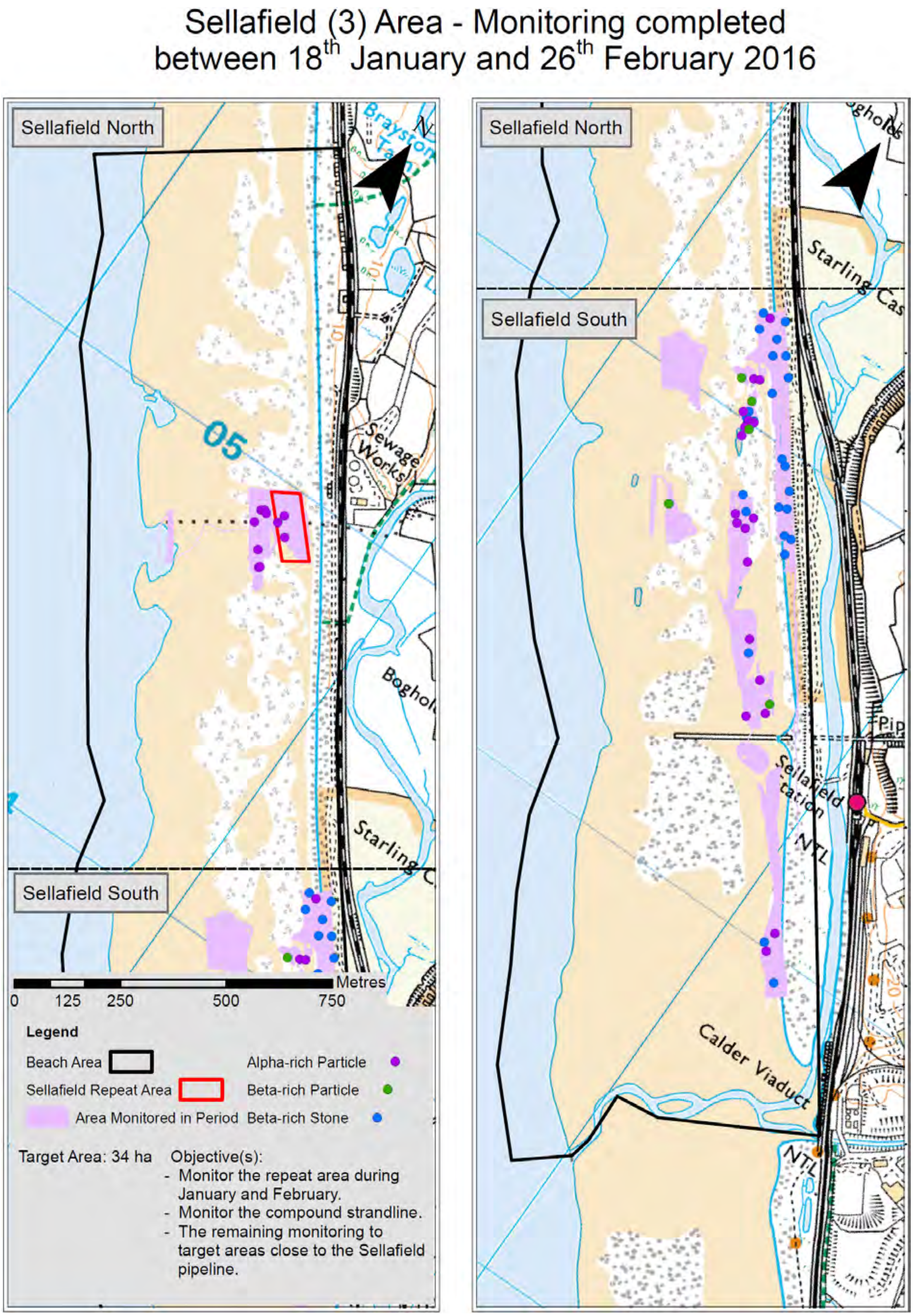


Figure A1.10 Sellafield beach visit in January and February 2016.

