Sellafield Ltd

Particles in the Environment

Annual Report for 2017 and Forward Programme

June 2018 **EM/2018/07**

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Executive Summary

Monitoring of the beaches has been part of the routine environmental monitoring programme at Sellafield since 1983. In 2003, during a routine survey, a radioactive particle was found which prompted a review of beach monitoring. Following agreement with the Environment Agency (EA) an intensive programme of beach monitoring commenced in 2006 using a vehicle mounted array of radiation detectors. This report details the progress that has been made during 2017 on the Particles in the Environment programme, addressing the objectives agreed with the EA. This report also sets out the forward programme of work for 2018 and summarises the forward strategy.

A total area of 152 ha of Cumbrian beaches was surveyed in 2017, meeting the programme's specification. This identified 226 radioactive items, of which 191 were classified as particles (less than 2 mm in size) and 35 as larger objects (greater than 2 mm in size). A total of 167 of the finds were designated alpha rich, with higher ^{241}Am activity than ^{137}Cs activity and 59 were designated as beta rich, where ^{137}Cs was the major radionuclide. All of the larger objects were designated beta rich. As observed previously, the majority of finds were recovered from Sellafield beach (76%). The numbers of finds in all categories were typical of those found in recent years.

The distributions of ^{137}Cs and ^{241}Am activities for particles and larger objects recovered in 2017 were within the ranges previously observed. This provides reassurance that they are part of the same general population and are within the range of activities that were considered in the health risk assessment.

A single particle was recovered during 2017 that exceeded the characterisation criteria specified by the EA and therefore required further detailed laboratory analysis. This characterisation identified the particle was graphitic, with radioactivity being dominated by ^{137}Cs. Measurements of the potential skin dose from the particle were below the threshold for a review of the programme and the particle was concluded to be within the bounds of the health risk assessment.

A sub-set of alpha rich and beta rich finds have also been analysed over recent years. Alpha rich particles were found to be mainly associated with iron and iron oxide and are likely to have originated from the use of flocculants during early reprocessing. An estimate of the age of these finds showed that they were mainly formed in the 1960s and 1970s, with releases stopping by 1983. Beta rich particles were associated with graphites, metals, rock fragments and minerals and were likely to be associated with materials that arrived at the Sellafield site several decades ago, although the exact age cannot be accurately determined. Beta rich larger objects were mainly associated with rock fragments and were of a similar age range to beta rich particles.

The Conceptual Site Model for the particles in the environment programme has been recently updated. This identified that particles and larger objects originated from historic sources and the various pipeline retrievals. The intertidal transport pathways for particles were determined to be due to a predominantly northward drift and burial/ exposure. Transport from the beach to the sea and *vice versa* was identified to be associated with storm events.

The work conducted during 2017 provides further evidence that the conclusion of the health risk assessment 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).

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1 Introduction

The overall objective of the Sellafield Ltd Particles in the Environment programme is to understand the nature of radioactive particles and larger 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 2017 on the Particles in the Environment programme and sets out the schedule of work for 2018 and the forward strategy.

In summary, this report includes the following:

Section 2 details the Environment Agency Requirements for the Particles in the Environment programme.

Section 3 provides information on the particle detection systems used for beach monitoring.

Section 4 details the progress made in 2017 on the beach monitoring programme.

Section 5 provides the analysis of the monitoring and find data gathered up to the end of the 2017.

Section 6 provides an update on work completed on developing an updated Best Available Techniques (BAT) case for work on particles detection in the environment.

Section 7 describes the transport and dispersion of particles and larger objects in the environment.

Section 8 explains how the regulators and stakeholders are being engaged by Sellafield Ltd and the framework for continued interactions.

Section 9 provides a brief update on the health risk assessment for beach finds, being led by Public Health England (PHE) Centre for Radiation, Chemical and Environmental Hazards under contract to the EA.

Section 10 outlines the work programme and objectives for 2018.

In addition there are two appendices included in this report which provide the underpinning information that was considered herein. These are:

Appendix 1 provides a series of maps illustrating the areas covered by each beach visit (noting that each visit would take several days) and the location and broad categories of the beach finds.

Appendix 2 provides tabulated data from the beach monitoring programme incorporating the 2017 data in the context of the totality of the dataset compiled since the programme began in 2006.

2 Environment Agency Requirements

2.1 Radioactive Substance Act Permit

The Environment Agency have issued Sellafield Ltd with an Environmental Permit to operate the site. The permit specifies:

> *4.2.2 The operator shall supply such information in relation to: ...*
> *(b) the samples, tests, surveys, analysis and calculations, environmental monitoring and assessments undertaken under conditions 3.2.1 and 3.2.5 in relation to disposals of radioactive waste; in such format and within such timescales as the Environment Agency may specify in writing.*
>
> (Environment Agency, 2017a)

Further detail on the Environment Agency's requirements is included in the Compilation of Environment Agency Requirements (CEAR) which specifies.

> *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.* (Environment Agency, 2017b)

This report provides the annual update of the programme

2.2 Intervention

The Environment Agency, Public Health England, the Food Standards Agency, Allerdale Borough Council and Copeland Borough Council, have agreed the criteria where further interventions could be required. Such interventions could include conducting further detailed monitoring and assessments, the use of signage on the beaches or providing further advice to the public.

> *The trigger levels for individual beaches, using vehicle based monitoring, are find rates of more than:*
>
> - *1,000 particles per ha of alpha-rich particles, predominantly containing americium-241 which emits alpha-radiation and some weak gamma radiation*
> - *20,000 particles per ha of beta-rich particles, predominantly containing caesium-137 which emits both beta and gamma radiation*
> - *40 particles per ha of particles with activity of more than 1 MBq alpha*
> - *1,600 particles per ha of particles with activity of more than 0.1 MBq beta*
>
> *The trigger levels for offshore monitoring (using any technique) are find rates of more than:*
>
> - *20 particles per tonne for alpha-rich particles*
> - *50 particles per tonne for beta-rich particles*

(Environment Agency, 2017c)

2.3 Characterisation

In addition to the above the Environment Agency also requires the characterisation of finds that meet the following criteria:

> - *The field estimate of equivalent skin does rate is more than 300 milligray (mGy) per hour.*
> - *Laboratory gamma scan results show more than 5 mega becquerels (MBq) of americium-241 activity.*
> - *Laboratory gamma scan results show more than 0.1 MBq of caesium-137 activity.*
>
> *Another criteria that determines if further analysis is needed is if the find appears unusual in terms of its radioactivity, radionuclide or physical characteristics. This criteria applies to particles and larger objects.*
>
> *Whilst larger objects pose a lower risk than particles, a particularly unusual object could need further analysis. Decisions about whether an object needs further analysis will be made on a case by case basis.*

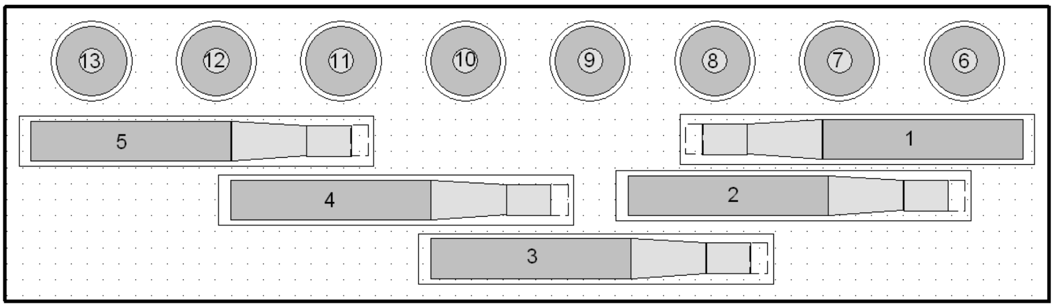
(Environment Agency, 2017c)

3 Detection Systems

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 the radionuclide ^{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. 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 had a 0.4 mm thick detection window. The eight FIDLER detectors were also mounted in the carbon fibre box and used a 0.4 mm carbon fibre protective window.

In May 2014 Nuvia Ltd commissioned the Groundhog Synergy2 system. The Synergy2 system was 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 with some additional benefit to the detection of ^{90}Sr (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.



Notes: 1 – 5 NaI detectors, 6 – 13 FIDLER detectors.

Figure 1: Synergy 2 detector layout.

Other beach areas monitored using the vehicle mounted equipment are the most recent tide-line (referred to as the "Strandline") and the "Compound Strandline" which is the area of Sellafield beach where the compound used to cut and contain sections of the sealines during the sealine retrieval project was located.

The line of wind-blown debris or highest tide-line (referred to as the stormline) between Drigg and St. Bees (with the exception of Nethertown beach where the rocky foreshore cannot be safely monitored) is also surveyed using hand held equipment. These surveys are conducted biannually and have been part of the wider environmental monitoring programme since 1983 applying a variety of detection techniques.

The surveys conducted in 2017 that used hand-held equipment applied 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.

Surveys are walked slowly (with a maximum speed of 1.0 m/s or 2.3 mph). Any items that are retrieved are bagged and returned to site and their position is recorded with the GPS.

It should be noted that from 2018 onwards monitoring of the high tideline will be only conducted using the vehicle mounted Groundhog Synergy2 system and there will be no walked surveys. This allows the area that is monitored to be increased from 1.8 ha to 6.6 ha per year and addresses concerns over health and safety, the restricted area that was monitored and the lack of beach finds. Further information is contained in Section 6.

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

4 Monitoring Conducted During 2017

This section covers the beach monitoring conducted using the Synergy2 vehicle as there were no finds from the monitoring using hand-held equipment (see Section 3). Information is presented on the areas monitored; the number and types of finds recovered and their geographical distribution. The results from the 2017 programme are compared with those from previous years to identify any changes that may affect the overall risk to beach users.

4.1 Beach Find Categories

Upon detection, beach finds are categorised as either a ‘Particle’ or ‘Larger Object’. Initial categorisation of a beach find is done when the item is recovered and packaged on the beach and the criterion for each category is as follows:

- **Particles** are finds < 2 mm in diameter.
- **Larger Objects** are finds >= 2mm in diameter (includes: granules, gravel, pebbles, stones *etc.*)

At times, it is difficult for the operators to assess exactly which item is the radioactive find in a bag containing a variety of different sediment sizes. If at all unsure, the operators always conservatively classify a beach find as a particle.

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:

- **Alpha rich** are finds with ^{241}Am activity greater than ^{137}Cs activity.
- **Beta rich** are finds with ^{137}Cs activity greater than ^{241}Am activity.
- **Cobalt-rich** are finds with positive ^{60}Co activity greater than the ^{137}Cs activity.
- **Excess beta** are 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 (*i.e.* a pure beta emitter such as ^{90}Sr may be present).

A small number of ^{226}Ra finds have been detected since the beach monitoring programme began but all of these finds have been removed from the dataset as they are naturally occurring items which are not related to Sellafield operations.

4.2 Planned Beach Monitoring For 2017

As detailed in Section 1 the aim of the beach monitoring programme is to provide reassurance that the overall risks to beach users are not greater than those estimated in the health risk assessment which 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.*
>
> (Brown & Etherington, 2011)

A programme of 150 ha was developed and agreed with the EA to meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the health risk assessment. In a change to previous years, the 2017 beach monitoring programme was aligned with the calendar year rather than the financial year. This change allows the beach monitoring programme to run alongside the wider environmental programme, making future reporting and management of the programme more efficient.

The 150 ha programme was split as follows:

- Sellafield programme (totalling 83 ha);
- Near-field programme (totalling 62 ha); and
- Far-field programme (totalling 5 ha).

The near-field programme focused on the beaches at Seascale, Braystones and St. Bees, whereas the far-field programme focused on Allonby beach. Once again, the bulk of the monitoring effort was placed on Sellafield beach in 2017.

The target areas that were planned for each beach are given in Table 1, with the full schedule in Figure 3.

Table 1: Planned area coverage (ha) for each beach in 2017.

Programme	Beach	Sellafield	Near-Field	Far-Field	Total
Sellafield	Sellafield	83	-	-	83
Near-Field	Braystones	-	22	-	22
	St. Bees	-	20	-	20
	Seascale	-	20	-	20
Far-Field	Allonby	-	-	5	5
Total		83	62	5	150

4.2.1 Sellafield programme

A programme of 83 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 33 ha per visit.

The reasons for selecting the beach at Sellafield for the majority of the monitoring programme are:

- 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 larger objects 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 the repopulation and mixing to be evaluated; 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.

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 2017 this area was monitored on seven occasions during the three scheduled monitoring periods. Monitoring was completed inside one tidal cycle, giving a footprint of that area of beach, with each visit typically being at least one month apart (further details can be found in Section 5.3.1).

4.2.2 **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 before and after 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.

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. Each visit to Braystones beach immediately follows visits to the adjoining beach at Sellafield. This is to investigate whether the removal of finds from Sellafield beach also has an impact on the find rates observed at Braystones. Each of these visits spanned two weeks and covered between 6 and 8 ha. The results are discussed in Section 5.2.2.

For St. Bees and Seascale there were five visits to each of these two beaches, with each survey 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.

	Week Starting	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near-Field Programme: Target Area (ha)	Far-Field Programme: Target Area (ha)
Q1 2017	02-Jan-17	St Bees (1)		4	
	09-Jan-17				
	16-Jan-17	Seascale (1) and Drigg Strandline Monitoring		4	
	23-Jan-17	Sellafield (1)	22		
	30-Jan-17				
	06-Feb-17				
	13-Feb-17				
	20-Feb-17				
	27-Feb-17	Braystones (1)		6	
	06-Mar-17				
	13-Mar-17	Walking Strandline Monitoring			
	20-Mar-17	St Bees (2)		4	
	27-Mar-17	Seascale (2)		4	
Q2 2017	03-Apr-17	Allonby (1)			5
	10-Apr-17	No Monitoring (Easter Holidays)			
	17-Apr-17				
	24-Apr-17	St Bees (3)		4	
	01-May-17	Seascale (3)		4	
	08-May-17	Sellafield (2)	28		
	15-May-17				
	22-May-17				
	29-May-17				
	05-Jun-17				
	12-Jun-17				
	19-Jun-17				
	26-Jun-17	Braystones (2)		8	
Q3 2017	03-Jul-17				
	10-Jul-17	St Bees (4)		4	
	17-Jul-17	Seascale (4)		4	
	24-Jul-17				
	31-Jul-17				
	07-Aug-17	No Monitoring (Summer Holidays)			
	14-Aug-17				
	21-Aug-17				
	28-Aug-17				
	04-Sep-17	St Bees (5)		4	
	11-Sep-17	Seascale (5)		4	
	18-Sep-17	Walking Strandline Monitoring			
	25-Sep-17	Sellafield (3)	33		
Q4 2017	02-Oct-17				
	09-Oct-17				
	16-Oct-17				
	23-Oct-17				
	30-Oct-17				
	06-Nov-17				
	13-Nov-17				
	20-Nov-17				
	27-Nov-17				
	04-Dec-17	Braystones (3)		8	
	11-Dec-17				
	18-Dec-17	Maintenance Week			
	25-Dec-17	No Monitoring (Christmas Holidays)			
		Cumulative Totals ==>	**83 ha**	**62 ha**	**5 ha**
		OVERALL TOTAL ==>	**150 ha**		

Figure 3: Beach monitoring programme for 2017.

4.2.3 **Far-field programme**

The far-field programme, totalling 5 ha, targets beaches with historically lower find rates. For 2017 this resulted in a single visit to Allonby, which is a large sandy beach that is popular with the public and has 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.

4.2.4 **Additional programme aims**

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 2017 included strandline monitoring 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, support vehicle 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.

4.3 Beach Areas Monitored in 2017

4.3.1 **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 health risk assessment.

4.3.2 Areas monitored in 2017

The beach monitoring programme for the 2017 financial year was completed with a total area of between 160.27 ha (Nuvia estimate) and 152.09 ha (Sellafield Ltd estimate), against a programme target of 150 ha (Table 2, Figure 4 to Figure 7 and Appendix 1). The following data and maps are based on Sellafield Ltd processed data.

Table 2 presents the area monitored in 2017 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 2 with Figure 3 illustrates that the total area monitored was higher than that originally included in the programme, with slightly more area being monitored at Seascale, St. Bees, Braystones and Allonby beaches. It is also notable that a limited amount of monitoring at Drigg beach was also undertaken as part of the driven strandline monitoring.

Table 2: Beach monitoring conducted during 2017.

Programme	Monitoring area	Number of days	Area covered (ha)	Available area (ha)	Monitoring as % of available
Sellafield	Sellafield	81	80.4	53.3	165%
Near-Field	Braystones	26	21.6	18.9	125%
	St. Bees	19	22.2	28.5	77%
	Seascale	17	21.6	81.6	26%
Far-Field	Allonby	3	5.1	136.9	8%
	Drigg	4	1.1	196.7	1%
Total		150	152	515.9	32%

4.4 Finds Recovered in 2017

A total of 226 finds were recovered during the 2017 monitoring programme from the beaches surrounding the Sellafield site (Table 3). Of these, 191 were classified as particles and the remaining 35 were classified as larger objects. The locations of these finds are shown in Figure 4, Figure 5, Figure 6 and 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 95 %) were recovered from Sellafield (76 %), Braystones (12 %) and St. Bees (7 %) beaches during 2017. More than 124 ha of beach were monitored at these three locations, accounting for more than 80 % of the total area surveyed in 2017. Of the 191 particles recovered, the majority were detected on Sellafield beach (72%), with most of the others being from Braystones (14%) and St. Bees (8%). A total of 35 radioactive larger objects were detected and all but one of these were recovered from Sellafield beach (Figure 4). A single larger object (a stone) was detected on Allonby beach during April 2017 and will be subject to further analysis (see Section 10.2.2 for more details).

Over 73 % of all finds recovered in 2017 were classified as alpha rich. There were 59 finds classified as beta rich in 2017, with all beta rich particles recovered from Sellafield beach. None of the finds that were recovered were classified as "excess beta" or "^{60}Co rich".

Table 3: Particle and larger object beach finds recovered during 2017.

Programme	Monitoring Area	No. of particles found			No. of larger objects found			Total finds
		Alpha rich	Beta rich	Other	Alpha rich	Beta rich	Other	
Sellafield	Sellafield	114	24	0	0	34	0	172
Near Field	Braystones	27	0	0	0	0	0	27
	St. Bees	16	0	0	0	0	0	16
	Seascale	7	0	0	0	0	0	7
Far field	Allonby	1	0	0	0	1	0	2
	Drigg	2	0	0	0	0	0	2
Total		167	24	0	0	35	0	226

4.4.1 **Sellafield finds 2017**

A total of 172 finds (138 particles, 34 larger objects) were recovered from Sellafield beach during 2017, compared with 203 finds in 2016. Of these, 114 were classified as alpha rich and 58 as beta rich. The area monitored during 2017 is comparable with the previous 12 months (80 ha in 2017, 82 ha 2016).

Monitoring of Sellafield beach during 2017 continued to focus on areas identified as having the highest rates of beta rich finds to establish if intensive monitoring of this area can impact the find rates. The number of beta rich finds detected on Sellafield beach in 2017 reduced when compared with the previous year, mainly due to a reduction in the number of larger objects being detected (34 in 2016, 67 in 2016).

The appearance of clusters of beach finds at the north end of Sellafield beach (see Figure 4) is an artefact of the repeat area being monitored on seven occasions during 2017.

4.4.2 **Near-field finds 2017**

Almost 22 ha were monitored at Braystones, with 27 alpha rich particles detected in 2017. Alpha rich particle find rates at Braystones were comparable with the previous year (1.3 finds/ha in 2017 and 1.0 finds/ha in 2016). Once again 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. To date, there is no evidence of a statistically significant long-term decline in find rates at Braystones beach that relates to the extended monitoring campaigns (see Section 5).

Five separate surveys were scheduled for St. Bees throughout 2017, with 19 days of monitoring completed during this period. A total of 22.2 hectares of beach was surveyed with 16 particles detected. There was a reduction in the number of finds detected at St. Bees in 2017 when compared with the previous year (25 particles were recovered in 2016). Finds rates at St. Bees are at the lowest levels since the introduction of Synergy2.

Monitoring at Seascale was conducted over 17 days (totalling of 21.6 ha) during 2017 with 7 particles being detected. Find rates at Seascale increased when compared with 2016 (1 find from 27.7 ha) but are below those from 2015 (7 finds from 16.2 ha) or 2014 (20 finds from 39.3 ha). This reflects the variability in find rates on this beach and similar variations have been observed at Seascale in the past.