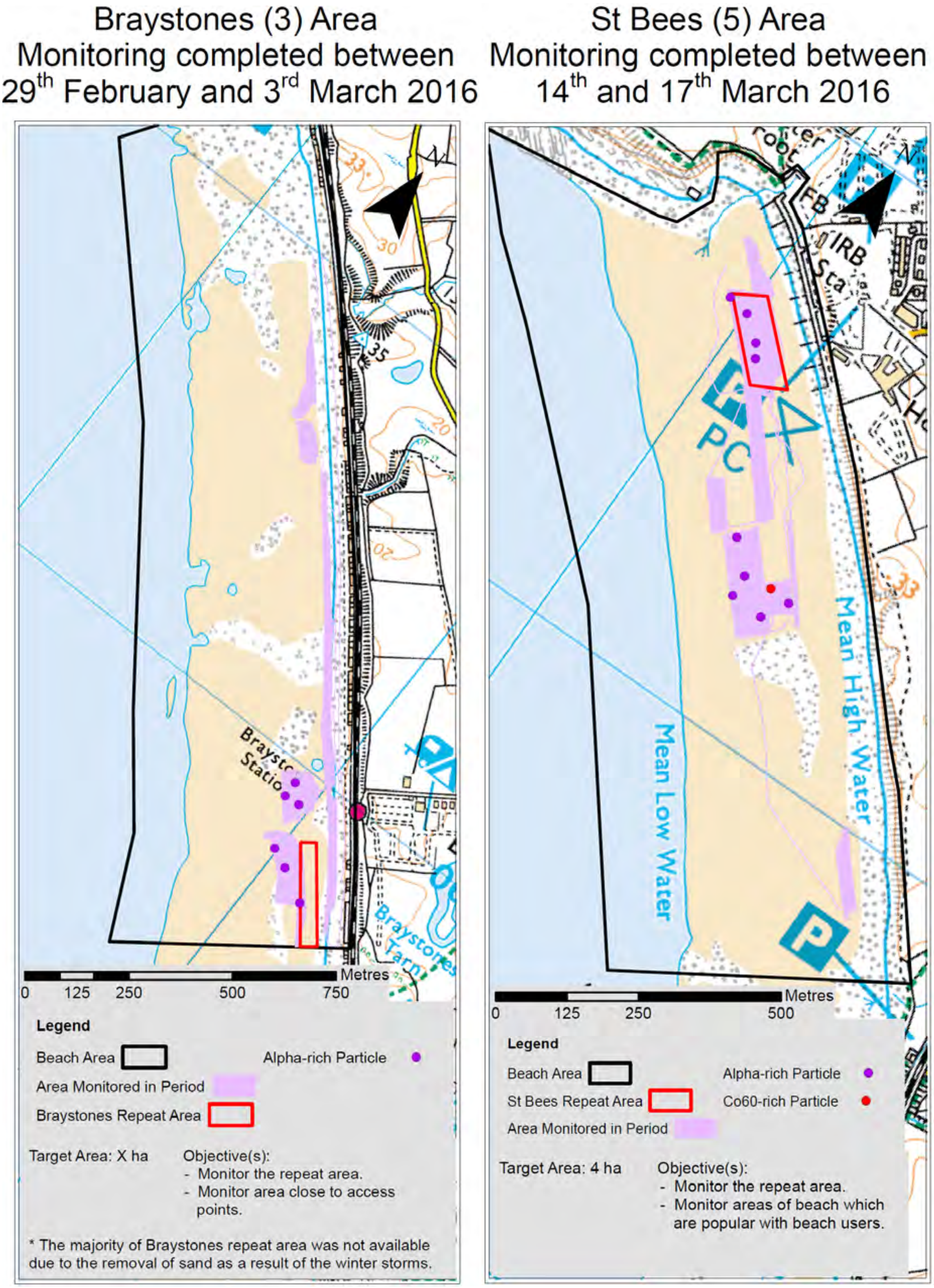


Figure A1.11 Braystones and St. Bees beach visits in February and March 2016.

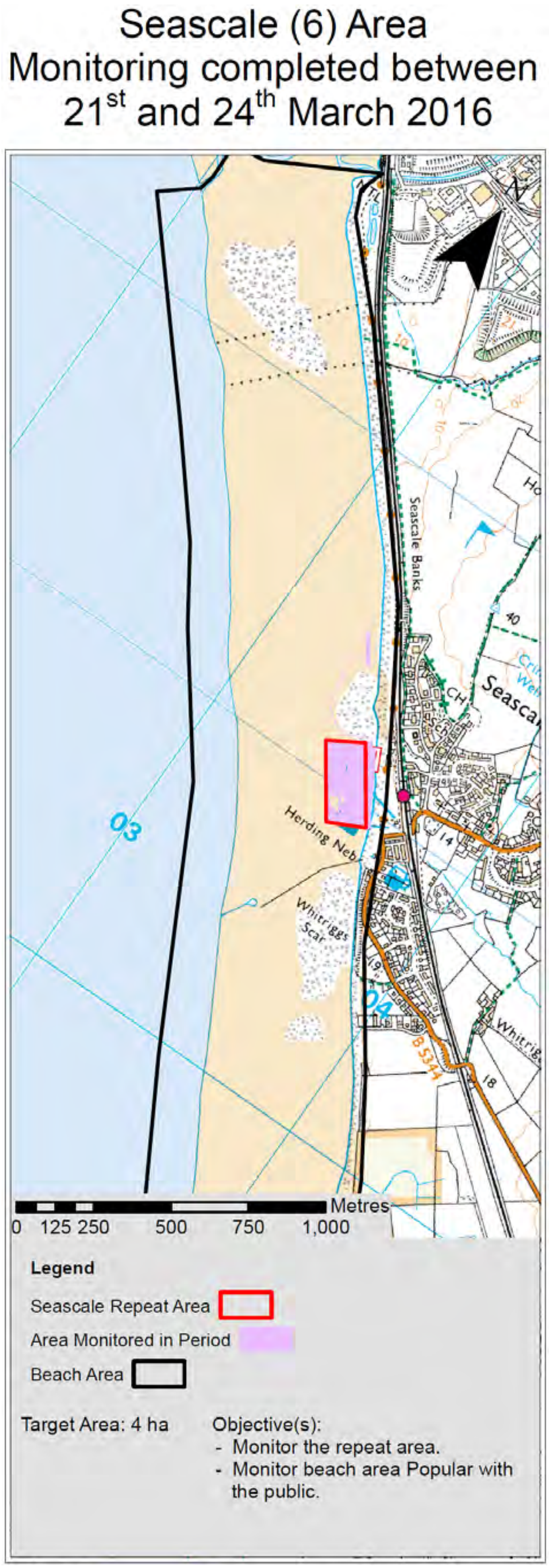


Figure A1.12 Seascale beach visits in March 2016.

Appendix 2: Summary Monitoring Data to the end of March 2016

Table A2.1 Total area monitored and finds by category and beach to the end of March 2016.

Beach location	Area covered ha	Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone	Total particles found	Total stones found
Allonby	72.27	13	0	2	0	0	0	15	0
Workington	24.01	5	0	1	1	0	0	6	1
Harrington	8.57	4	0	0	0	0	0	4	0
Whitehaven	8.80	8	0	1	0	0	0	9	0
St. Bees	324.32	217	0	15	0	2	0	234	0
Braystones	316.59	377	0	35	0	4	0	416	0
Sellafield [1]	518.09	897	6	307	575	9	1	1213	582
Seascale	312.15	61	0	23	3	1	0	85	3
Drigg	141.46	23	0	3	0	1	0	27	0
TOTAL [2]	1726.26	1605	6	387	579	17	1	2009	586

Note 1:The Table excludes the two radium stones detected on Sellafield beach since the start of beach monitoring in 2006.
Note 2:The total area excludes monitoring from other beach areas (Southerness 14.26 ha, Goatwell Bay 5.76 ha, Parton 1.86 ha, Nethertown 2.45 ha and Silecroft 12.14 ha). Including this additional area gives an overall total of 1762.73 ha.

Table A2.2 Particle and stone activity summary by category and monitoring system to the end of March 2016.