4.4.3 **Far-field finds 2017**

A single survey took place at Allonby during April 2017. 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 7). A total of 5.1 ha were monitored during the survey with 2 finds detected (1 particle, 1 larger object). These were the first finds at Allonby since 2014 although the find rate in 2017 is lower than the peak recorded in 2014 where 9 alpha rich particles and 1 beta rich particle were recovered from 13.6 ha of monitoring. The recovery of a beta rich larger object from Allonby was unexpected and is discussed further in Sections 4.6 and 10.2.2.

There were 2 alpha rich particles recovered from Drigg beach during the annual vehicle driven strandline monitoring in January 2017. A 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 5.2).

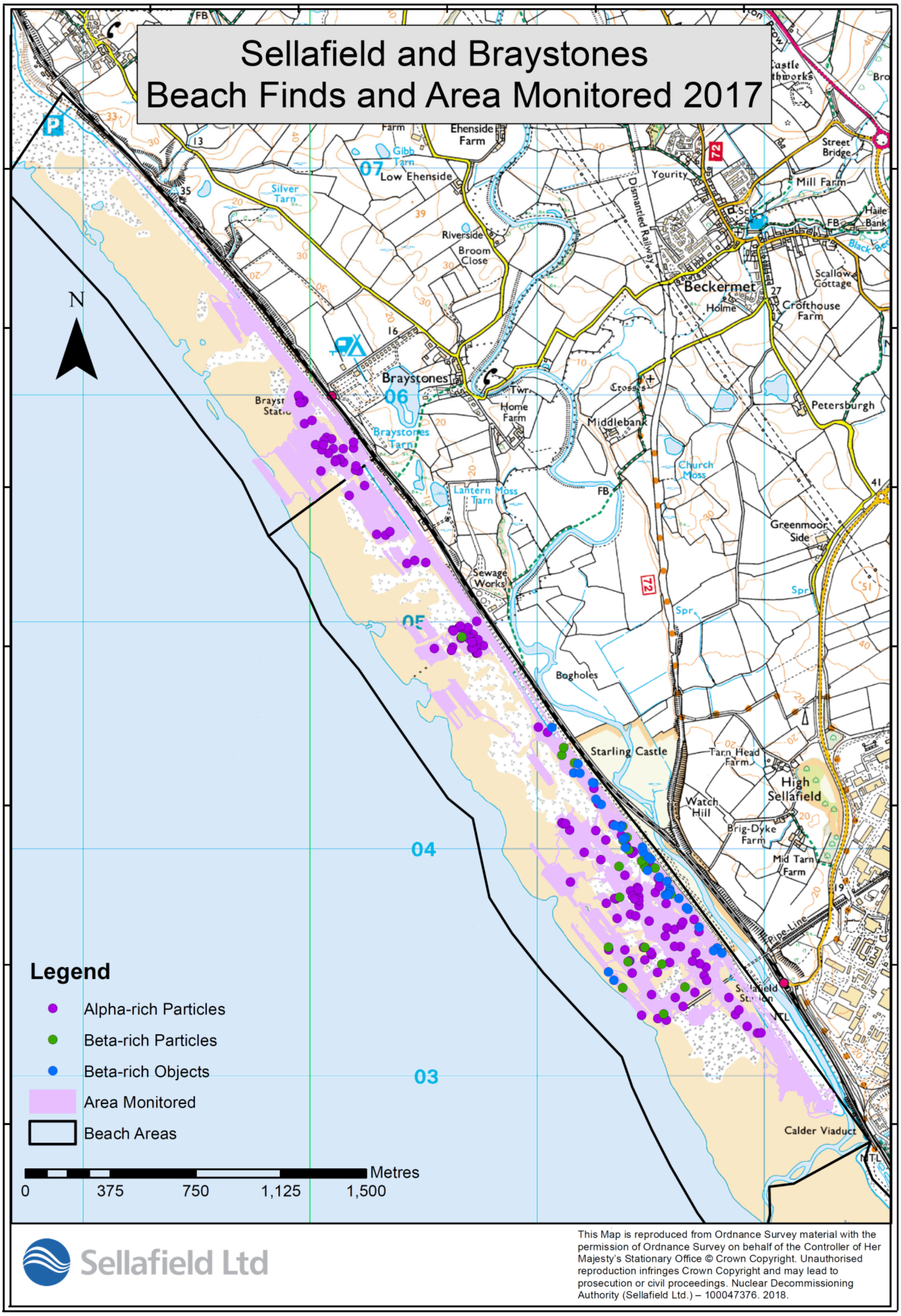


Figure 4: Sellafield and Braystones beach find locations and areas monitored in 2017.

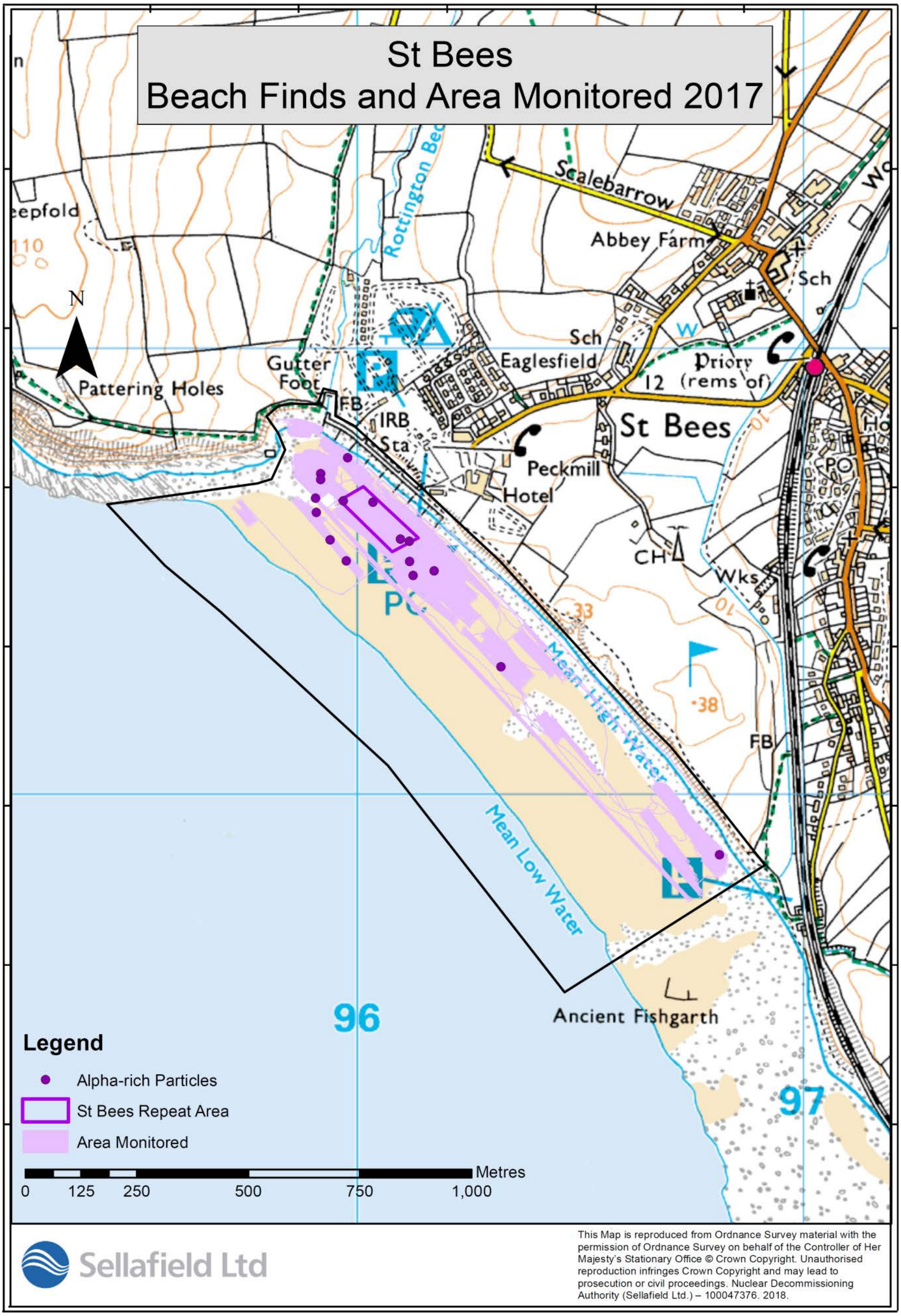


Figure 5: St. Bees beach find locations and areas monitored in 2017.

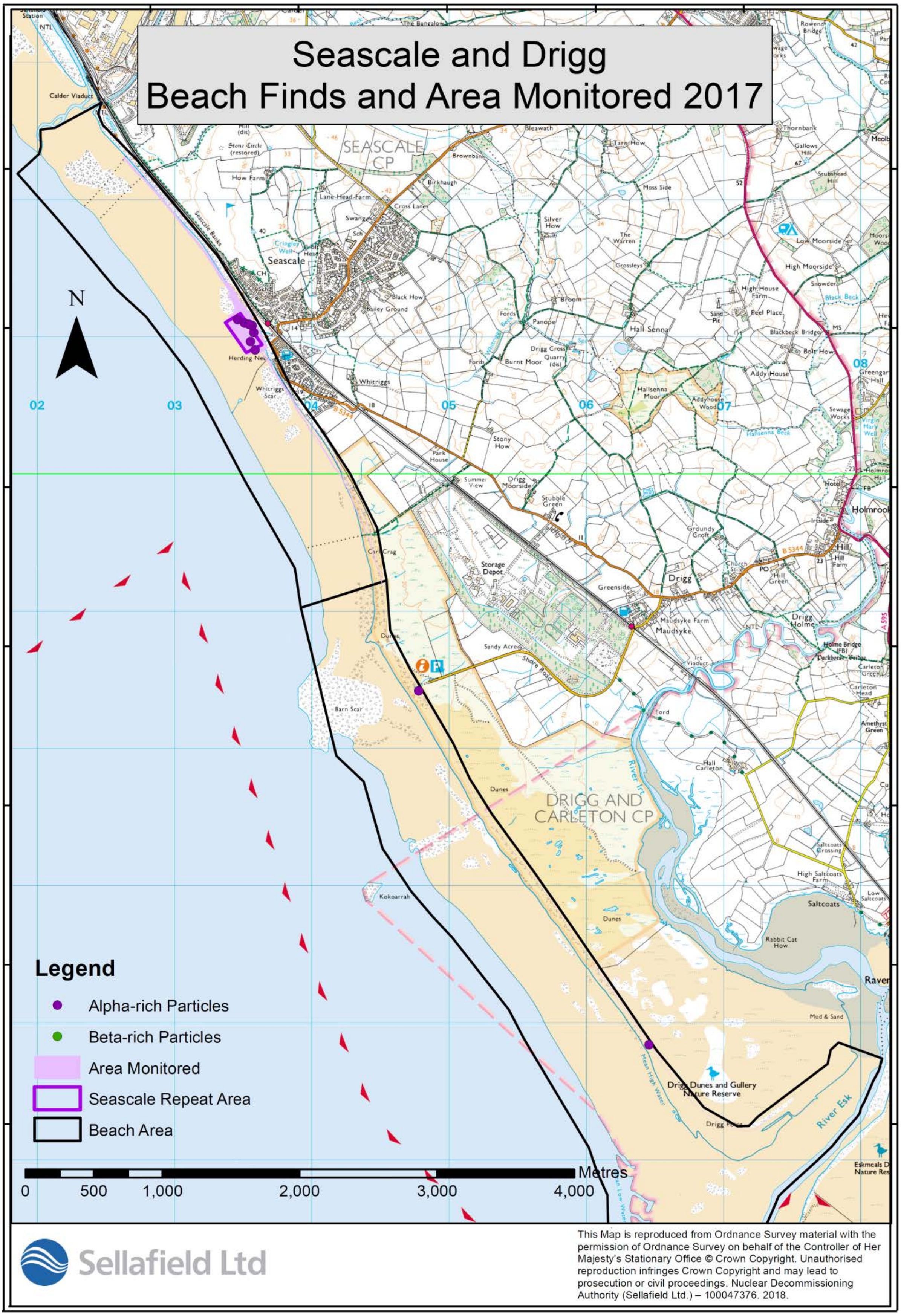


Figure 6: Seascale and Drigg beach find locations and areas monitored in 2017.

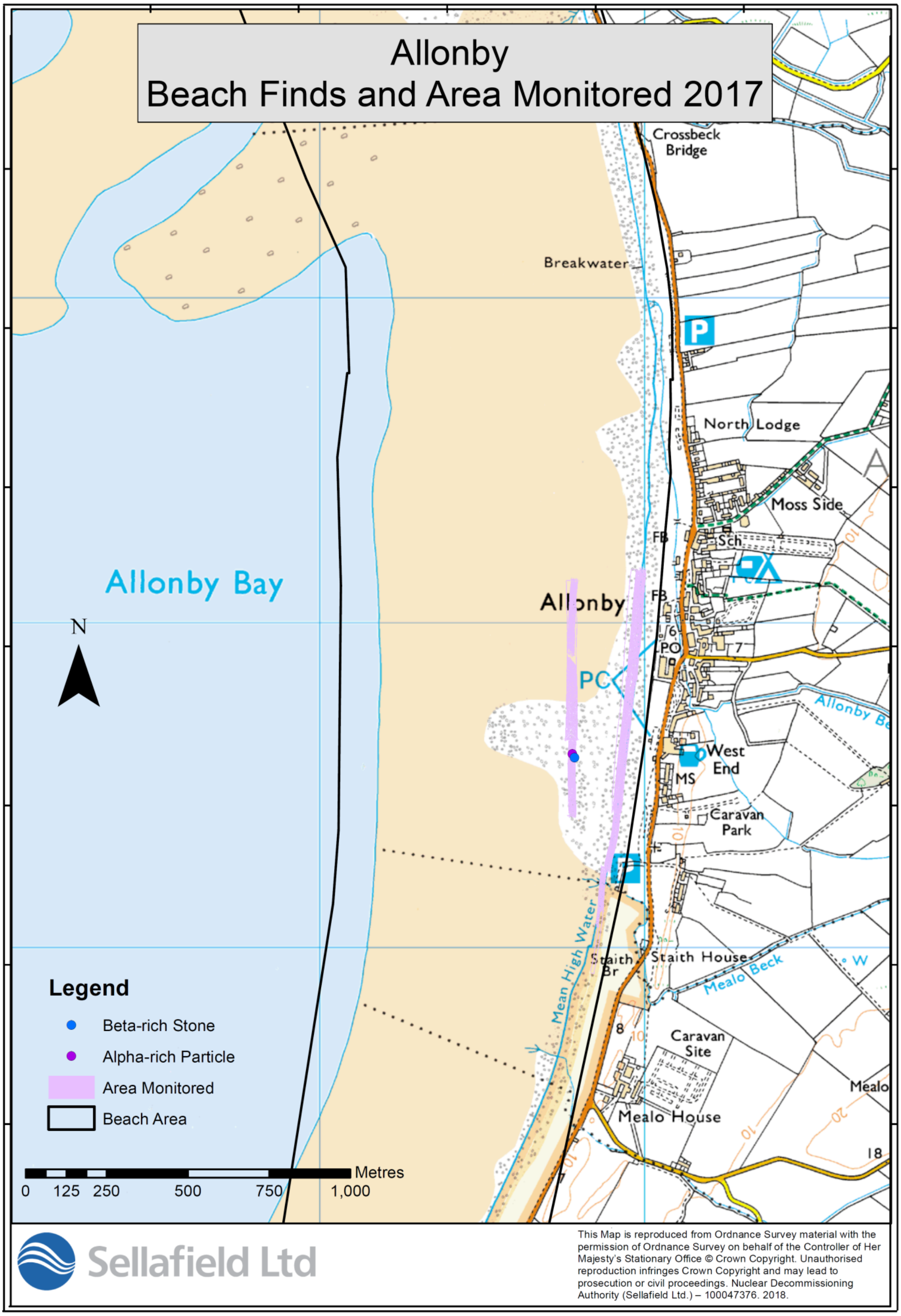


Figure 7: Allonby beach find locations and areas monitored in 2017.

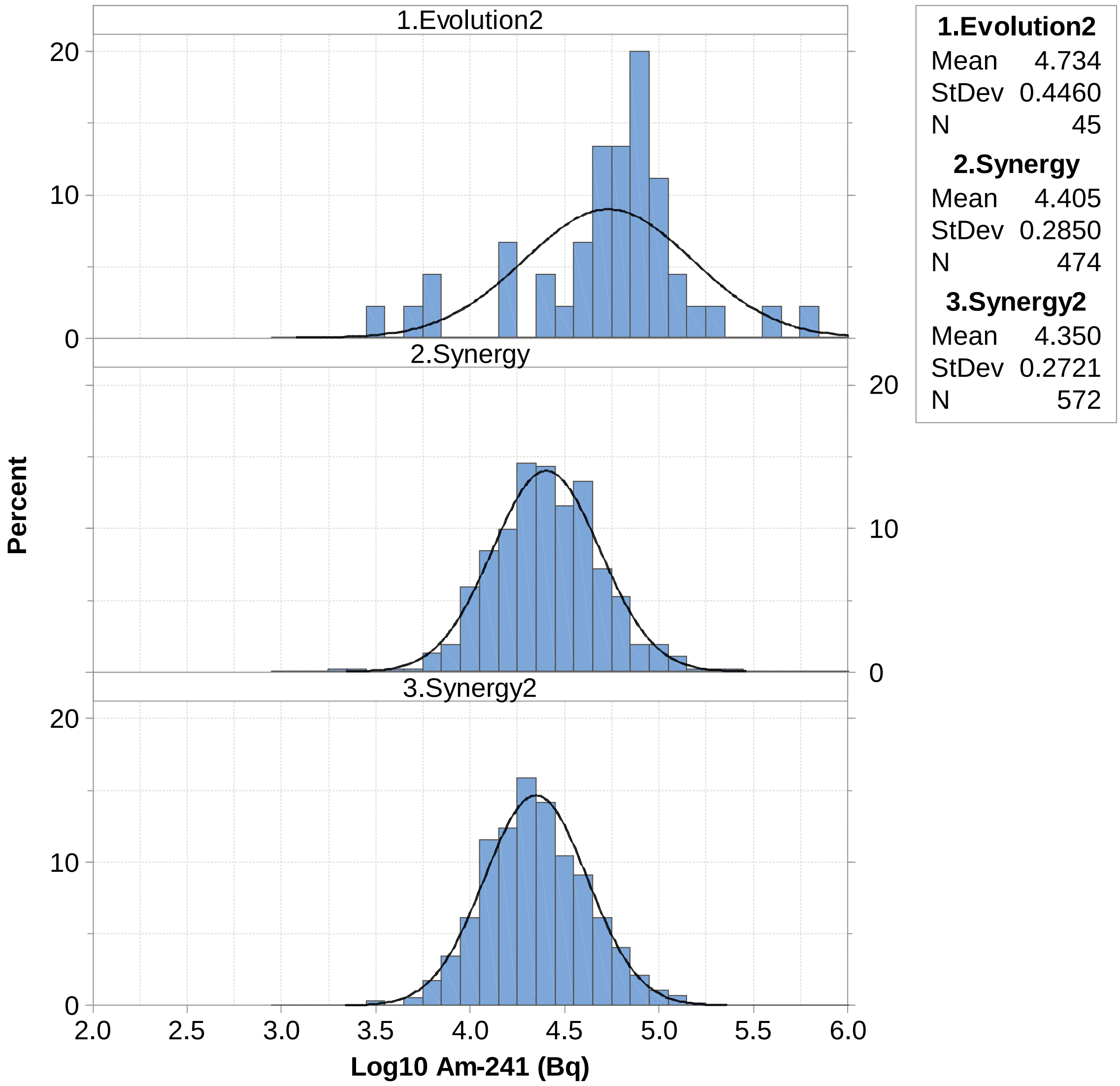
4.5 Activity Distributions Measured In 2017

As noted in the Particles Annual Report for 2015/16 (Sellafield Ltd, 2016), the introduction of Synergy 2 appears to have impacted on the distributions of the activity of particles being recovered. Figure 8 shows that the mean of the distribution of ^{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. The introduction of Synergy2 can be seen to have slightly shifted the activity distribution towards lower activity alpha rich particles (as shown by the reduction in mean going from Synergy to Synergy2). 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.

Figure 9 shows that there was also a change in the distribution of detected ^{137}Cs activity when the system was changed from Evolution to Synergy. This was found to be a decrease in the total number of finds detected, with an increase in the mean activity of finds and a reduction in the standard deviation. The mean ^{137}Cs activity also increased when going from Synergy to Synergy 2 and there was a further reduction in the standard deviation of the distribution. Work is ongoing to establish the causes for these changes in activity distributions, although the most likely explanation is that they are associated with improvements to the standardisation of detector heights on the monitoring equipment.