Activities in Bq	Classification								
	Alpha rich			Beta rich			Co60 rich		
	Pre-Synergy	Synergy	Synergy 2	Pre-Synergy	Synergy	Synergy 2	Pre-Synergy	Synergy	Synergy 2
Total number	62	983	567	599	206	161	11	6	1
No. of particles	59	980	567	210	110	67	10	6	1
No. of stones	3	3	0	389	96	94	1	0	0
Particle Mean ^{241}Am	7.82E+04	3.00E+04	2.49E+04	3.68E+02	4.87E+02	2.13E+02	4.48E+03	-	-
Particle Max. ^{241}Am	6.34E+05	2.52E+05	1.46E+05	1.15E+03	1.63E+03	7.17E+02	4.48E+03	-	-
Number of Particles Containing ^{241}Am	59	980	567	18	13	13	1	0	0
Stone Mean ^{241}Am	1.74E+04	2.40E+05	0.00E+00	7.70E+02	4.56E+02	7.49E+02	-	-	-
Stone Max. ^{241}Am	3.54E+04	6.18E+05	0.00E+00	4.99E+03	1.17E+03	5.27E+03	-	-	-
Number of Stones Containing ^{241}Am	3	3	0	58	12	23	0	0	0
Particle Mean ^{137}Cs	4.09E+01	1.99E+01	3.95E+02	1.62E+04	2.05E+04	2.75E+04	8.17E+01	8.41E+01	-
Particle Max. ^{137}Cs	6.09E+01	3.36E+01	7.38E+03	7.19E+04	2.92E+05	1.74E+05	8.17E+01	8.41E+01	-
Number of Particles Containing ^{137}Cs	2	7	19	210	110	67	1	1	0
Stone Mean ^{137}Cs	7.04E+03	5.46E+01	-	4.01E+04	5.97E+04	1.07E+05	-	-	-
Stone Max. ^{137}Cs	7.20E+03	5.46E+01	-	8.75E+05	1.04E+06	3.73E+06	-	-	-
Number of Stones Containing ^{137}Cs	2	1	0	389	96	94	0	0	0
Particle Mean ^{60}Co	8.85E+00	1.03E+01	-	6.57E+01	-	-	1.27E+04	7.35E+03	1.09E+04
Particle Max. ^{60}Co	8.85E+00	1.65E+01	-	2.42E+02	-	-	1.97E+04	2.38E+04	1.09E+04
Number of Particles Containing ^{60}Co	1	7	0	5	0	0	10	6	1
Stone Mean ^{60}Co	- [1]	-	-	1.22E+02	-	-	2.35E+04	-	-
Stone Max. ^{60}Co	-	-	-	5.33E+02	-	-	2.35E+04	-	-
Number of Stones Containing ^{60}Co	0	0	0	6	0	0	1	0	0

Note 1: Where no analysis results above the detection limit have been reported or no finds have been recovered, the activity is indicated by "–"
Note 2: the total number of Alpha-rich Synergy particles differs from the total derived from Table A2.1 due to the inclusion of the Alpha-rich seabed find
Note 3: the Table excludes to two stones containing ^{226}Ra

Table A2.3 Total area monitored and finds by category, beach and financial year.

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Allonby	2007/2008	-						
	2008/2009	10.89	0	0	1	0	0	0
	2009/2010 Pre-Synergy	-						
	2009/2010 Post-synergy	-						
	2010/2011	7.47	0	0	0	0	0	0
	2011/2012	12.42	1	0	0	0	0	0
	2012/2013	10.02	3	0	0	0	0	0
	2013/2014	8.00	2	0	0	0	0	0
	2014/2015 Synergy 2	13.09	7	0	1	0	0	0
	2015/2016	10.37	0	0	0	0	0	0
Workington	2007/2008	-						
	2008/2009	10.53	0	0	1	0	0	0
	2009/2010 Pre-Synergy	-						
	2009/2010 Post-synergy	-						
	2010/2011	-						
	2011/2012	-						
	2012/2013	3.20	1	0	0	0	0	0
	2013/2014	5.83	1	0	0	0	0	0
	2014/2015 Synergy 2	4.45	3	0	0	1	0	0
	2015/2016	-						

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Harrington	2007/2008	-						
	2008/2009	-						
	2009/2010 Pre-Synergy	-						
	2009/2010 Post-synergy	-						
	2010/2011	2.53	2	0	0	0	0	0
	2011/2012	2.56	1	0	0	0	0	0
	2012/2013	0.97	1	0	0	0	0	0
	2013/2014	0.86	0	0	0	0	0	0
	2014/2015 Synergy 2	1.65	0	0	0	0	0	0
	2015/2016	-						
Whitehaven	2007/2008	1.53	0	0	0	0	0	0
	2008/2009	-						
	2009/2010 Pre-Synergy	-						
	2009/2010 Post-synergy	-						
	2010/2011	4.28	8	0	1	0	0	0
	2011/2012	2.01	0	0	0	0	0	0
	2012/2013	-						
	2013/2014	-						
	2014/2015 Synergy 2	-						
	2015/2016	-						