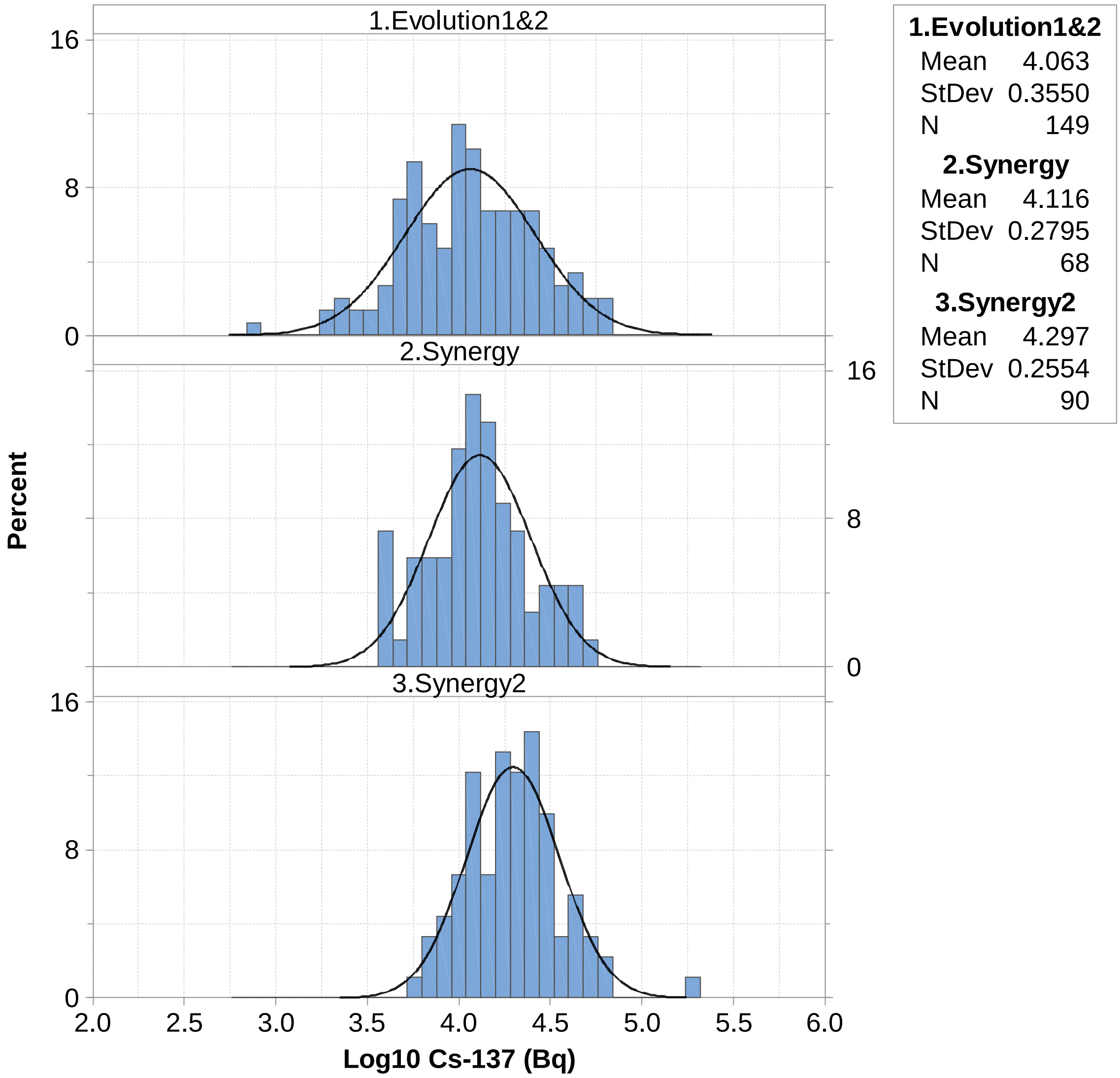
The distribution of ^{137}Cs and ^{241}Am activities, shown in Figure 8 and Figure 9, since Synergy2 was introduced remain within previously observed ranges, providing reassurance that they are part of the same general population. This provides confidence that the PHE advice remains valid. It is now over seven years since the most active beta rich particle find was recovered (from Whitehaven beach) and over 10 years since the most active alpha rich particle find was recovered (from Sellafield beach).

It should be noted that no ^{60}Co Rich or Excess Beta finds were recovered in 2017. These types of finds were last recovered in 2016 and 2009 respectively (see Appendix 2, Table A2.3).



Note: Log10 = 3 = 1,000 (1E+03); Log1 0= 4 = 10,000 (1E+04) and Log 10 = 5 = 100,000 (1E+05), all in Bq.

Figure 8: Distribution of ^{241}Am activity of alpha rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.



Note: Log10 = 3 = 1,000 (1E+03); Log10 = 4 = 10,000 (1E+04) and Log10 = 5 = 100,000 (1E+05), all in Bq.

Figure 9: Distribution of ^{137}Cs activity of beta rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.

4.6 Finds Reportable Through the EA Intervention and Characterisation Criteria

As part of the surveillance of the beach monitoring programme, Sellafield Ltd is required to notify the EA of any instances where the trigger levels within the EA Intervention and Characterisation criteria are exceeded (see Section 2).

There were no exceedences of the EA Intervention Criteria (specified in Section 2.2) in 2017. Find rates from the programme have consistently been several orders of magnitude below the intervention criteria thresholds.

A single find exceeded the find characterisation criteria (specified in Section 2.3) during 2017. A beta rich particle was detected in October 2017 on Sellafield beach that had a ^{137}Cs activity of 1.86E+05 Bq. This particle was within the range of previous measurements and therefore did not require immediate further consideration and did not challenge the health risk assessment. However, as it contained more than 1E+05 Bq of ^{137}Cs, it was sent for more detailed laboratory analysis, which is reported in Section 5.5.

Another criterion that determines if further analysis is needed is if the find appears unusual in terms of its radioactivity, radionuclide or physical characteristics. This criterion applies to particles and larger objects.

In April 2017 a larger object (a stone) was detected on Allonby beach. The measured ^{137}Cs activity was 1.0E4 Bq and did not exceed any triggers set out in the EA Characterisation criteria. However, the find was considered to be unusual due to its physical characteristics. The find had approximate dimensions of 15 mm x 10 mm and was situated around 150 m from the mean high water mark, on a sandy area of beach and at a depth of 7 cm.

Allonby beach is the most northerly beach in the monitoring programme and approximately 45 km from the Sellafield Site. An object of this size being detected on Allonby beach is not in line with the understanding of the Conceptual Site Model, which suggests it's unlikely that natural processes could transport an object of this size to this location (Atkins, 2018). There are a number of mechanisms that could account for the movement of radioactive larger objects to the northerly beaches as outlined below. This list is not exhaustive and there is no current evidence to support or disprove these possibilities.

- Commercial fishing and potentially dredging;
- Movement of monitoring equipment; and
- Storm events

The larger object recovered from Allonby beach is scheduled to undergo further detailed laboratory analysis to provide further evidence of its composition and potentially evidence of a the transport mechanisms involved in its transit along the coast (Section 10.2.2).

5 Data Analysis Review

5.1 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 cells (note that the area of each cell equals 1 ha) and calculating 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 larger objects). It should be noted that ^{60}Co rich and Excess Beta finds could not be analysed statistically due to the low number recovered. As the differences between Synergy and Synergy 2 monitoring technology are small, the data were combined for this analysis. 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 are shown in Figure 10 and are summarised in Figure 11, which illustrates that alpha rich particle finds are predominantly recovered to the north of the Sellafield discharge pipeline with a peak to the north (at around 1.5 km) and a gradual reduction with distance. There is a discontinuity in Figure 10 and Figure 11 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 larger objects were found to be more tightly clustered, with again a peak at approximately 600 m to the north of the pipeline.

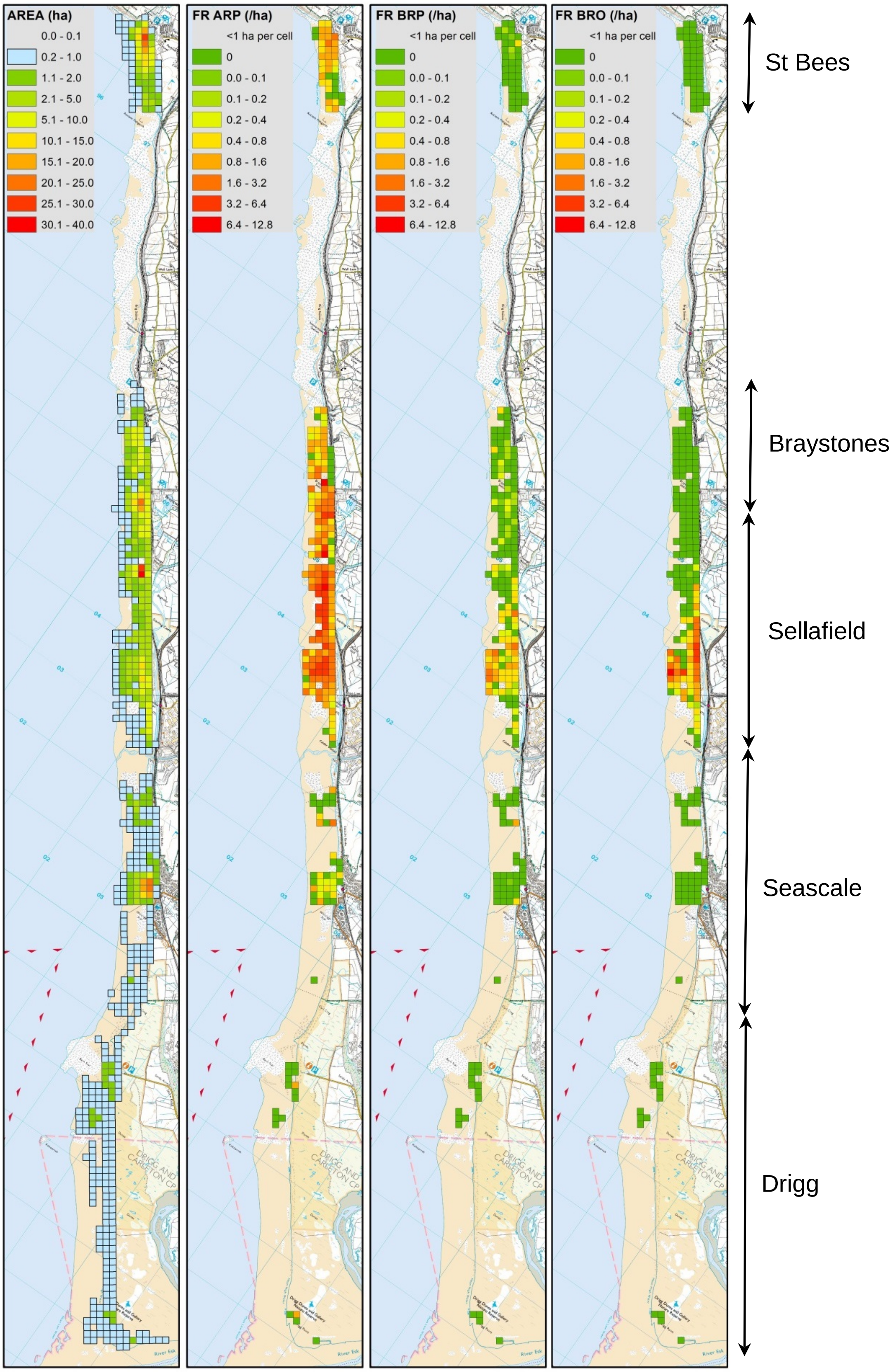
Work conducted for the Conceptual Site Model (detailed in Section 7) illustrated that the northerly movement of particles would be expected based on coastal processes and that the differences between alpha rich and beta rich particle find rate distributions may be due to differences in timing of the release or the distances from the beach that particles were released.

5.2 Find Rates per Hectare

5.2.1 Find rate trend analysis

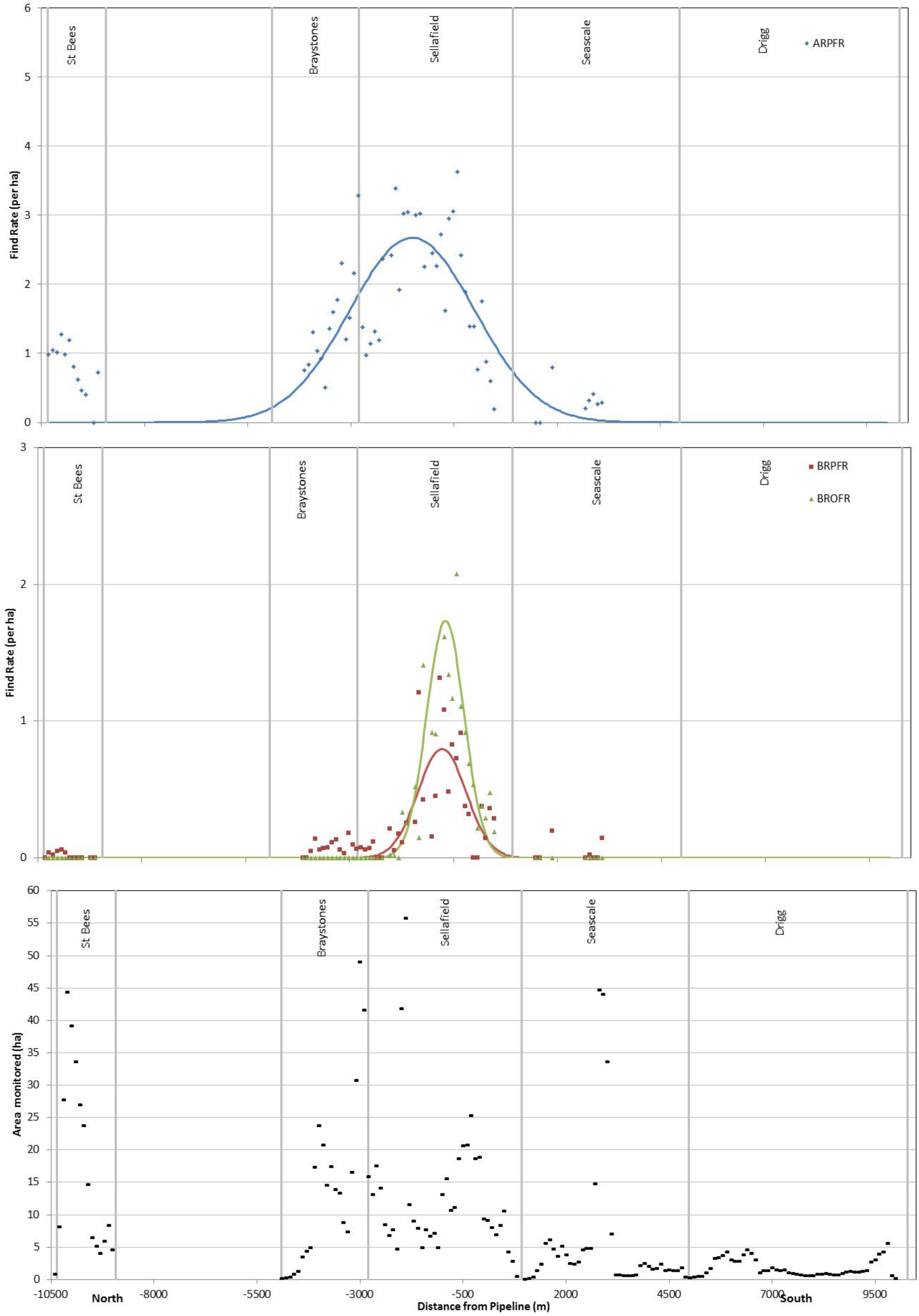
The analysis of the spatial distribution of find rates shown in Figure 11 illustrates that find rates are not consistent spatially and that the peaks of the distributions of alpha rich particles, beta rich particles and beta rich larger objects all occur on Sellafield beach. However, it is also clear 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 larger objects being the least dispersed, with a peak closest to the point the historic sealines crossed 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).

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 areas of approximately 10 ha (or approximately 2-3 weeks of monitoring effort) which was found to be suitable to allow trending.



Notes: Area = total area monitored per 100 m x 100 m cell, FR ARP= Alpha rich particle find rate; FR BRP = Beta rich particle find rate; FR BRO = Beta rich larger object find rate.

Figure 10: Find rate map for the Synergy and Synergy 2 monitoring periods.



Notes: alpha rich particles (blue), beta rich particles (red), beta rich larger objects (green); monitoring areas (black). ARPFR = alpha rich particle find rate BRPFR = beta rich particle find rate; BROFR = beta rich larger object find rate.

Figure 11: Spatial distribution of find rates.

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 larger object find rates reduced quickly when monitoring began with the Evolution System in 2006. Since then they have remained reasonably constant.

Monitoring during 2017 focused 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. Figure 12 shows that there was no consistent evidence of depletion in find rates to the end of 2017 although monitoring during 2017 has shown a downward trend in beta rich particle find rates.

Work has been completed in 2017 reviewing the Conceptual Site Model (see Section 7). This work has highlighted the importance of storm events in the dispersion of particles and larger objects in the environment. Storms can move particles offshore and onshore depending on their intensity and the prevailing wave and current directions.

5.2.2 **Annual find rates**

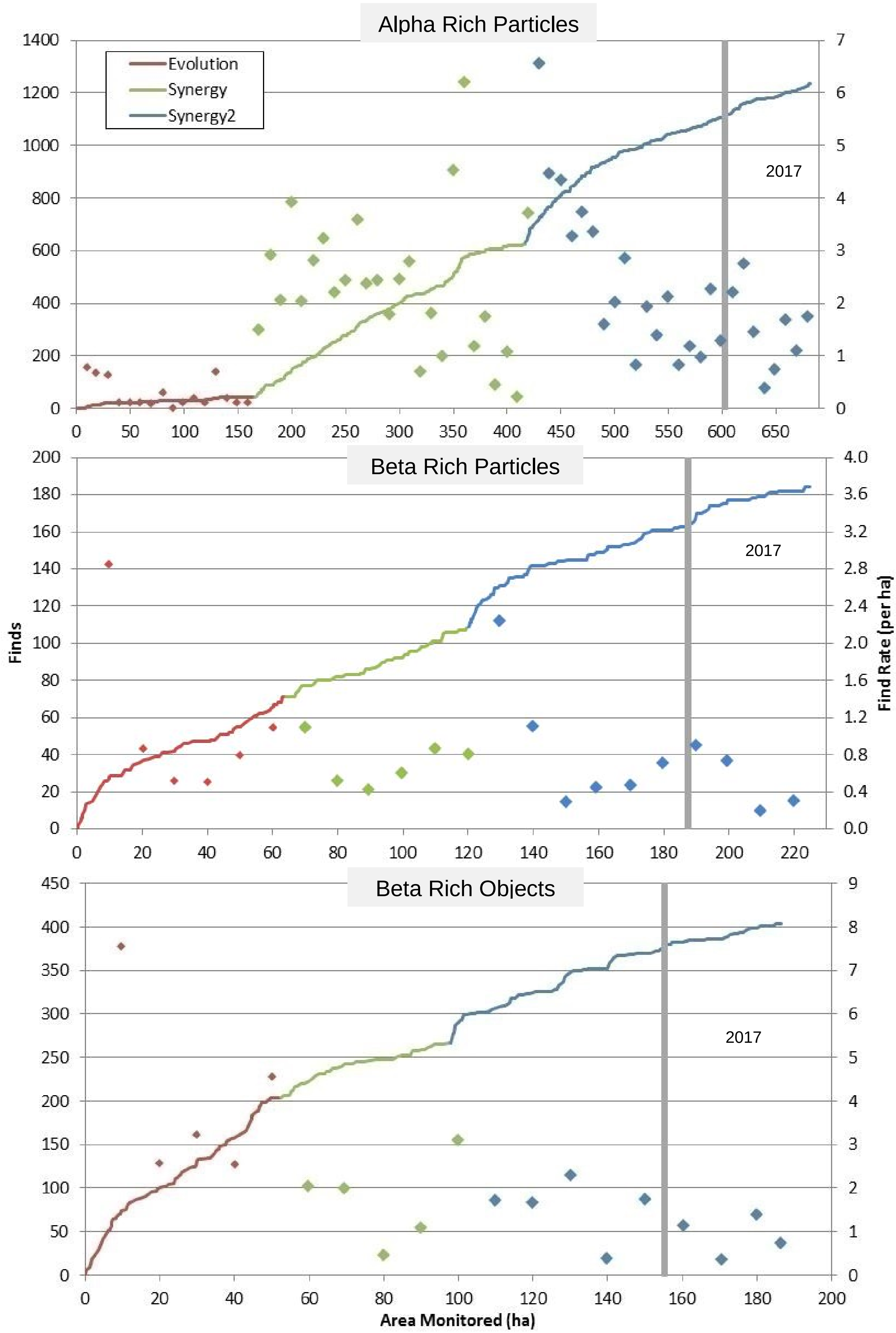
The annual find rates for each of the beaches that are monitored in West Cumbria, since the introduction of Synergy 2, are shown in Figure 13, Figure 14 and Figure 15 as well as Table A2.4 in Appendix 2.