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
St. Bees	2007/2008	25.95	2	0	4	0	0	0
	2008/2009	43.11	1	0	2	0	0	0
	2009/2010 Pre-Synergy	38.62	1	0	2	0	1	0
	2009/2010 Post-synergy	21.88	0	0	0	0	0	0
	2010/2011	43.89	57	0	3	0	0	0
	2011/2012	25.17	39	0	2	0	0	0
	2012/2013	26.41	8	0	0	0	0	0
	2013/2014	39.27	32	0	0	0	0	0
	2014/15 Synergy	4.86	2	0	0	0	0	0
	2014/2015 Synergy 2	33.83	42	0	2	0	0	0
	2015/16	21.33	33	0	0	0	1	0
Braystones	2006/2007	7.03	1	0	2	0	0	0
	2007/2008	11.82	0	0	2	0	0	0
	2008/2009	19.06	0	0	3	0	0	0
	2009/2010 Pre-Synergy	21.38	2	0	2	0	0	0
	2009/2010 Post-synergy	30.75	57	0	6	0	1	0
	2010/2011	62.43	107	0	7	0	1	0
	2011/2012	46.40	55	0	4	0	1	0
	2012/2013	39.49	55	0	5	0	1	0
	2013/2014	34.93	25	0	3	0	0	0
	2014/2015 Synergy 2	19.01	57	0	0	0	0	0
	2015/2016	24.29	18	0	1	0	0	0

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Sellafield	2006/2007	5.50	0	0	4	5	0	0
	2007/2008	65.69	24	2	90	213	2	1
	2008/2009	96.98	19	0	57	143	2	0
	2009/2010 Pre-Synergy	26.83	2	1	20	25	3	0
	2009/2010 Post-synergy	23.77	68	1	9	23	0	0
	2010/2011	49.73	126	2	16	33	0	0
	2011/2012	43.28	124	0	21	13	1	0
	2012/2013	44.63	122	0	24	19	1	0
	2013/2014	40.89	34	0	5	8	0	0
	2014/2015 Synergy 2	38.23	174	0	35	35	0	0
	2015/2016	82.56	204	0	26	58	0	0
Seascale	2007/2008	27.73	0	0	6	0	1	0
	2008/2009	61.33	3	0	7	3	0	0
	2009/2010 Pre-Synergy	37.59	1	0	4	0	0	0
	2009/2010 Post-synergy	39.11	9	0	3	0	0	0
	2010/2011	38.50	10	0	0	0	0	0
	2011/2012	15.12	2	0	0	0	0	0
	2012/2013	15.88	7	0	1	0	0	0
	2013/2014	12.96	7	0	0	0	0	0
	2014/15 Synergy	3.16	0	0	0	0	0	0
	2014/2015 Synergy 2	33.66	17	0	2	0	0	0
	2015/16	27.12	5	0	0	0	0	0

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Drigg	2007/2008	19.80	2	0	2	0	1	0
	2008/2009	33.65	1	0	1	0	0	0
	2009/2010 Pre-Synergy	0.01	0	0	0	0	0	0
	2009/2010 Post-synergy	19.47	0	0	0	0	0	0
	2010/2011	30.36	10	0	0	0	0	0
	2011/2012	8.76	3	0	0	0	0	0
	2012/2013	10.79	0	0	0	0	0	0
	2013/2014	9.22	0	0	0	0	0	0
	2014/2015 Synergy 2	8.32	5	0	0	0	0	0
	2015/2016	1.08	2	0	0	0	0	0
Total	2007/08 – 2015/16	1726.26	1605	6	387	579	17	1

Table A2.4 Find rates by category, beach and financial year.

Beach Location	Financial Year	Find rate by Find category & Type					
		Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Allonby	2007/2008						
	2008/2009	0	0	0.092	0	0	0
	2009/2010 Pre-Synergy						
	2009/2010 Post-synergy						
	2010/2011	0	0	0	0	0	0
	2011/2012	0.080	0	0	0	0	0
	2012/2013	0.299	0	0	0	0	0
	2013/2014	0.250	0	0	0	0	0
	2014/2015 Synergy 2	0.535	0	0.076	0	0	0
	2015/2016	0	0	0	0	0	0
Workington	2007/2008						
	2008/2009	0	0	0.095	0	0	0
	2009/2010 Pre-Synergy						
	2009/2010 Post-synergy						
	2010/2011						
	2011/2012						
	2012/2013	0.312	0	0	0	0	0
	2013/2014	0.172	0	0	0	0	0
	2014/2015 Synergy 2	0.674	0	0	0.225	0	0
	2015/2016						