These data illustrate that find rates during 2017 were broadly within the typical ranges previously observed for all beaches. A notable peak in the particle find rates on Sellafield and Braystones beaches was observed in 2014 when Synergy2 was introduced, although the find rates subsequently reduced to a level below that previously measured by Synergy. This is also shown in Figure 12.

The annualised alpha rich and beta rich particle find rates following the introduction of the Synergy2 system in May 2014 for the main beaches are shown in Figure 13 and Figure 14. These figures shows that alpha rich particle find rates across all beaches are below the peak Synergy 2 levels, with relatively consistent find rates on St. Bees, Sellafield and Seascale beaches when compared to the previous year. All of the beta rich particles detected in 2017 were found on Sellafield beach.

Beta rich larger object find rates over the last four years are displayed in Figure 15. The number of larger objects recovered during 2017 decreased when compared with the previous three years, with almost all larger objects being recovered from Sellafield beach since the introduction of Synergy2 (the notable exception being the larger object recovered from Allonby in 2017).

It should be noted that similar find rate trends were obtained to those described above when the analysis was restricted to the areas of peak finds (as applied in Figure 12).



Notes: Data are taken from the at the spatial peaks (+/- 1 standard deviation) along the coast. Points show find rates averaged over 10 ha areas, vertical lines show the start of the 2017 monitoring period.

Figure 12: Trends in finds with area monitored and 10 ha averaged find rates.

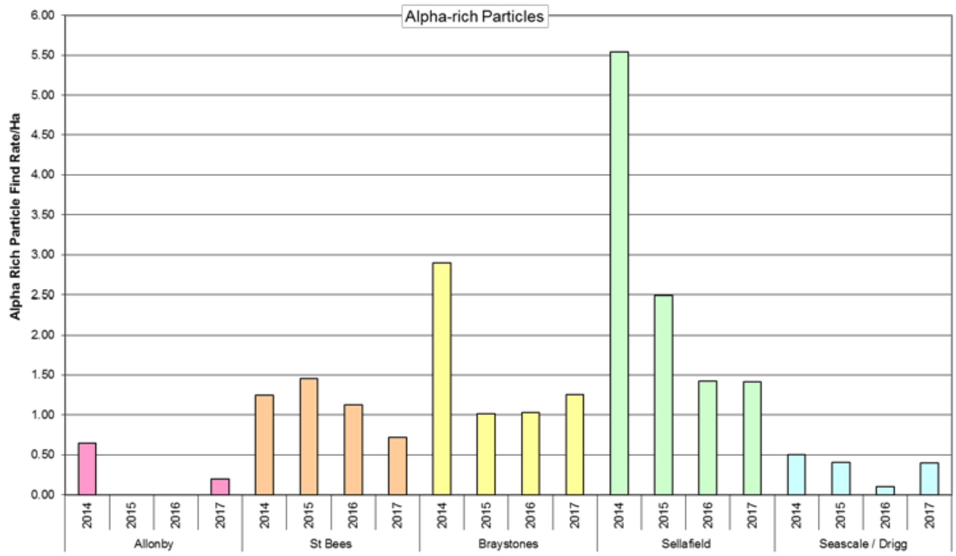


Figure 13: Alpha rich particle find rates since the introduction of Synergy 2.

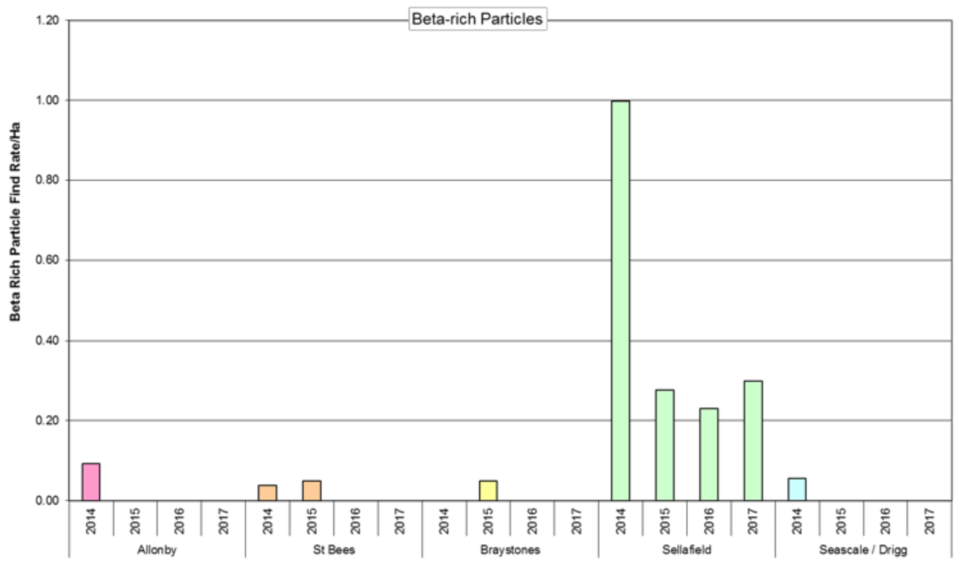


Figure 14: Beta rich particle find rates since the introduction of Synergy 2.

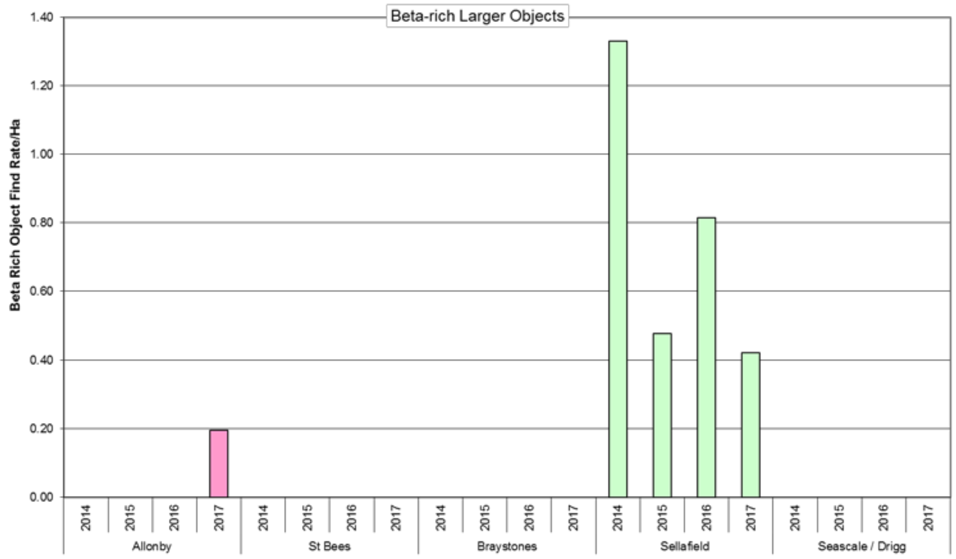


Figure 15: Beta rich larger object find rates since the introduction of Synergy 2.

5.3 Investigation Monitoring

5.3.1 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 4 times respectively) during the 2017 programme. The purpose of this monitoring was 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 could be 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 alpha rich particles can occur in as little as two tidal cycles (i.e. within a 24 hour period). It should be noted however that none of the repeat areas have provided information on beta rich particles or larger objects as these finds are constrained to a limited area of the beach (see Figure 10 and Figure 11) which does not intersect with any of the repeat areas.

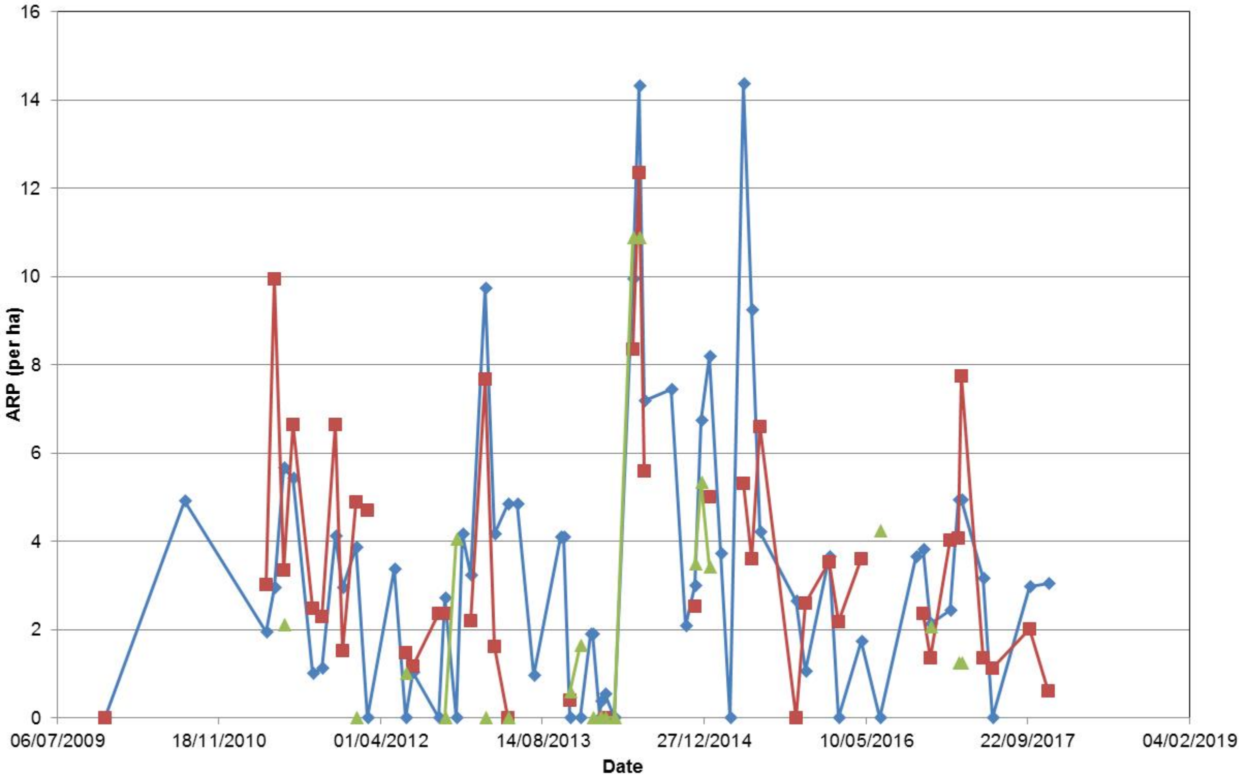
Data from the 1 ha Sellafield Repeat Area have also been analysed and a statistically significant positive autocorrelation was found between adjacent monitoring periods, with these monitoring periods typically being separated by at least a month. A positive autocorrelation indicates that find rates are not responding to influences of the monitoring programme, rather to external factors, with such factors having a timescale of the order of months.

The alpha rich particle find rates within the Sellafield 1 ha repeat area were compared with those determined from a 36 ha box located 800 m to the south of the repeat area and the data from the 1 ha Braystones repeat area. A time series analysis from these areas of the beach is shown in Figure 16 and illustrates that there is a statistically significant correlation in the find rates between these geographically distinct locations (shown graphically in Figure 17). This analysis provides further evidence that the find rates within the Sellafield repeat area are responding to external factors that affect the entire beach.

Figure 10 illustrates the spatial distribution of find rates along the coast and an analysis was conducted to specifically identify whether the intensive monitoring of repeat areas at St Bees, Braystones, Sellafield and Seascale had depopulated these specific areas of the beaches. The results of this analysis are shown in Figure 18 and illustrate that the spatial pattern of find rates is unaffected by the presence of the repeat areas despite these areas having been sampled at a rate around 5 - 10 times higher than the adjacent cells.

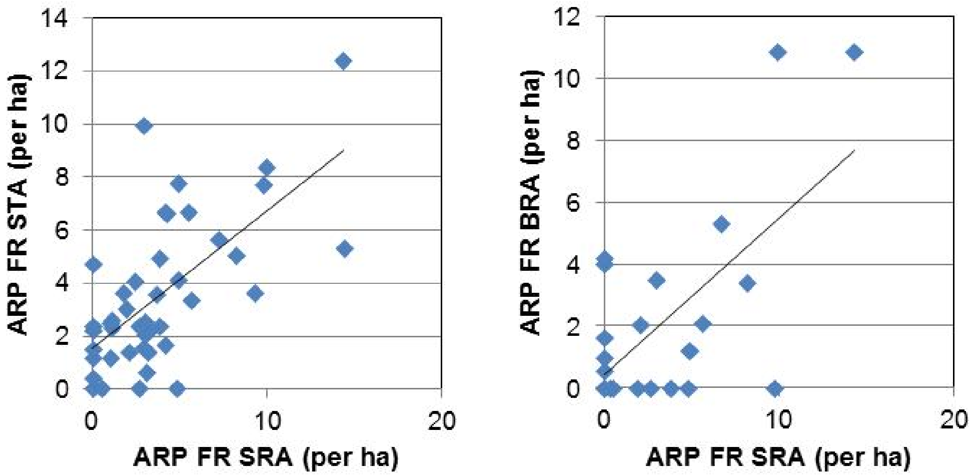
In conclusion, the analysis of repeat area data confirms the conclusion of the Conceptual Site Model (Atkins, 2018) and geomorphology study (Golder, 2016d) in that the beaches are well mixed and that trends in find rates are likely to be influenced by external factors that accrete or erode sediments along the coastal frontage. The use of repeat areas was reviewed to ensure that they address the programme aim of providing public reassurance. Consequently the following conclusions were made:

- The monitoring of repeat areas at St Bees and Seascale should be retained as these represent the areas of the beach that are routinely used by the public. There is however no need for these to be constrained to an area of 1 ha and St Bees repeat area should be extended to include a wider area of routinely used beach.
- Monitoring at Braystones repeat area should be continued as it provides the highest find rates on Braystones beach and is a sentinel point for the identification of the northward migration of finds (as shown in Figure 10 and Figure 11).
- Monitoring of the current repeat area at Sellafield should be discontinued and monitoring should be refocussed on a larger repeat area of the beach where peaks in alpha rich particles, beta rich particles and beta rich larger objects are found.



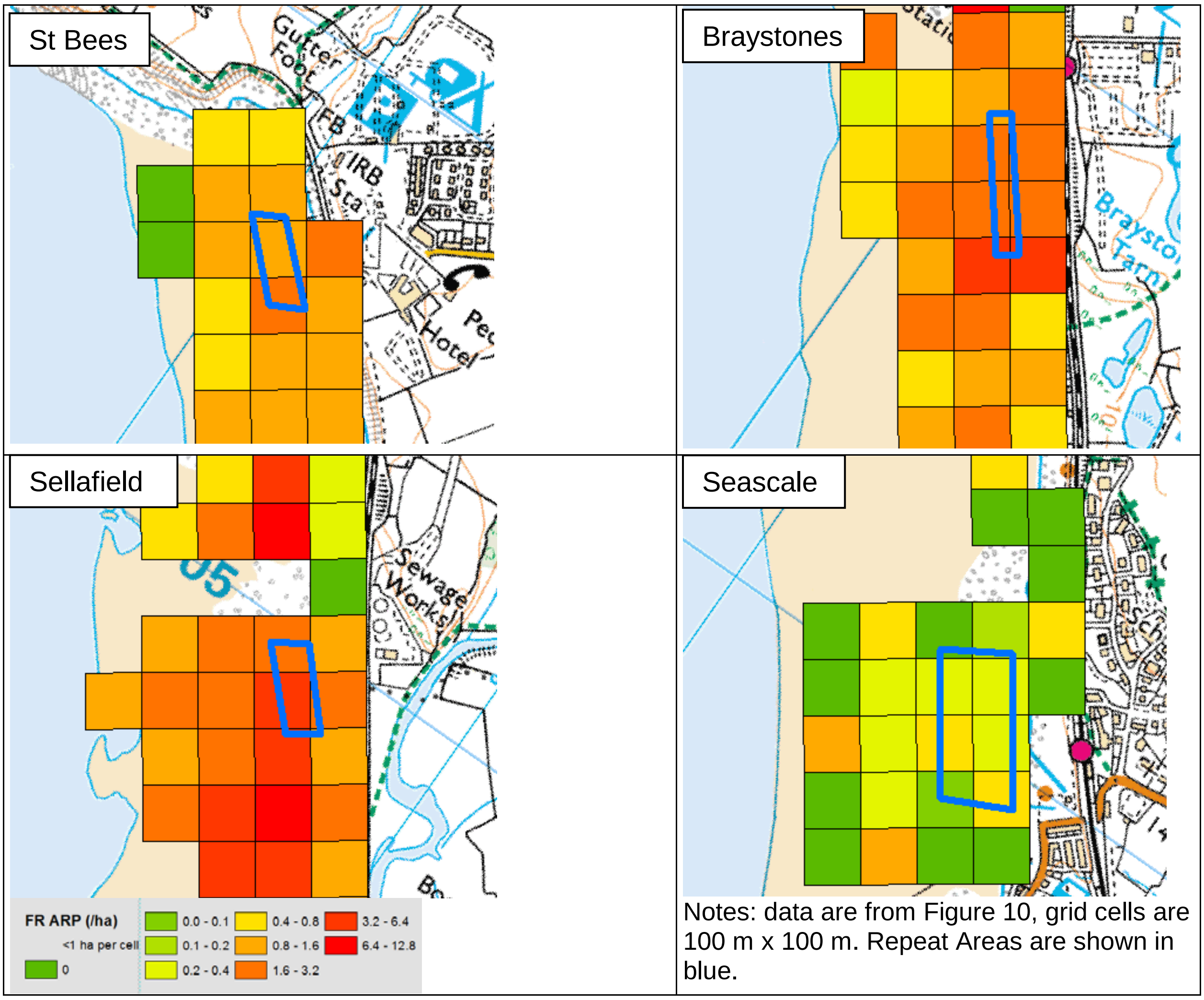
Notes: Alpha rich particle find rates are shown for the Sellafield 1 ha repeat area (blue); a 36 ha area of the beach 800 m south of the repeat area (red) and the 1 ha Braystones repeat area (green).

Figure 16: Time series analysis of alpha rich particle find rate trends.



Notes: ARP FR SRA = alpha rich particle find rate in the Sellafield 1 ha repeat area; ARP FR STA = alpha rich particle find rate in a 36 ha area of the beach 800 m south of the repeat area; ARP FR BRA = alpha rich particle find rate in the 1 ha Braystones repeat area.

Figure 17: Correlation analysis of alpha-rich particle find rates.



Notes: data are from Figure 10, grid cells are 100 m x 100 m. Repeat Areas are shown in blue.

Figure 18: Spatial comparison of find rates in repeat areas with those in adjacent areas of the beach.

5.4 Find Characterisation

5.4.1 Alpha rich particles

A total of 1898 alpha-rich finds were recovered between 2006 and 2017, with 1892 of these being classed as particles. Overall 45 alpha rich particles and an alpha rich larger object have been subject to further detailed laboratory analysis.

For alpha-rich particles, knowledge of the ^{241}Pu to ^{241}Am activity ratio can assist in the calculation of the age of beach finds (this analysis is detailed in Section 5.4.5). Information on the $^{238,239,240}Pu$ to ^{241}Am activity ratio is important for the health risk assessment (Brown & Etherington, 2011). It should be noted that ^{238}Pu and ^{239}Pu activities are often reported above the analytical limit of detection through High Resolution Gamma Spectrometry applying an overnight counting time, whereas only 8 measurements of the radioisotope ^{240}Pu were reported above limit of detection. Figure 19 shows a histogram of the $^{238,239,240}Pu$ to ^{241}Am activity ratio demonstrating that the modal band is 0.5 - 0.6 and that only 9 of the 116 measurements of this ratio (8% of the total) have shown that $^{238,239,240}Pu$ activity exceeds ^{241}Am activity. The 50th percentile of $^{238,239,240}Pu$: ^{241}Am was found to be 0.53 with 95% confidence limits of 0.13 and 2.16.