Beach Location	Financial Year	Find rate by Find category & Type					
		Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Harrington	2007/2008						
	2008/2009						
	2009/2010 Pre-Synergy						
	2009/2010 Post-synergy						
	2010/2011	0.791	0	0	0	0	0
	2011/2012	0.391	0	0	0	0	0
	2012/2013	1.027	0	0	0	0	0
	2013/2014	0	0	0	0	0	0
	2014/2015 Synergy 2	0	0	0	0	0	0
	2015/2016						
Whitehaven	2007/2008	0	0	0	0	0	0
	2008/2009						
	2009/2010 Pre-Synergy						
	2009/2010 Post-synergy						
	2010/2011	1.870	0	0.234	0	0	0
	2011/2012	0	0	0	0	0	0
	2012/2013						
	2013/2014						
	2014/2015 Synergy 2						
	2015/2016						

Beach Location	Financial Year	Find rate by Find category & Type					
		Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
St. Bees	2007/2008	0.077	0	0.154	0	0	0
	2008/2009	0.023	0	0.046	0	0	0
	2009/2010 Pre-Synergy	0.026	0	0.052	0	0.026	0
	2009/2010 Post-synergy	0	0	0	0	0	0
	2010/2011	1.299	0	0.068	0	0	0
	2011/2012	1.550	0	0.079	0	0	0
	2012/2013	0.303	0	0	0	0	0
	2013/2014	0.815	0	0	0	0	0
	2014/15 Synergy	0.412	0	0	0	0	0
	2014/2015 Synergy 2	1.241	0	0.059	0	0	0
	2015/16	1.547	0	0	0	0.047	0
Braystones	2006/2007	0.142	0	0.284	0	0	0
	2007/2008	0	0	0.169	0	0	0
	2008/2009	0	0	0.157	0	0	0
	2009/2010 Pre-Synergy	0.094	0	0.094	0	0	0
	2009/2010 Post-synergy	1.854	0	0.195	0	0.033	0
	2010/2011	1.714	0	0.112	0	0.016	0
	2011/2012	1.185	0	0.086	0	0.022	0
	2012/2013	1.393	0	0.127	0	0.025	0
	2013/2014	0.716	0	0.086	0	0	0
	2014/2015 Synergy 2	2.998	0	0	0	0	0
	2015/2016	0.741	0	0.041	0	0	0

Beach Location	Financial Year	Find rate by Find category & Type					
		Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Sellafield	2006/2007	0	0	0.727	0.909	0	0
	2007/2008	0.365	0.030	1.370	3.242	0.030	0.015
	2008/2009	0.196	0	0.588	1.475	0.021	0
	2009/2010 Pre-Synergy	0.075	0.037	0.745	0.932	0.112	0
	2009/2010 Post-synergy	2.860	0.042	0.379	0.967	0	0
	2010/2011	2.534	0.040	0.322	0.664	0	0
	2011/2012	2.865	0	0.485	0.300	0.023	0
	2012/2013	2.733	0	0.538	0.426	0.022	0
	2013/2014	0.832	0	0.122	0.196	0	0
	2014/2015 Synergy 2	4.552	0	0.916	0.916	0	0
	2015/2016	2.471	0	0.315	0.703	0	0
Seascale	2007/2008	0	0	0.216	0	0.036	0
	2008/2009	0.049	0	0.114	0.049	0	0
	2009/2010 Pre-Synergy	0.027	0	0.106	0	0	0
	2009/2010 Post-synergy	0.230	0	0.077	0	0	0
	2010/2011	0.260	0	0	0	0	0
	2011/2012	0.132	0	0	0	0	0
	2012/2013	0.441	0	0.063	0	0	0
	2013/2014	0.540	0	0	0	0	0
	2014/15 Synergy	0	0	0	0	0	0
	2014/2015 Synergy 2	0.505	0	0.059	0	0	0
	2015/16	0.184	0	0	0	0	0

Beach Location	Financial Year	Find rate by Find category & Type					
		Alpha rich particle	Alpha rich stone	Beta rich particle	Beta rich stone	^{60}Co rich particle	^{60}Co rich stone
Drigg	2007/2008	0.101	0	0.101	0	0.051	0
	2008/2009	0.030	0	0.030	0	0	0
	2009/2010 Pre-Synergy	0	0	0	0	0	0
	2009/2010 Post-synergy	0	0	0	0	0	0
	2010/2011	0.329	0	0	0	0	0
	2011/2012	0.343	0	0	0	0	0
	2012/2013	0	0	0	0	0	0
	2013/2014	0	0	0	0	0	0
	2014/2015 Synergy 2	0.601	0	0	0	0	0
	2015/2016	1.848	0	0	0	0	0

Sellafield Ltd

Sellafield Site

Sellafield, Seascale
Cumbria CA20 1PG
www.sellafieldsites.com