Elemental and morphological analysis showed that these alpha-rich particles consist mainly of iron/iron oxide material (94%), see Figure 20. Electron microscopy analysis measured largest dimensions of these particles to range between 90 and 1300 μm.

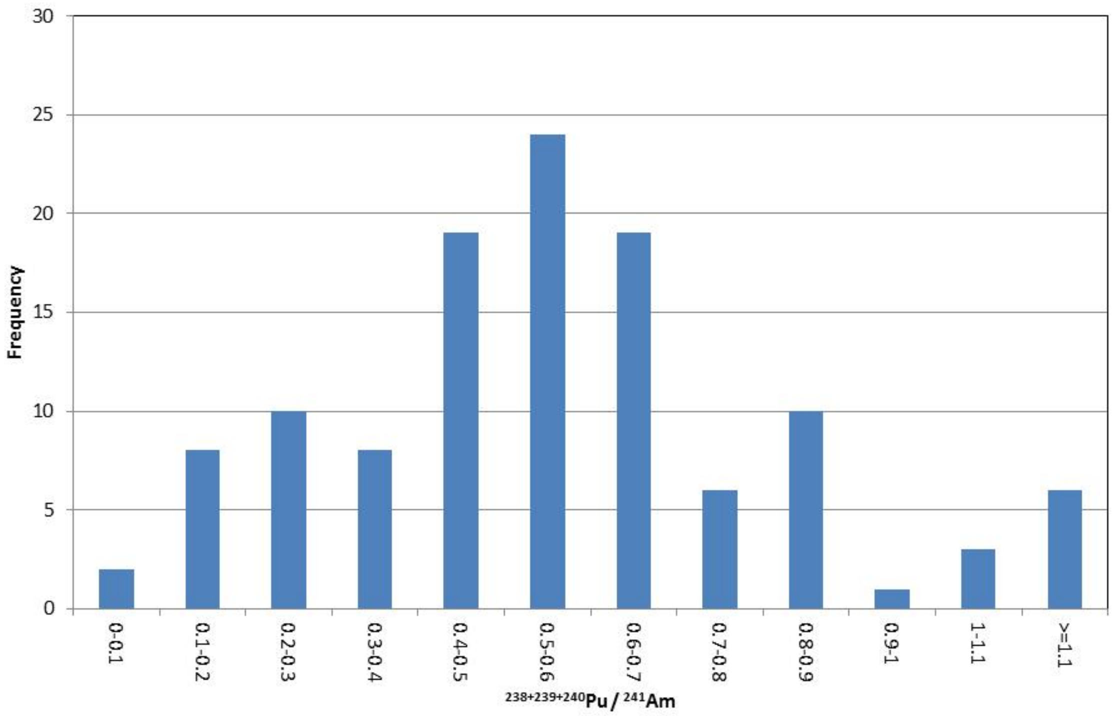


Figure 19: Frequency distribution of the ratios of $^{238,239,240}Pu$: ^{241}Am in alpha rich particles.

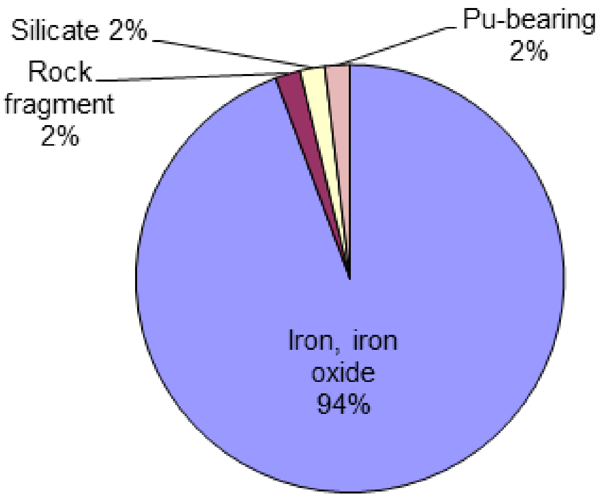


Figure 20: Composition of further analysed alpha-rich particles.

5.4.2 **Beta rich particles**

A total of 391 beta-rich particles were recovered between 2006 and 2017, 98 of these have been subject to further detailed laboratory analysis.

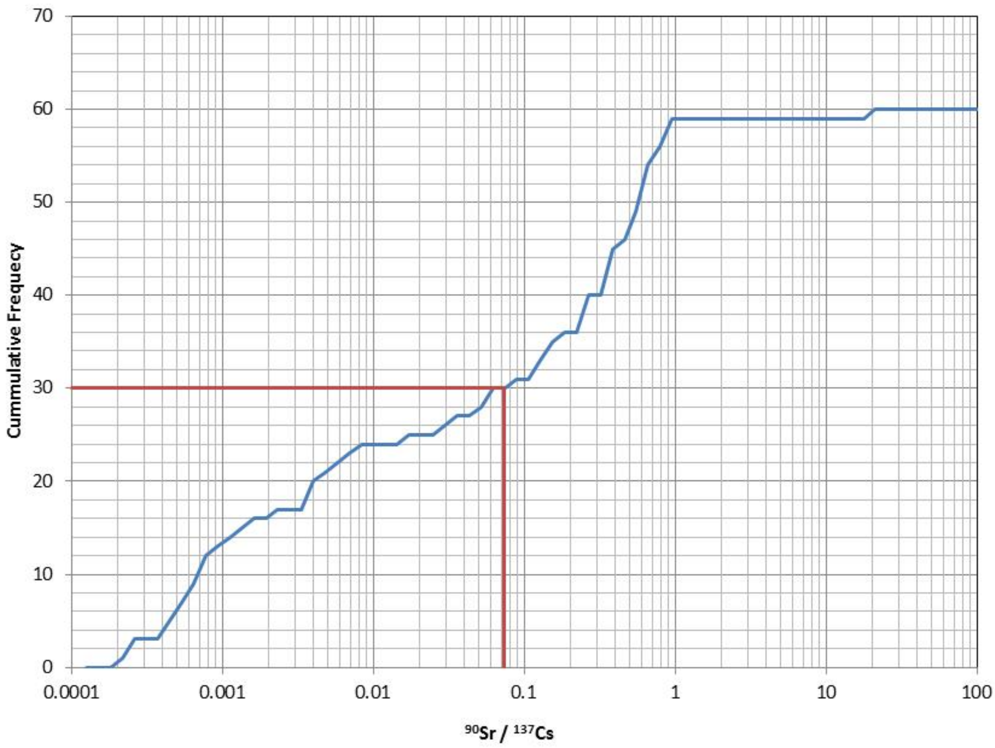
Measurements of ^{90}Sr activity are important for understanding the health risks associated with beta rich particles. A total of 60 particles have been analysed to determine their ^{90}Sr activities. Figure 21 shows the cumulative frequency distribution of the ratio of ^{90}Sr:^{137}Cs in beta rich particles, illustrating the median value for ^{90}Sr:^{137}Cs is 0.073 with upper and lower 95% confidence limits of 0.90 and 0.0023. These data illustrate that the assumption of a ^{90}Sr:^{137}Cs of 1.67 applied in the health risk assessment (Brown & Etherington, 2011) is highly conservative when compared with the available data from the beach monitoring programme.

Figure 22 shows that these beta-rich particles consist of a mixture of graphite (37%), metal/zirconium (27%), biotite (18%), rock fragment (10%) and iron/iron oxide (8%).

5.4.3 **Beta rich larger objects**

A total of 48 beta rich larger objects have been subject to further detailed laboratory analysis. Figure 23 shows the cumulative frequency distribution of the ratio of ^{90}Sr to^{137}Cs in beta rich larger objects. The median value for ^{90}Sr: ^{137}Cs is 0.0095 with upper and lower 95% confidence limits of 0.68 and 0.00016, indicating that beta rich larger objects contain a lower proportion of ^{90}Sr than beta rich particles.

Figure 24 shows that these beta-rich larger objects consist mainly of rock fragments (76%). The graphite larger object included in this group of beach finds was marginally over the 2 mm criterion (2.03 mm) to be classified as a particle.



Notes: Red line indicates the 50th percentile (median).

Figure 21: Cumulative frequency distribution of ^{90}Sr: ^{137}Cs in beta rich particles.

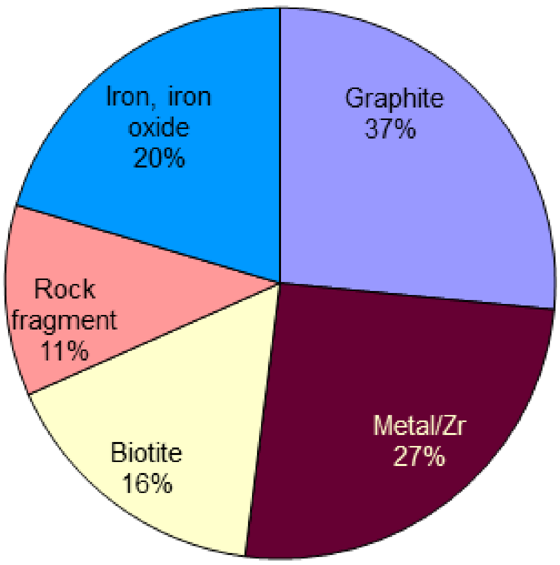
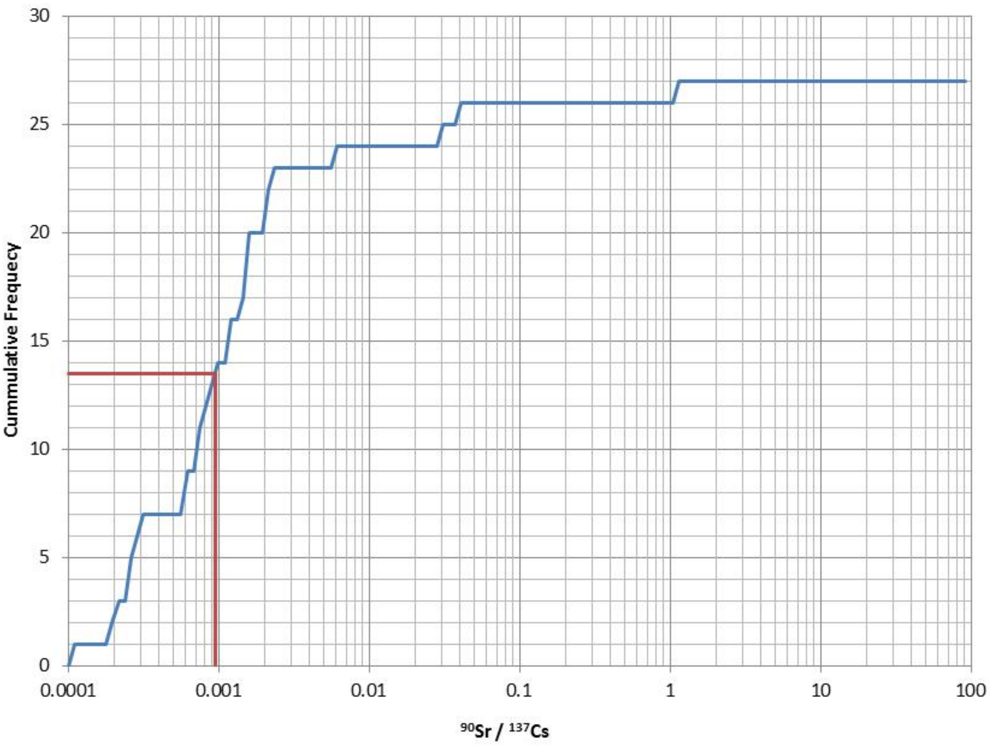


Figure 22: Composition of further analysed beta-rich particles.



Notes: Red line indicates the 50th percentile (median).

Figure 23: Cumulative frequency distribution of ^{90}Sr: ^{137}Cs in beta rich larger objects.

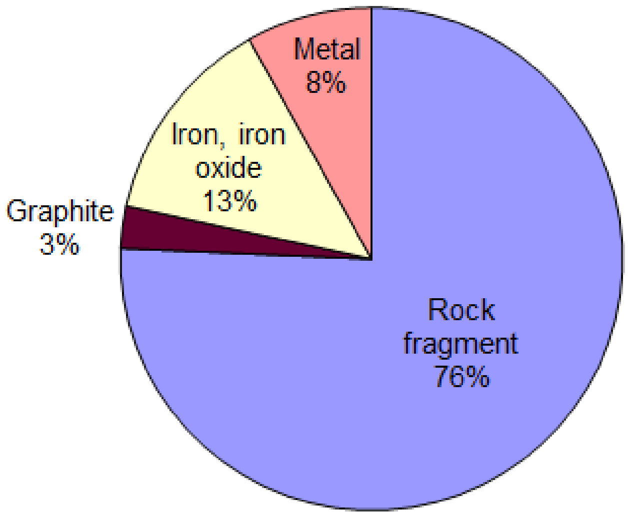


Figure 24: Composition of further analysed beta-rich larger objects.

5.4.4 **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. Only 34 of the alpha rich particle finds recovered up to the end of December 2017 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, only 43 (or 11 %) contained measurable levels of ^{241}Am activity.

Aside from the unusual alpha rich 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 higher at 1.63E+03 Bq, which is just below the activity of finds recovered by detection of ^{241}Am.

Relatively few alpha rich larger objects have been found, with only six recovered to date. Of these, three also contained detectable levels of ^{137}Cs. Of the 688 beta rich larger objects, 116 also contained detectable levels of ^{241}Am.

5.4.5 Age estimates of beach finds

The age of beach finds can be estimated using information on the radioisotope fingerprint and the half-life of each radioisotope. For beta rich finds the ratio of ^{134}Cs: ^{137}Cs can be applied, with ^{134}Cs having a half-life of 2.1 years and ^{137}Cs having a longer half-life of 30.1 years. The advantage of using isotopes of the same element is that they should behave similarly in terms of their chemistry and environmental transport. Calculations using the FISPIN model for reference Magnox fuel show that following 180 days of cooling after removal from a reactor there would be around four times more ^{137}Cs than ^{134}Cs in the spent nuclear fuel. Similar calculations for oxide fuels show ^{134}Cs: ^{137}Cs ratios of around 1:1 for cooling periods of less than 2 years and 1:13 for 10 year cooling periods.

All the measurements of ^{134}Cs on beta rich particles have been at the limit of detection, which is *circa* 20 Bq. Typically ^{137}Cs activities in beta-rich particles are around 2E+04 Bq hence it is possible to conclude that beta-rich particles are more than around 15 - 20 years old. However, a lower limit of detection for ^{134}Cs was achieved by the laboratory of 0.06 Bq for 24 of the particles which enabled an age estimate of more than 32 - 43 years to be defined. It is clear that whilst the exact age of beta rich particles cannot be identified, they were most likely formed between 1953 - 1985 when beta activity discharges to the sea were more than an order of magnitude higher than contemporary levels.

Age estimates for the majority of beta rich larger objects were broadly in line with those for beta rich particles, with the laboratory achieving a limit of detection for ^{134}Cs of 0.06 Bq for 35 larger objects, providing age estimates of greater than 30 - 40 years. Three beta rich larger objects had positive determinations for both ^{134}Cs and ^{137}Cs allowing a direct estimate of their age to be made. These larger objects were retrieved in 2006, 2007 and 2008 and assuming that they originated from liquors derived from the Magnox reference fuel they could have been formed between 1987-1992, 1996-1997 and 1993-1997. The ^{137}Cs activity of these larger objects was in the range 7E+03 Bq to 8E+03 Bq and hence they were in the lowest 10% of larger object activities that have been detected. Most beta rich larger objects were classified as stones and hence were likely to have been formed from natural materials coming into contact with radioactive effluents that were released from the sealines (see Section 7).

Age estimates for alpha rich particles can be made from measurements of the activity concentrations of ^{241}Pu and ^{241}Am. Americium-241 is the long-lived daughter radionuclide (the half-life of ^{241}Am is 432 years) of ^{241}Pu and is therefore produced as ^{241}Pu decays (the half-life of ^{241}Pu is 14.3 years). A review of the source and pathways of alpha rich finds (Sellafield Ltd, 2010) identified that isotopes of americium are removed from those of plutonium during the chemical separation phase of reprocessing. Consequently, any ^{241}Am present in beach particles must have originated from the radioactive decay of ^{241}Pu after chemical separation. It should be noted that the absence of fission products (primarily ^{137}Cs) identified that alpha rich particles were not fuel fragments and were therefore produced at some point following reprocessing (Sellafield Ltd, 2010). In addition, the types of fuel being reprocessed at Sellafield before approximately 1970 would have initially contained very little ^{241}Am and hence age estimates would be accurate to within a few years. The age of alpha rich finds was estimated from a sub-set of 180 finds where both ^{241}Am and ^{241}Pu were measured. The results are shown in Figure 25 and indicate that the majority of alpha rich finds were produced during reprocessing in the late 1960's and early 1970's and that releases of alpha rich particles stopped by around 1983.

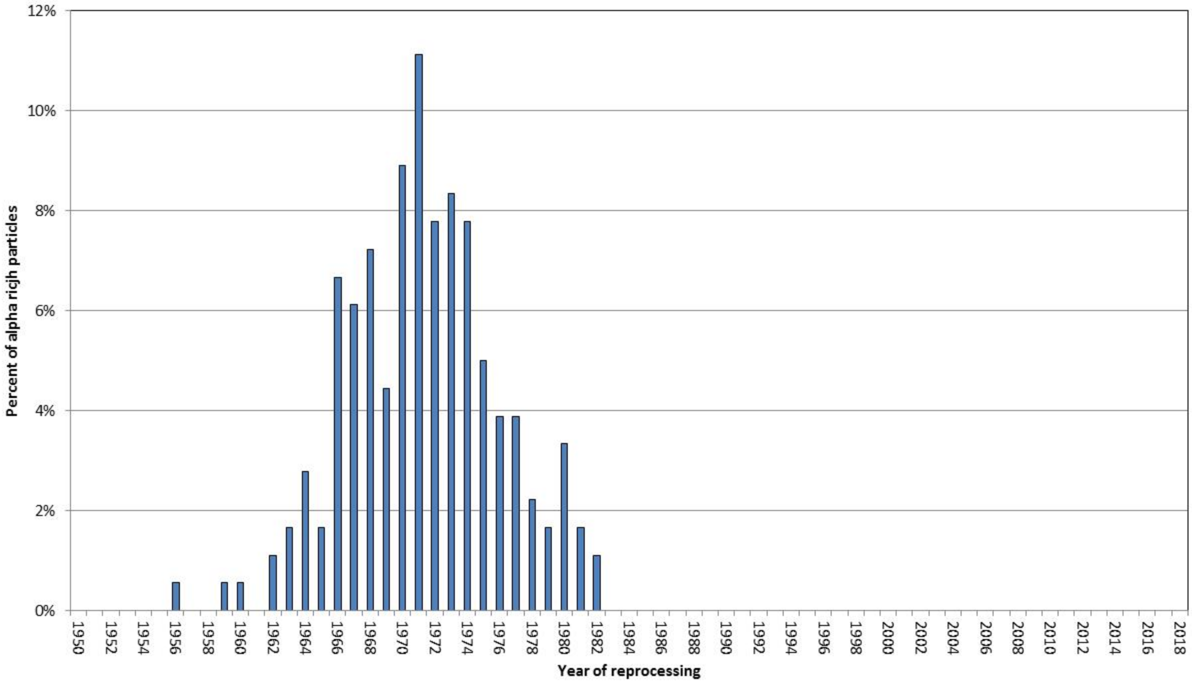


Figure 25: Age estimation for alpha rich particle finds based on the ^{241}Am: ^{241}Pu ratio.

5.5 Further Analysis of Beach Finds

5.5.1 Analytical approach

During 2017 only one beta-rich particle has been recovered that required further analysis as it exceeded the EA characterisation criteria (see Section 2.3). This particle (LSN2200903) was found on Sellafield beach on the 3rd of October 2017 at a depth of 20 cm. Initial contact dose measurements in the field by Nuvia identified that the particle could have a skin dose rate of 279 mSv hr^{-1}. A gamma scan in the Sellafield Ltd laboratories identified a ^{137}Cs activity of 1.86E+05 Bq and a ^{134}Cs activity of <6.1E-02 Bq, indicating that the particle may have originated from nuclear fuels received at Sellafield before the mid 1970s.

Further laboratory analyses were performed on this particle to provide information on the ^{90}Sr and ^{137}Cs activities and on skin dose rates. These data are discussed below and complement information on other beach finds discussed in recent annual reports, which also include details of the physical and radiochemical analysis methods (Sellafield Ltd, 2017c).

5.5.2 Petrographic results and conclusions

Based on Scanning Electron Microscopy (SEM) with an Energy Dispersive X-Ray Analyser (EDX), the particle is considered to be anthropogenic (see Figure 26). It is a subangular, finely platy and highly fractured particle. Its metallic lustre and carbon-rich composition suggest that it is graphite. A common surface deposit was found to be rich in caesium and there are widespread platy subhedral crystals of strontium-bearing barite at the surface. Rare micron scale fines at the surface have plutonium and uranium compositions.

Graphite is a very soft material, so dispersal in the environment is possible through contact transfer. The coating of the particle is also susceptible to the same transfer mechanism and fragmentation is also a high risk.

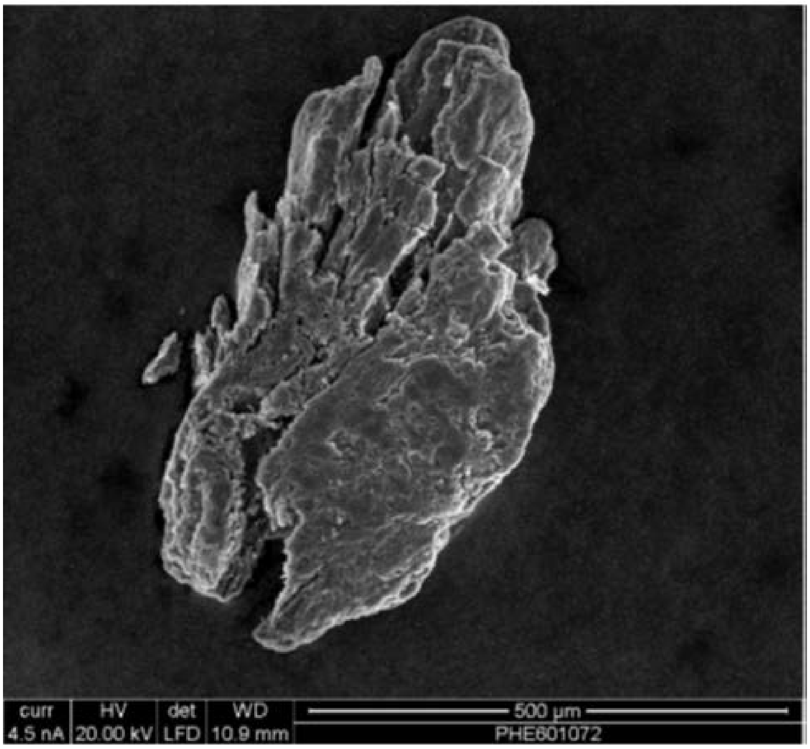


Figure 26: Scanning electron micrograph of particle LSN220090.

5.5.3 Radionuclide activity

Details of the radionuclide activities of particle LSN2200903 are given in Table 4. The principal beta emitter present is ^{137}Cs (1.84E+05 Bq) with a much smaller contribution from ^{90}Sr (1.4E+02 Bq). The individual alpha-emitting radionuclides were not analysed in detail as only 20 Bq of total alpha activity was reported.

Table 4: Radiochemical analysis of particle LSN2200903.

Area	Type	Total Beta	^{90}Sr	^{137}Cs	Total Alpha
Sellafield	Graphite (A)	211000 Bq	140 Bq	184000 Bq	20 Bq

(A) – Anthropogenic

5.5.4 ^{90}Sr: ^{137}Cs ratio

As noted previously, knowing what the ^{90}Sr:^{137}Cs activity ratio is of a beach find is an important parameter for calculating radiological doses. The radionuclide ^{137}Cs can be determined relatively easily and non-destructively through High Resolution Gamma Spectrometry whereas determination of ^{90}Sr activity is more resource demanding and time consuming. Analysis of LSN2200903 provided a ^{90}Sr activity of 1.40E+02 Bq and a ^{90}Sr:^{137}Cs ratio of 7.6E-04. This confirms that dose contributions from ^{90}Sr will be much lower than those from the ^{137}Cs present in this find.

5.5.5 Skin contact dose rate measurements

Skin contact dose rate measurements of beach finds have been conducted since 2015 by PHE (Tanner *et al*., 2017a; Tanner *et al*., 2017b; Eakins *et al*., 2017). Three techniques were applied to the beach find although only two techniques were of sufficient quality to report. These were thermoluminescent detectors (EXTRAD® TLD) and radiochromic dye film. The annual report for 2016/17 provides a summary of these techniques (Sellafield Ltd, 2017c).

The mean skin contact dose rate measurement results are presented in Table 5. The dose rate assessed was in terms of $H_p(0.07)$ averaged over 1 cm^2, with units of mSv h^{-1}. This is taken as an adequate estimator of the dose to skin averaged over the most exposed 1 cm^2, for a skin depth of 50 – 100 μm, which has the units of mGy h^{-1}.

Table 5: Skin dose rate estimates for particle LNS2200903.

EXTRAD TLD	Radiochromic Dye Film	Average Dose Rate
230± 20 mSv h^{-1}	140± 40 mSv h^{-1}	185 mSv h^{-1}

The measured skin contact dose rate was determined to be 230 mSv h^{-1} (230 mGy h^{-1}) using EXTRAD®TLD. It is notable that this result, obtained from a detailed laboratory investigation is similar to the result obtained from the field analysis of this particle (279 mSv hr^{-1}) providing confidence in the field measurements as a reliable initial assessment. This result implies that a 2 Gy dose to the most exposed 1 cm^2 of skin would require this particle to be in contact with the skin for about 8 hours. Though relatively high compared to most other beach finds (Sellafield Ltd, 2016; 2017), the contact dose rate is below the 300 mSv h^{-1} threshold previously recommended by PHE for an urgent review of the health risk assessment (Brown & Etherington, 2011).

5.6 Beach Monitoring Programme Conclusions

The 2017 programme has provided data that remains consistent with the health risk assessment. The types of material being recovered during 2017 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 health 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)

6 Assessment of Best Available Technique (BAT)

6.1 Particles in the Environment BAT/ Optioneering

One of the key Environment Agency requirements, detailed in Section 2, is that the Particles in the Environment programme must apply Best Available Techniques for the monitoring and detection of environmental radioactivity. The definition of Best Available Techniques (BAT) encompasses both the monitoring equipment and the programme design.

The following programme objectives were agreed with the Sellafield Particles Working Group (Sellafield Ltd, 2017a):

- Assess total representative persons dose (to be conducted by Public Health England).
- Assess total impact on wildlife (e.g. dose) (this is to be addressed by the Environment Agency).
- Provide public and stakeholder reassurance.
- Assess long term trends (as an indicator).
- Understand / monitor behaviour of radionuclides in the environment.

Furthermore specific programme objectives were identified for the Particles in the Environment programme as follows:

- Assess whether the conclusions of the health risk assessment (as detailed in Section 9) remain valid.
- Monitor for abnormal radioactive material and remove in line with the principle of As Low As Reasonably Practicable (ALARP).

A requirement of BAT is that it is kept under review to account for technology developments and to ensure that the programme continues to address the agreed objectives. The latest BAT review was submitted to the Environment Agency in September 2017 (Sellafield Ltd, 2017b), developing on the considerations in the 2014 BAT review report (Sellafield Ltd, 2014b).

6.2 2017 BAT Assessment Conclusions and Recommendations

The conclusions of the 2017 review of the Particles in the Environment BAT Assessment were as follows:

- *Monitoring to date has shown that the risks to health from finds recovered from the West Cumbrian coast are within the bounds of the PHE risk assessment. That is, that they represent a very low risk to either beach users or consumers of locally caught seafood and that the level of risk is significantly lower than risks that people accept when using beaches.*
- *The overall beach monitoring trend (since the introduction of Synergy in 2009) is of consistent alpha rich particle find rates though with short term variations.*
- *There is evidence that Beta Rich Particle find rates have reduced over time (since 2008).*
- *The current beach monitoring methodology is BAT for the detection of alpha rich finds and beta rich finds containing ^{60}Co, ^{90}Sr, ^{137}Cs and ^{241}Am. A watching brief should be maintained on technology developments although it is expected that improvements to the current techniques will continue to yield benefits to the programme. It should be noted that only modifications that have been verified to provide a significant improvement will be considered, in order to ensure that the programme adopts a systematic approach to data collection.*

- *The variations in find rate with depth for alpha rich particle and beta rich particle finds were found to agree well with the expected variations based on the theoretical limits of detection of Synergy. Little information on the true depth profile of finds could be obtained from the current monitoring.*
- *The selection of samples for further laboratory analysis based on the contact dose rate is appropriate as the measured contact dose is strongly correlated with measurements of skin dose. However, characterisation is only required for finds that exceed the EA find characterisation criteria.*
- *Current methods for walking surveys represent BAT. Further optimisation is possible through consolidating the monitoring undertaken by Sellafield Ltd and Nuvia Ltd and focusing walked surveys on areas of the beach that are known to be used by the public but are not accessible to the vehicle, in particular the stormline.*
- *Monitoring of the seabed was demonstrated not to represent BAT as expert reviews have concluded that (1) material would be transported towards the beaches (2) the intertidal zone is well mixed (3) the health risks from the consumption of West Cumbrian seafoods has been recently re-estimated and shown to reduce by several orders of magnitude from the initial screening estimates. However, a watching brief should be kept on the use of a seabed ROV should changes to the advice occur.*
- *Investment in marine modelling does not represent BAT as there is no currently available modelling package and hence modelling would require a significant development and data collection effort. Given that reliable source term data are unavailable to input into the model then the benefit realisation would be low.*
- *The current risk-based programme of beach monitoring represents BAT. A review of the health risk assessment is being conducted by PHE presently and the outcome of this review should be used to re-evaluate the monitoring programme.*

(Sellafield Ltd, 2017b)

A list of the recommendations of the 2017 BAT case and the progress in addressing the recommendations is shown in Table 6. The Environment Agency reviewed the 2017 BAT case and provided the following assessment (Environment Agency, 2018).

> *The report meets our requirement for Sellafield Limited to review its environmental monitoring programmes as detailed in CEAR specification 4.2.2 Part 2/v011 paragraph 7 and so required by permit condition 4.2.2. Sellafield Limited have therefore demonstrated compliance with this condition....*
>
> *... We support the recommendations made in the report and will continue to work with Sellafield Limited and other stakeholders to review the monitoring approach for 2020 onwards following completion of the review of the public health risk assessment by Public Health England.*
>
> (Environment Agency, 2018)

A further review was completed following the production of the BAT Case focussing on the optimisation of the strandline monitoring (Sellafield Ltd, 2018). The recommendations of this review and their rationale are detailed in Table 7. The review was shared with the Environment Agency and no objections were raised to the modification of the programme hence all strandline monitoring for 2018 and onwards will be conducted using the Synergy2 vehicle.

Table 6: BAT case recommendations and progress.

BAT Recommendation	Progress
1. Continue the current beach monitoring approach with the 2017 and 2018 programmes as agreed with the EA.	2017 programme completed to specification and 2018 programme is ongoing.
2. Provide analysis and input data for PHE to use for their review of the risk assessment.	Ongoing. See Section 5.
3. Maintain a watching brief on monitoring methods for beach particles (in particular the application of miniaturised gamma spectrometers) and for seabed particles (in particular ROVs and the seabed detection of alpha rich material).	Ongoing.
4. Develop a specification for the alignment of the walked surveys of the coast to refocus these surveys on areas of the beach that are used by the public but are inaccessible to the monitoring vehicle.	Superseded. See Table 7.
5. Continue to maintain and develop the forward strategy for programme to enable the programme to be optimised in line with the principles of BAT.	Ongoing. See Section10.
6. Conduct laboratory characterisation on finds only as required by the characterisation criteria developed by the Environment Agency following PHE advice.	Ongoing. See Section 5.4.
7. Continue statistical work to underpin the monitoring programmes and sampling arrangements for the beach environment.	Ongoing. See Section 5.

Table 7: Recommended revisions to the strandline monitoring.

Recommendation	Rationale
Remove the existing requirement to monitor the Compound Strandline.	Since the Compound Strandline monitoring commenced in 2009 it is notable that there have been no items detected that differ from the items routinely detected in the beach monitoring programme (particles and larger objects). The beach monitoring programme largely focuses on Sellafield beach and in particular the areas in the vicinity of the discharge pipelines. The routine beach monitoring programme is scheduled to undertake quarterly monitoring on Sellafield beach during 2018 and beyond.
Remove the requirement for walked strandline monitoring and introduce a single programme of biannual vehicle strandline surveying (from St. Bees to Drigg, excluding Nethertown), focusing on the high tideline.	The stormline is difficult to access by operators and members of the public, and is also located close to coastal habitats. In comparison, the high tideline is readily accessible by members of the public, can contain a large amount of debris and is away from the wildlife that can reside above the high tideline. All of the high tideline is accessible to the beach monitoring vehicle and this would remove the need to complete walked surveys in the future. The detection system on the beach monitoring vehicle has 13 detectors, includes inbuilt alarms and has a monitoring swathe of 2 m, this monitoring technique is considered to be BAT. In comparison, walked surveys rely on single detectors and health physics operators to identify when radioactive contamination is present.
Visually inspect the stormline and investigate any industrial waste that may have originated from the Sellafield site. The visual inspection will take place alongside the high tideline monitoring.	The support vehicle will be driven along the high tideline, at beach monitoring speed (1 m/s), allowing the operator to visually inspect the debris situated in the nearby stormline. Any industrial waste items (rubber gloves, gaskets etc) would be investigated and monitored. Contaminated items would follow the established procedures for beach finds where they are bagged and returned to site and their positions are recorded with the GPS.
Remove the requirement for annual monitoring of the most recent tideline by vehicle.	Large sections of the recent tideline are monitored routinely as part of the beach monitoring programme due to its position on the beach, effectively duplicating effort. Since the vehicle based monitoring of the recent tideline commenced in 2009 it is notable that there have been no items detected that differ from the items routinely detected in the beach monitoring programme (particles and larger objects).

Notes: from (Sellafield Ltd, 2018).

7 Transport and Dispersion

A high-level multidisciplinary desk based review of the 2014 Conceptual Site Model (CSM) for particles in the environment (Rankine & Jackson, 2014) was conducted (Atkins, 2018). This review updated the 2014 CSM with additional information that was collected during the intervening years to address information gaps identified by Rankine & Jackson (2014), in particular:

- The review of coastal geomorphology and sediment transport (Golder, 2016d).
- Characterisation of the chemical and physical properties of particles (Sellafield Ltd, 2017c).
- Updates to the health risk assessments (Oatway & Brown, 2015a).
- Updates to habit data, including information from a review conducted for Sellafield Ltd in 2014 (Golder, 2014).
- Further analysis and characterisation of the seabed via grab sampling as detailed in (Sellafield Ltd, 2017b).

The project was conducted following a consultative process incorporating a number of technical meetings:

- Scoping meeting between Sellafield Ltd and Akins to agree the key features of the CSM update.
- A half-day workshop was held to consider and agree the updates to the report. This was attended by Sellafield Ltd, Akins, Public Health England and the Environment Agency.
- Presentation of the draft CSM to the Sellafield Particles Working Group and COMARE.

The update to the CSM focussed on the main types of radioactive particles and larger objects found on the Cumbrian Coast (alpha rich and beta rich particles and beta rich larger objects). In addition, the update only considered human health receptors as the EA are currently assessing the risks to non-human biota. Minor exposure routes (such as exposure to contaminated fishing gear and transfer of material by wind from the beach to more inland locations) were excluded from the CSM due to their very low radiological risk (Oatway & Brown, 2015a).

An analysis was conducted on the transport and dispersion of particles and larger objects in the Irish Sea, including the dominant coastal mechanisms transferring particles from the offshore environment to the beach. These can be summarised as follows:

- Figure 27 shows the most likely transport direction in the offshore coastal environment would be for northward transport parallel to the coast.
- Figure 28 shows that transport in the immediate offshore region would be influenced by the direction of the dominant wave energy, moving material towards the coast, although there may be a movement of beach material offshore during storms. A low energy offshore region was identified where silts and sediment could accumulate.
- Figure 29 illustrates that within the beach environment transport in the littoral zone (the region up to the extreme high water mark) would be dominated by tide and current driven exchange, whilst transport above the extreme high water mark (*i.e.* the terrestrial environment) would be mainly through the action of the wind.

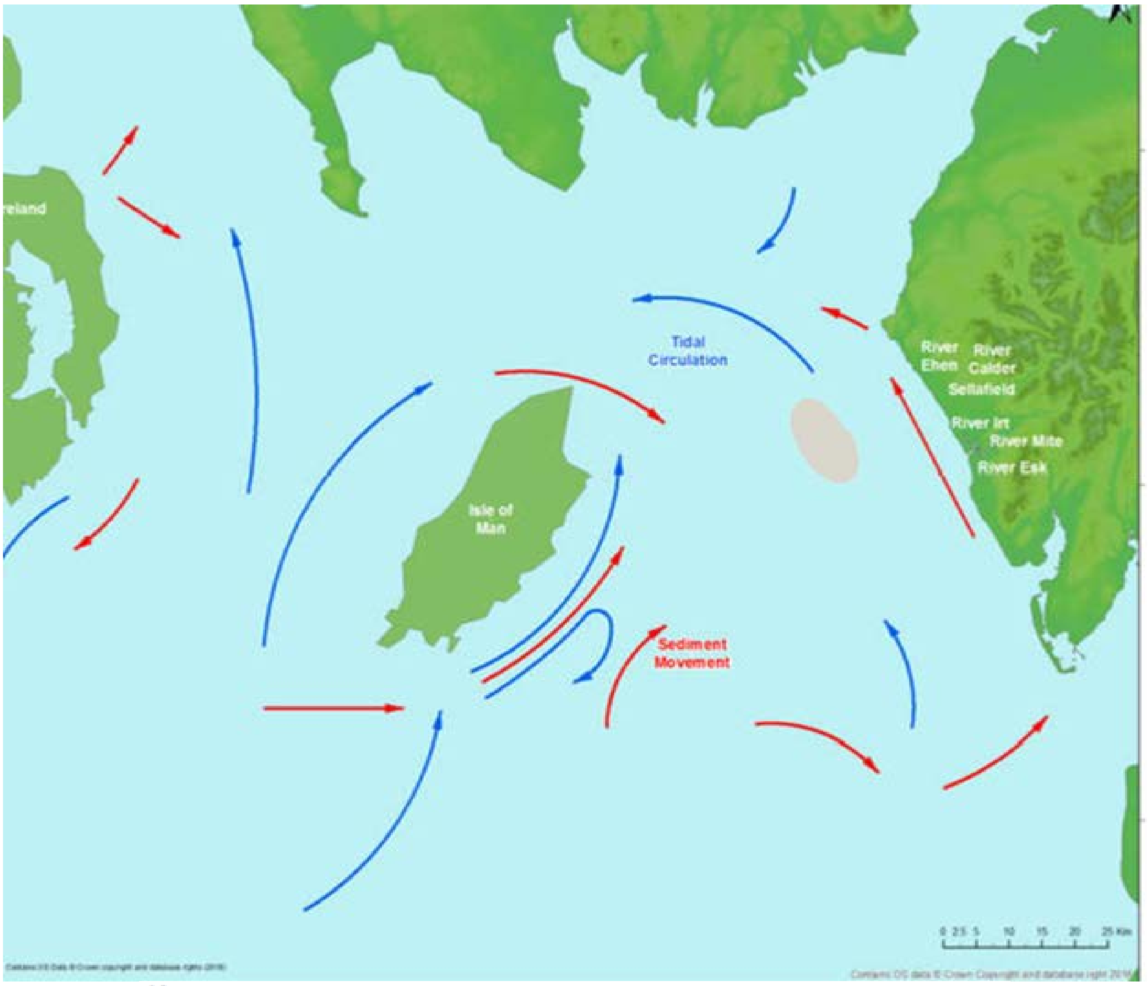
The CSM concluded that:

> *Radioactive objects detected on the beaches close to the Sellafield site are most likely to have entered the environment via the sea discharge pipelines, either during their operation prior to the introduction of filtration, or during the SRP [sealine retrieval project]. The exact origin of the radioactive objects is unlikely to have a significant influence on their current behaviour in the environment and the continuing entry of particles into the environment has been discounted primarily due to the introduction of ultrafiltration and the commissioning of EARP in 1994.*
>
> *At present, there are an unknown number of radioactive objects on the seabed. Such radioactive objects may be moved with the general sediment in a predominantly northerly direction. Areas of lower energy may offer a potential area for deposition of radioactive objects. In general, however, it would be expected that such radioactive objects would be transported in a fashion reflecting their overall size and density (i.e. fine grained radioactive particles may be transported in the same fashion as silt, larger grained particles would be expected to be transported in the same fashion as sand).*
>
> (Atkins, 2018)

A graphical representation of the CSM is shown in Figure 30, illustrating the main sources, pathways and receptors.

The key aspects of the CSM are summarised as follows:

- **Sources** - there are no ongoing sources with existing material in the environment (originating from historic sources and the pipeline retrievals) presenting a secondary diffuse source.
- **Pathways** - intertidal transport is dominated by drift and burial/ exposure; movement from the sea to the beach occurs in moderate storms; and movement from the beach to the sea occurs in severe storms.
- **Receptors** - these are as considered in the previous health risk assessments.



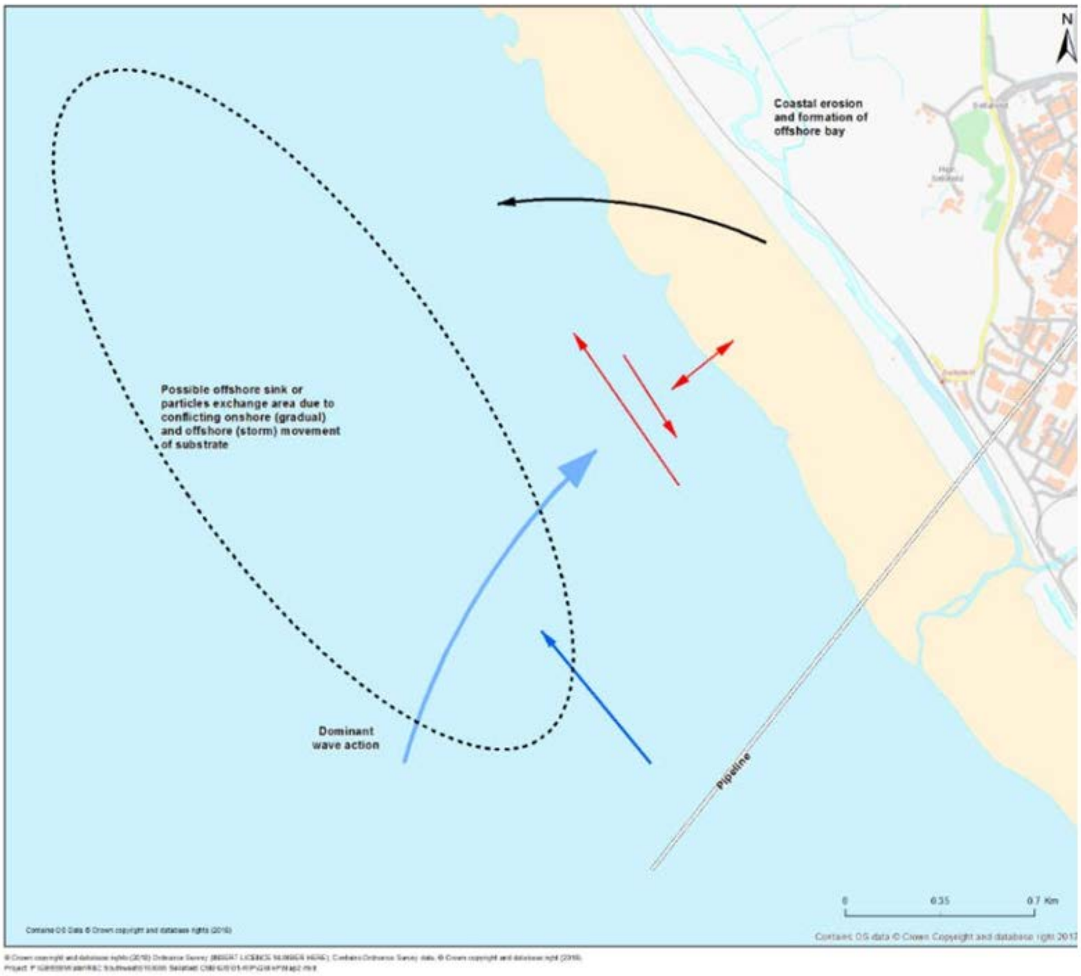
Key:

General description of the flow of water in the Irish Sea

General description of the sediment transport in the Irish Sea

Area of mud indicating a region of relatively low energy

Figure 27: Schematic diagram of Irish Sea water flows and transport.



Key:

- General south to north water and sediment movement
- Predominant wave energy
- Sediment transport in the littoral zone; net transport is to the north
- Net erosion of the coastline during storm events
- Potential accumulation of sediment

Figure 28: Schematic diagram of coastal transport pathways.

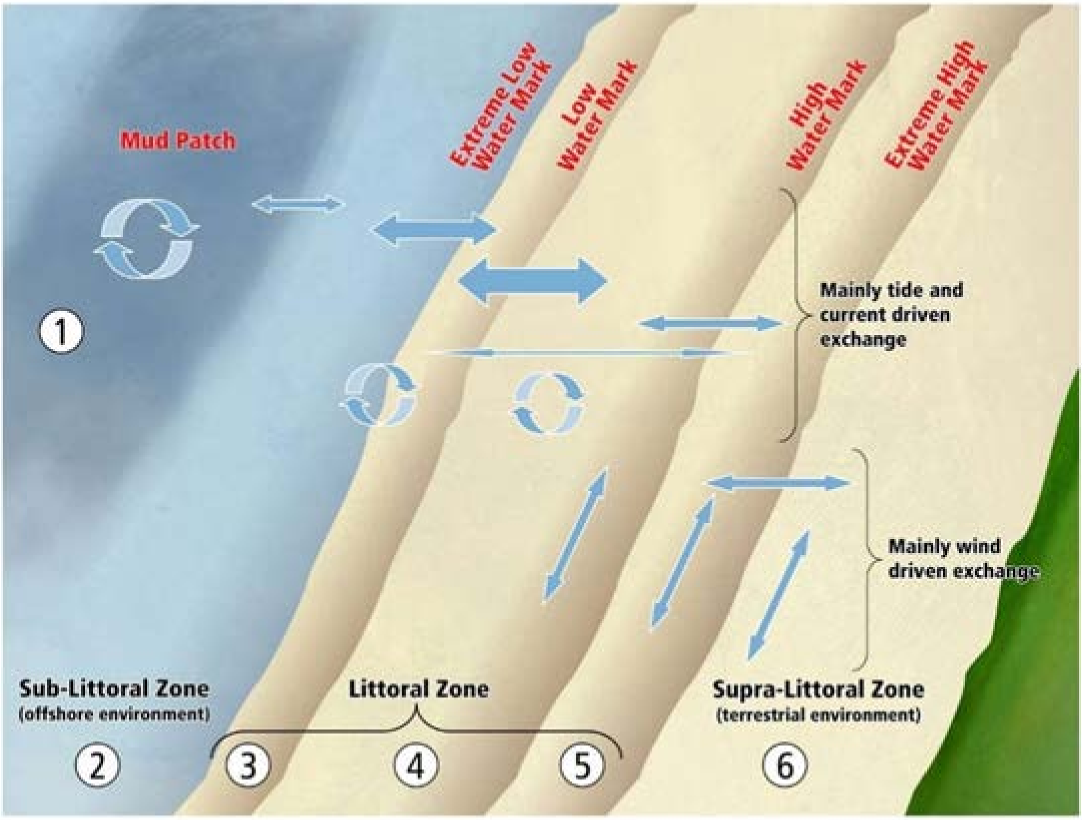


Figure 29: Schematic diagram of nearshore-onshore transport pathways.

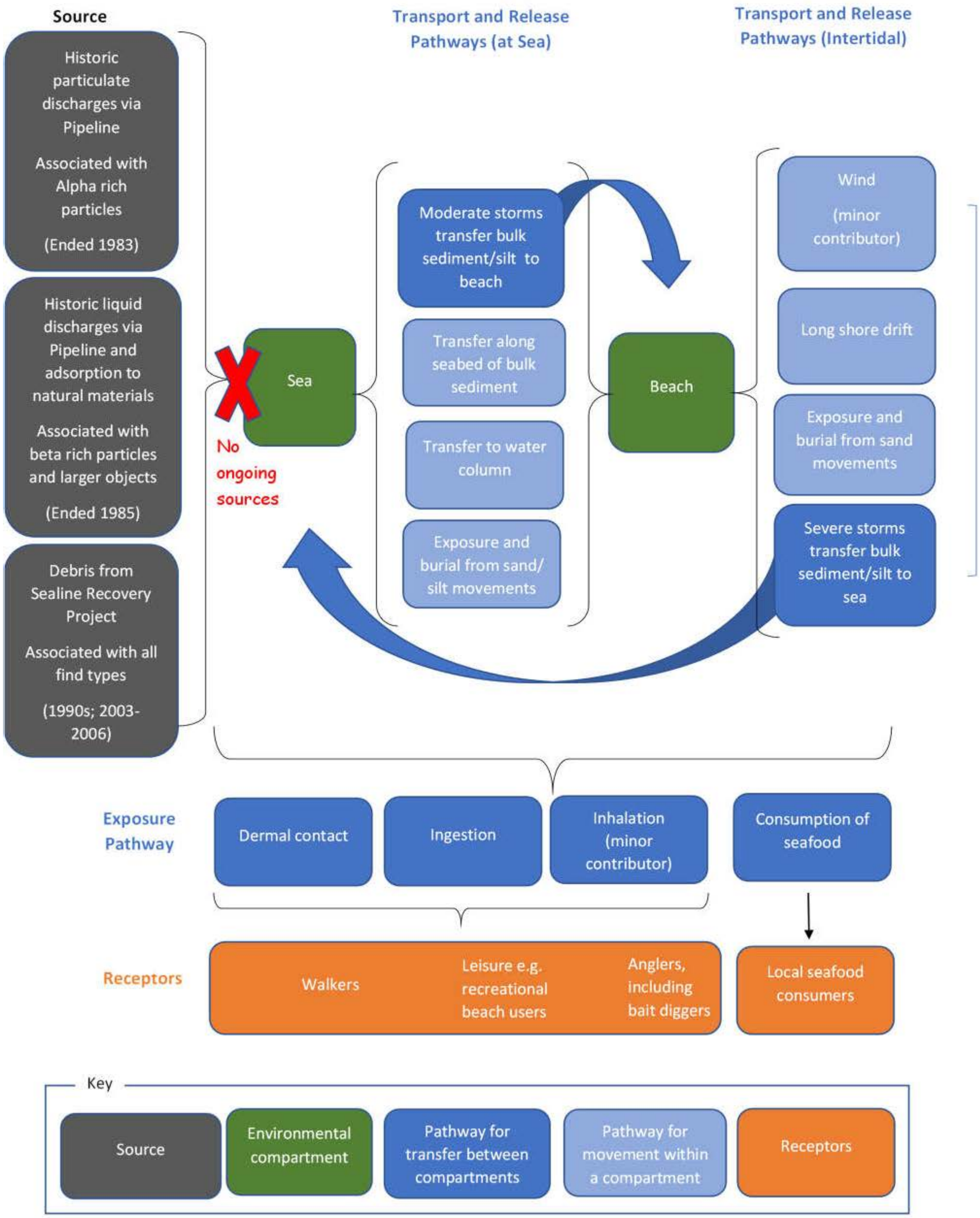


Figure 30: Schematic diagram of the Conceptual Site Model.

8 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. They include:

- General updates and availability of information via the internet;
- 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.

8.1 General Engagement with the Environment Agency

As part of managing the delivery of work against the specification detailed in Section 2, 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 4.6).

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 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.

8.2 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.

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 of the committee’s questions at first hand.

8.3 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 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 November 2017, the updated Conceptual Site Model was presented at this working group. Further details of this work can be found in Section 7.

Additionally, the Group has provided an opportunity to review the Sellafield particles forward programme and the Group will remain a key forum for taking this work forward. Further details of the work being carried out on the forward strategy are included in Section 10.3.

8.4 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 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/

9 Health Risk Assessment

Public Health England (PHE) is responsible for the health risk assessment for Particles in the Environment. PHE 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 the headquarters of the 'Centre for Radiation, Chemical and Environmental Hazards' is at Chilton in Oxfordshire.

The health risk assessment completed in 2011 concluded the following:

> *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.*
>
> (Brown & Etherington, 2011)

The EA asked for the 2011 health risk assessment to be updated to include the data from the Synergy detection system. This update was completed in August 2012 and 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.*
>
> (Etherington, et al., 2012)

As part of the work controlled by the Sellafield Particles Working Group, PHE has 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 & Brown, 2015b) is reproduced overleaf.

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.

(Oatway & Brown, 2015b)

The highest overall risks are shown in Table 8, illustrating that risks to adults and children using the beach and consuming seafood 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). Therefore these risks are around 1000 times more likely than a radiation induced fatal cancer from exposure to radioactive particles in the environment.

Table 8: 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).

PHE have been requested by the Environment Agency to update their recommendations if supported by available evidence. This is to account for the information from the beach monitoring programme and from the further analysis of finds that has been collected since 2012. A full review of the available data was started in February 2017 and it is expected that an updated assessment of the health risk to the public from radioactive particles and larger objects found on the beaches near the Sellafield site will be available by April 2019 (see Section 10.2.1).

10 Forward Programme

10.1 Proposed Beach Monitoring Programme for 2018

For 2018, a programme of 152 ha has been developed to meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the health risk assessment. The programme follows the familiar template of recent years, with the 152 ha to be split into three programmes: a Sellafield programme (totalling 80 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 solely on the beach at Allonby.

Using one monitoring vehicle, such as the Metrac H5, the area that can be realistically achieved in a year is around 150 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 strandline monitoring and occasional vehicle/equipment maintenance.

Sellafield Ltd believes the agreed monitoring 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 October 2017 meeting of the Sellafield Particles Working Group with a minor modification to the programme to accommodate an increased monitoring effort on Allonby beach agreed with the EA in February 2018. Any further changes to the programme, which may stem from abnormal finds, difficulties in accessing the proposed beaches or other operational issues, will be made in full consultation with the EA.

The 2018 scheduled target areas for each beach are given in Table 9 and full details of the programme are included in Figure 31.

Pending the outcome of the ongoing review by PHE of the Health Risk Assessment the Particles in the Environment programme may be integrated within the wider Sellafield Environmental Monitoring programme from 2020. This is in-line with the strategy detailed in Section 10.3 and may result in a reduction in the scope of the monitoring programme to an annual area coverage of 105 ha as detailed in Table 10. Reporting of the results of the Particles in the Environment programme will then be through the Annual Report on Discharges and Environmental Monitoring (Sellafield Ltd, 2017d).

Table 9: Planned area coverage for each beach in 2018.

Programme	Beach	Area to be monitored (ha)			
		Sellafield	Near-Field	Far-Field	Total
Sellafield	Sellafield	80	-	-	80
Near-Field	Braystones	-	22	-	22
	St. Bees	-	20	-	20
	Seascale	-	20	-	20
Far-Field	Allonby	-	-	10	10
Total		80	62	10	152

Table 10: Potential area coverage for each beach for 2020 onwards.

Programme	Beach	Area to be monitored (ha)			
		Sellafield	Near-Field	Far-Field	Total
Sellafield	Sellafield	70	-	-	70
Near-Field	Braystones	-	10	-	10
	St. Bees	-	10	-	10
	Seascale	-	10	-	10
Far-Field	Allonby	-	-	5	5
Total		70	30	5	105

	Week Starting	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near-Field Programme: Target Area (ha)	Far-Field Programme: Target Area (ha)
Q1 2018	01-Jan-18	Sellafield (1)	20		
	08-Jan-18				
	15-Jan-18				
	22-Jan-18				
	29-Jan-18				
	05-Feb-18				
	12-Feb-18	Braystones (1)		6	
	19-Feb-18				
	26-Feb-18	No Monitoring (Biannual Maintenance)			
	05-Mar-18	Strandline Monitoring			
	12-Mar-18	St Bees (1)		4	
	19-Mar-18	Seascale (1) and Drigg Strandline Monitoring		4	
	26-Mar-18	No Monitoring (Easter Holidays)			
Q2 2018	02-Apr-18				
	09-Apr-18	St Bees (2)		4	
	16-Apr-18	Seascale (2)		4	
	23-Apr-18	Allonby (1)			10
	30-Apr-18				
	07-May-18	Sellafield (2)	30		
	14-May-18				
	21-May-18				
	28-May-18				
	04-Jun-18				
	11-Jun-18				
	18-Jun-18				
	25-Jun-18	Braystones (2)		8	
Q3 2018	02-Jul-18				
	09-Jul-18	St Bees (3)		4	
	16-Jul-18	Seascale (3)		4	
	23-Jul-18	No Monitoring (Summer Holidays) Biannual Maintenance			
	30-Jul-18				
	06-Aug-18				
	13-Aug-18				
	20-Aug-18				
	27-Aug-18				
	03-Sep-18	St Bees (4)		4	
	10-Sep-18	Seascale (4)		4	
	17-Sep-18	Strandline Monitoring			
	24-Sep-18	Sellafield (3)	30		
Q4 2018	01-Oct-18				
	08-Oct-18				
	15-Oct-18				
	22-Oct-18				
	29-Oct-18				
	05-Nov-18				
	12-Nov-18				
	19-Nov-18	Braystones (3)		8	
	26-Nov-18				
	03-Dec-18	St Bees (5)		4	
	10-Dec-18	Seascale (5)		4	
	17-Dec-18				
	24-Dec-18				
		Cumulative Totals ==>	**80 ha**	**62 ha**	**10 ha**
		OVERALL TOTAL ==>	**152 ha**		

Figure 31: 2018 beach monitoring programme.

10.2 Investigation Programme for 2018

Three items of further research are to be conducted in 2018, these are:

- The update of the health risk assessment (Brown & Etherington, 2011).
- Further detailed analysis of beach finds.
- Trials of Unmanned Aerial Vehicles (UAVs) equipped with miniaturised detectors.

10.2.1 **Update of the health risk assessment**

The risk assessment 'Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site' by Brown & Etherington (2011) was based on the available beach monitoring data of the time – between 2006 and 2009. Since then a wealth of beach monitoring information and analytical data have become available and considered (Etherington *et al*. (2012); Oatway & Brown (2015b); Golder (2016a; b; c; 2017a; b). Consequently, a review of the risk assessment was required as part of the BAT assessment for the programme (see Section 6) and to close out items in the forward strategy (see Section 10.3).

Public Health England (PHE) have been requested by the EA to review the health risks posed by radioactive particles and larger objects in the environment around the Sellafield site. This risk assessment review is to be undertaken during 2018/19 and will include reviewing:

- habit data,
- activity distributions of particles and larger objects and their populations,
- radiochemical contents and health risks.

It is anticipated that the finalised risk assessment review will be published by April 2019, although engagement with key stakeholders will be undertaken throughout 2018.

10.2.2 **Further detailed analysis of beach finds**

The detailed analysis of beach finds in 2018 will be conducted through the following:

- A reactive approach for particles that meet the EA characterisation criteria (Section 2.3), hence meeting the programme aim of providing reassurance
- A proactive analysis of previous finds (particles and larger objects) that do not meet the EA characterisation criteria, hence addressing the programme aim of understanding and monitoring the behaviour of radioactivity in the environment.

Particles recovered in 2018 that meet the EA characterisation criteria (see Section 2.3) will be analysed to address concerns expressed in the health risk assessment that such particles may prompt an urgent review of the risk assessment. It is anticipated that the analysis will involve High Resolution Gamma Spectrometry, the measurement of ^{90}Sr activities and the evaluation of skin doses (Brown & Etherington, 2011).

It is anticipated that a total of 20 beach finds that are below the EA characterisation criteria will be analysed during the period 2018 - April 2020. The specification of these finds is yet to be finalised, although it is currently anticipated that alpha rich and beta rich particles will be analysed as well as at least two beta rich larger objects (the stones found on Workington and Allonby beaches in December 2014 and April 2017 respectively).

10.2.3 Trials of unmanned aerial vehicles

Unmanned aerial vehicles (UAVs) have previously been used for the visual assessment of changes to Sellafield beach and also for the production of mapped height data (Sellafield Ltd, 2017c). Recent developments in the miniaturisation of gamma detectors have enabled these instruments to be able to be attached to UAVs and operated for a sufficient period of time to provide useful information on the spatial pattern of radioactivity. Scoping calculations for the 2017 BAT case (Sellafield Ltd, 2017b) identified that a "gamma camera" attached to a UAV would be unlikely to detect alpha rich or beta rich particles. However, there may be merit in this technology for surveying areas inaccessible to the beach monitoring vehicle to detect any high activity items if they are present. Consequently, it is anticipated that a trial of a UAV mounted gamma spectrometer will be undertaken in 2018.

10.3 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 the COMARE Contaminants working group. Details of developing the strategy and the prioritisation of tasks have been given previously (Sellafield Ltd, 2017a). Twelve tasks were identified and ranked as being high or medium priority and their latest status are shown in Table 11. It should be noted that the list in Table 11 has been optimised so some of the listed tasks meet several of the requirements detailed in the workplan.

Table 11: Strategy 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 (Sellafield Ltd, 2016).
PHE to conduct a reappraisal of the health risk assessment following the Synergy 2 trials (to be completed before 2018).	Ongoing (see Section 10.2.1).
Evaluate the detection efficiency of Synergy 2 for buried particles.	Completed (Sellafield Ltd, 2017c).
Design of beach monitoring programme to focus on high find rate beaches.	Ongoing (see Section 10.1).
Analysis of beach monitoring repeat areas to understand repopulation rates.	Completed (see Sections 5.3.1)
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.	Completed (Sellafield Ltd, 2017c).
Ongoing pro-active response to storm events.	Ongoing (see Section 5.3).
Sellafield Ltd to review photographic data including the use of drones.	Completed (Sellafield Ltd, 2017c).
PHE to review the effective doses associated with the 2014 Seascale ^{90}Sr rich particle (S1164/SEA) and are to provide a letter response.	Completed. (Sellafield Ltd, 2017c).
PHE conducting dose rate measurement work to advise on best techniques.	Ongoing (see Section 5.5.5)
Sellafield Ltd to develop staged proposals on optimising the sentinel monitoring programme.	Ongoing in consultation with stakeholders (see Section 8.3.)
Characterisation of finds from site (*e.g.* drainage finds containing [Hg]). Gully pot samples sent as part of characterisation. The RSR permit compliance requires Sellafield Ltd to use BAT to avoid release in future and therefore there is an ongoing routine action on Plant to demonstrate compliance.	Moved to routine programme.

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Appendix 1: Beach Monitoring and Find Maps

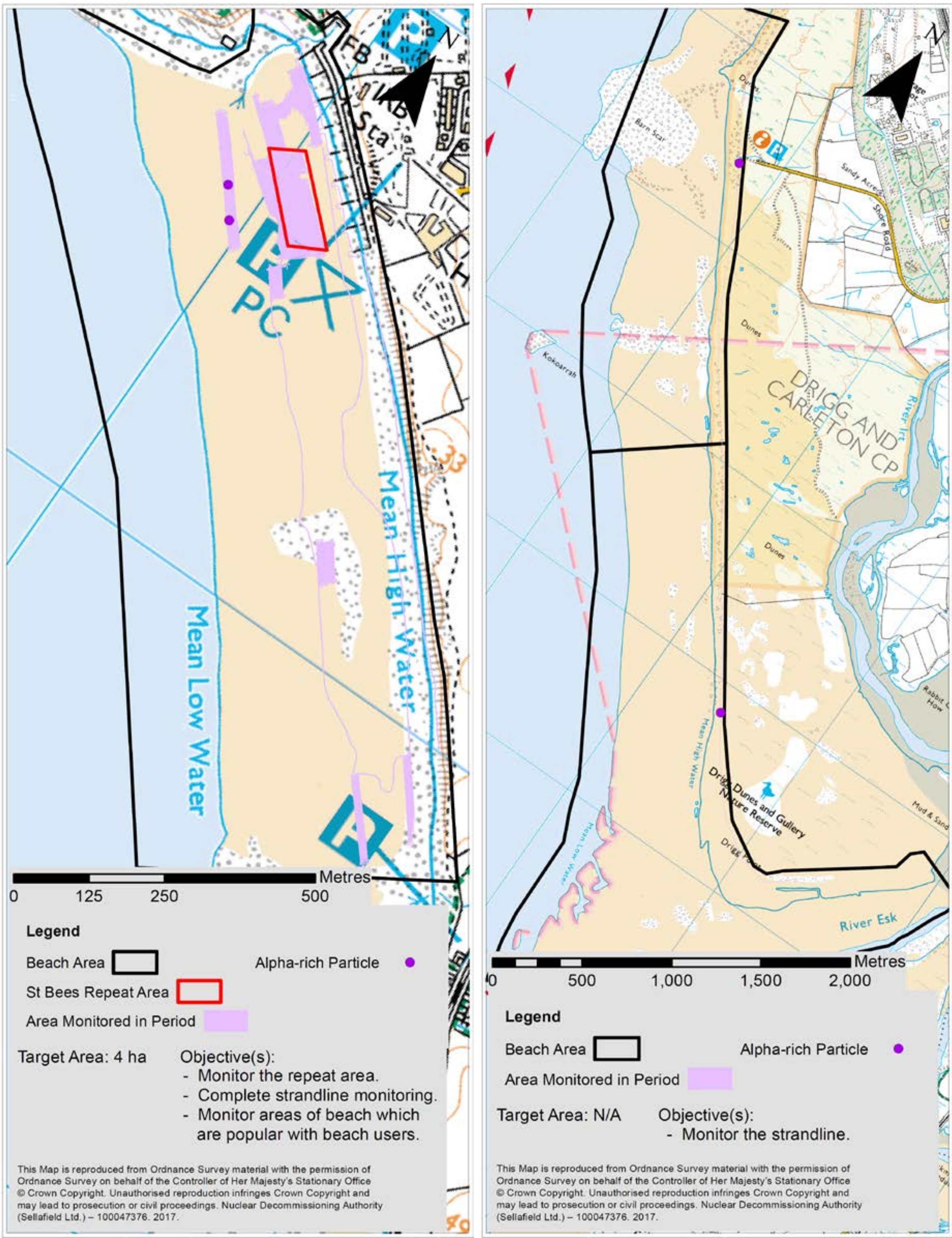

Figure A1.1 St. Bees and Drigg beach visits in January 2017.

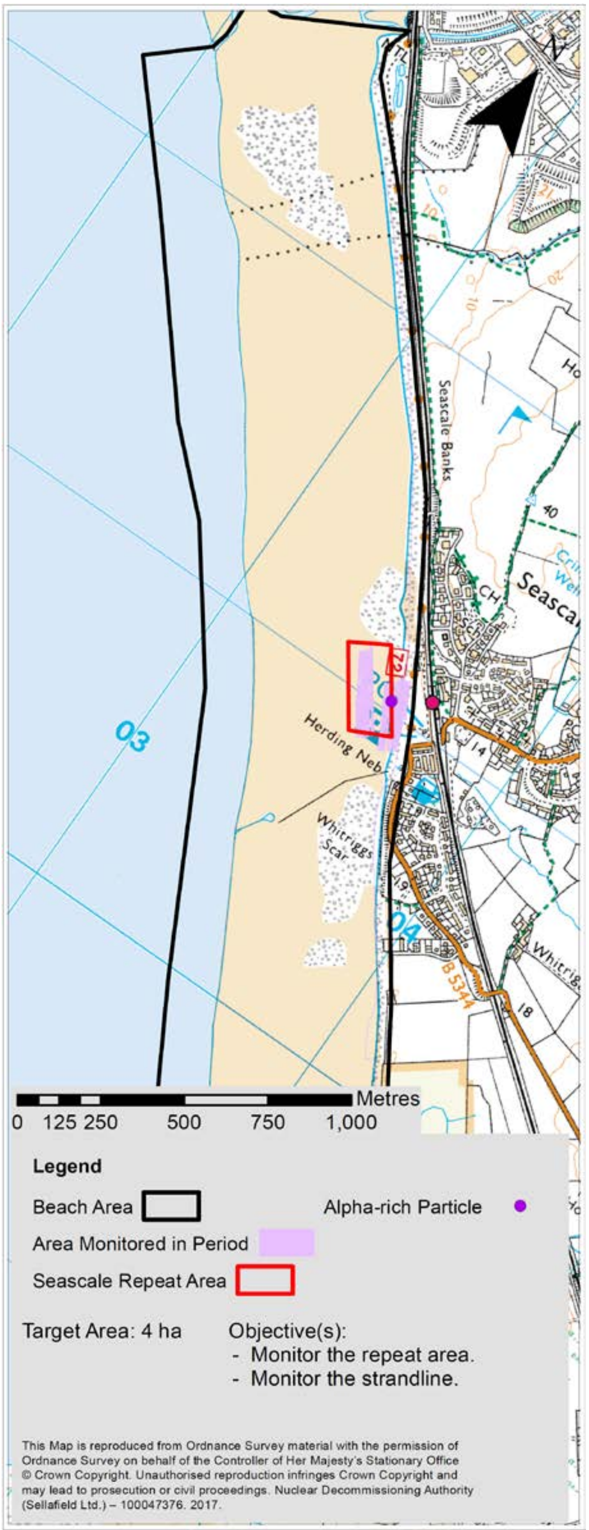

Figure A1.2 Seascale beach visit in January 2017.

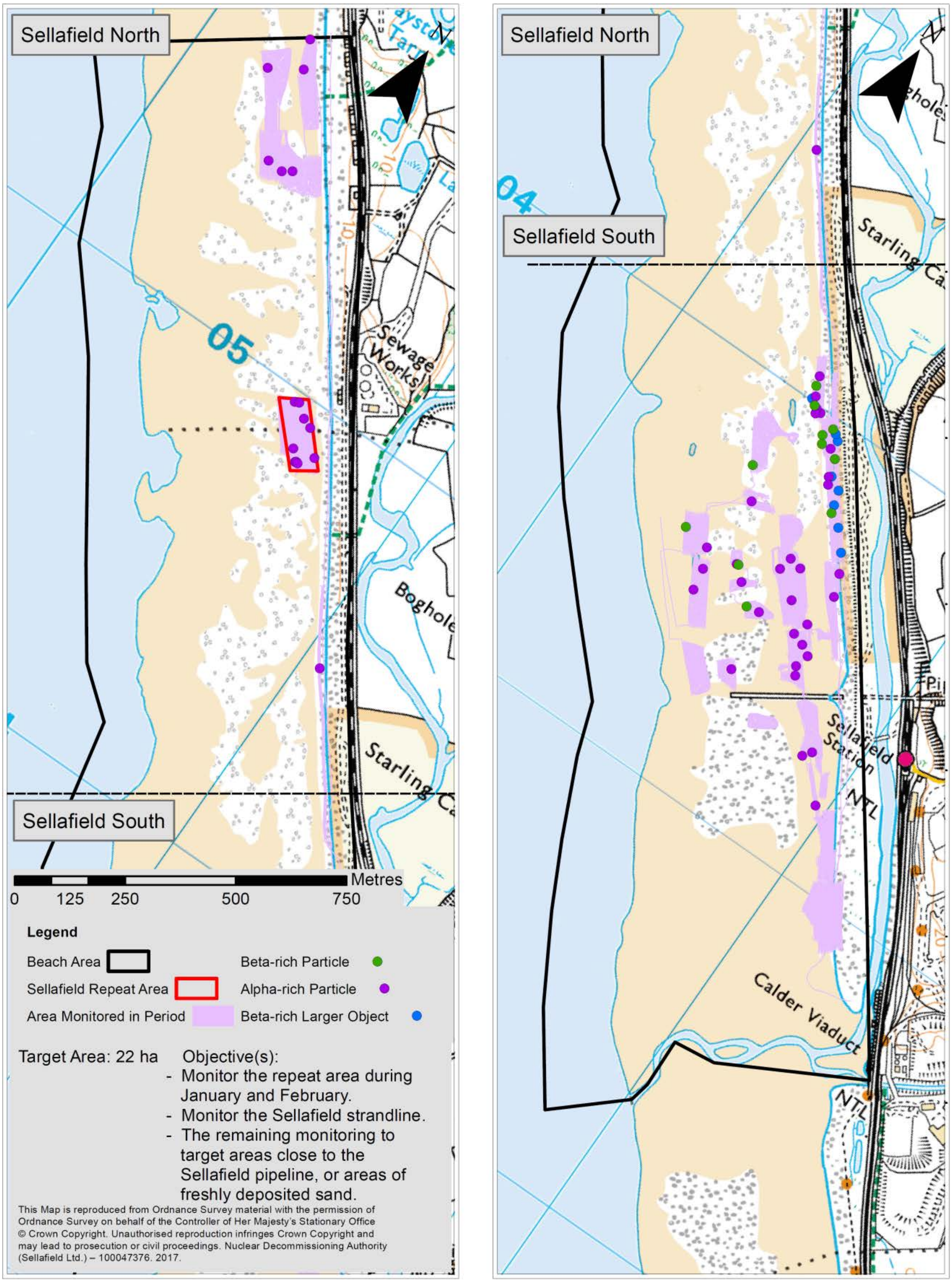

Figure A1.3 Sellafield beach visit in January and February 2017.

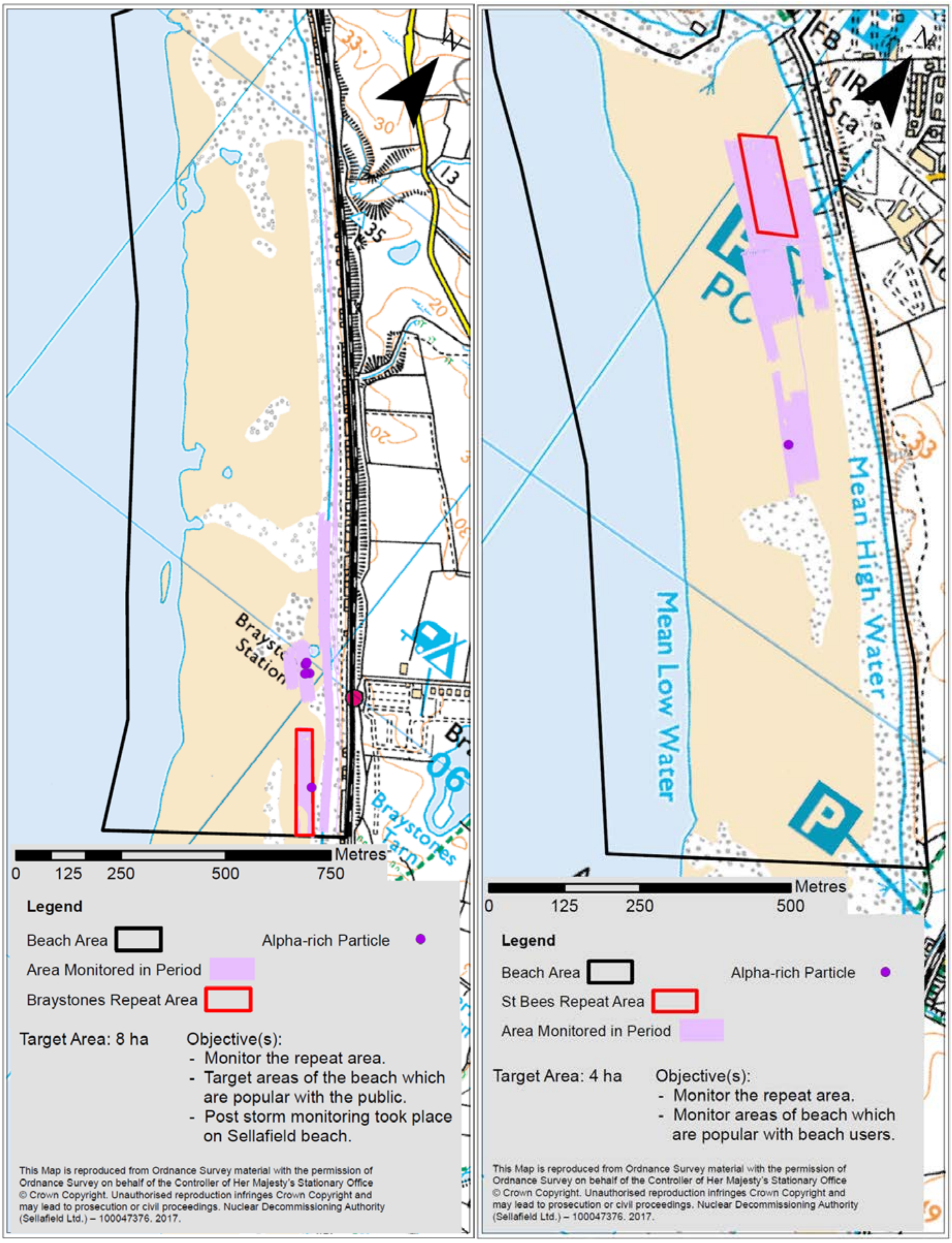

Figure A1.4 Braystones and St. Bees beach visits in February and March 2017.

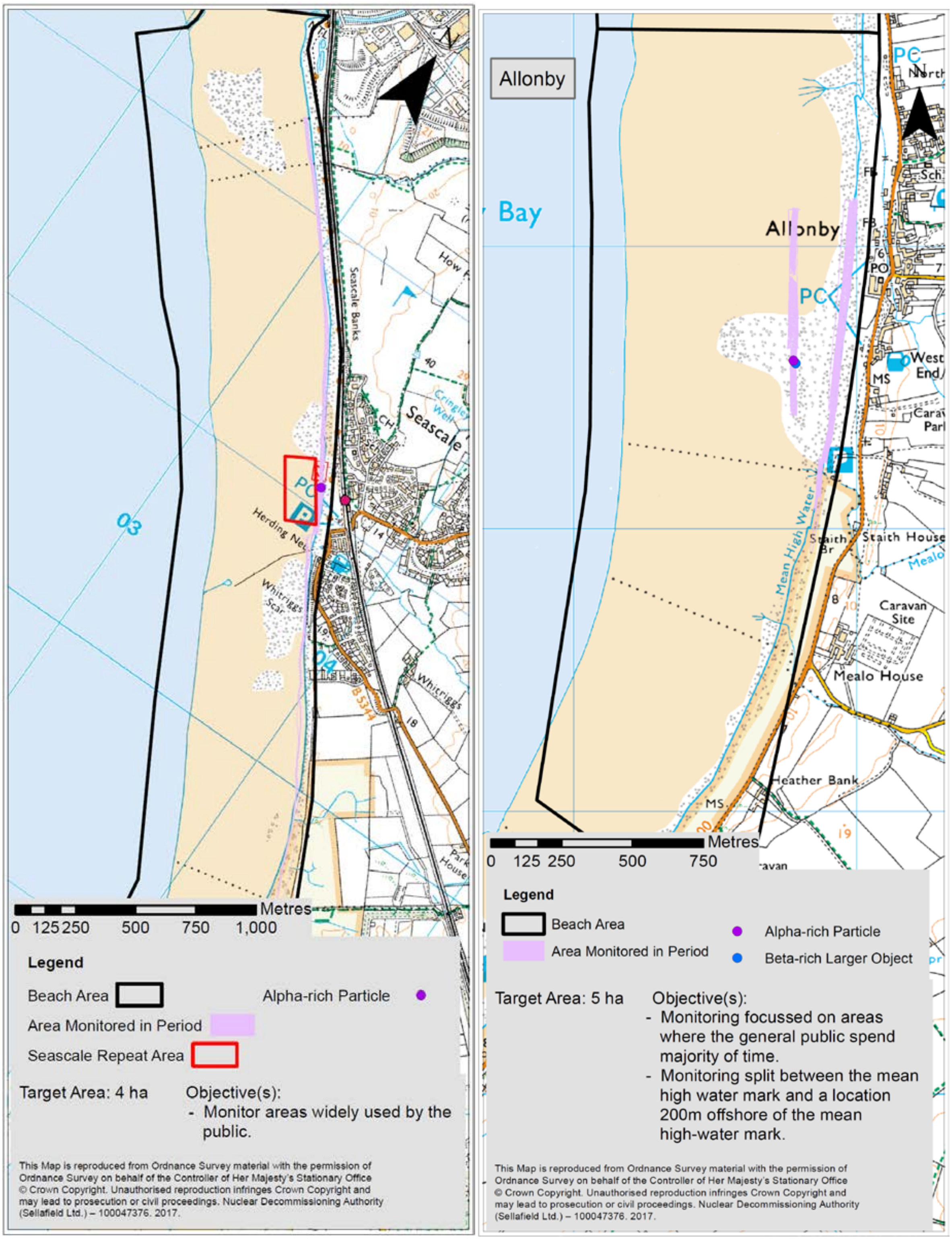

Figure A1.5 Seascale and Allonby beach visits in March and April 2017.

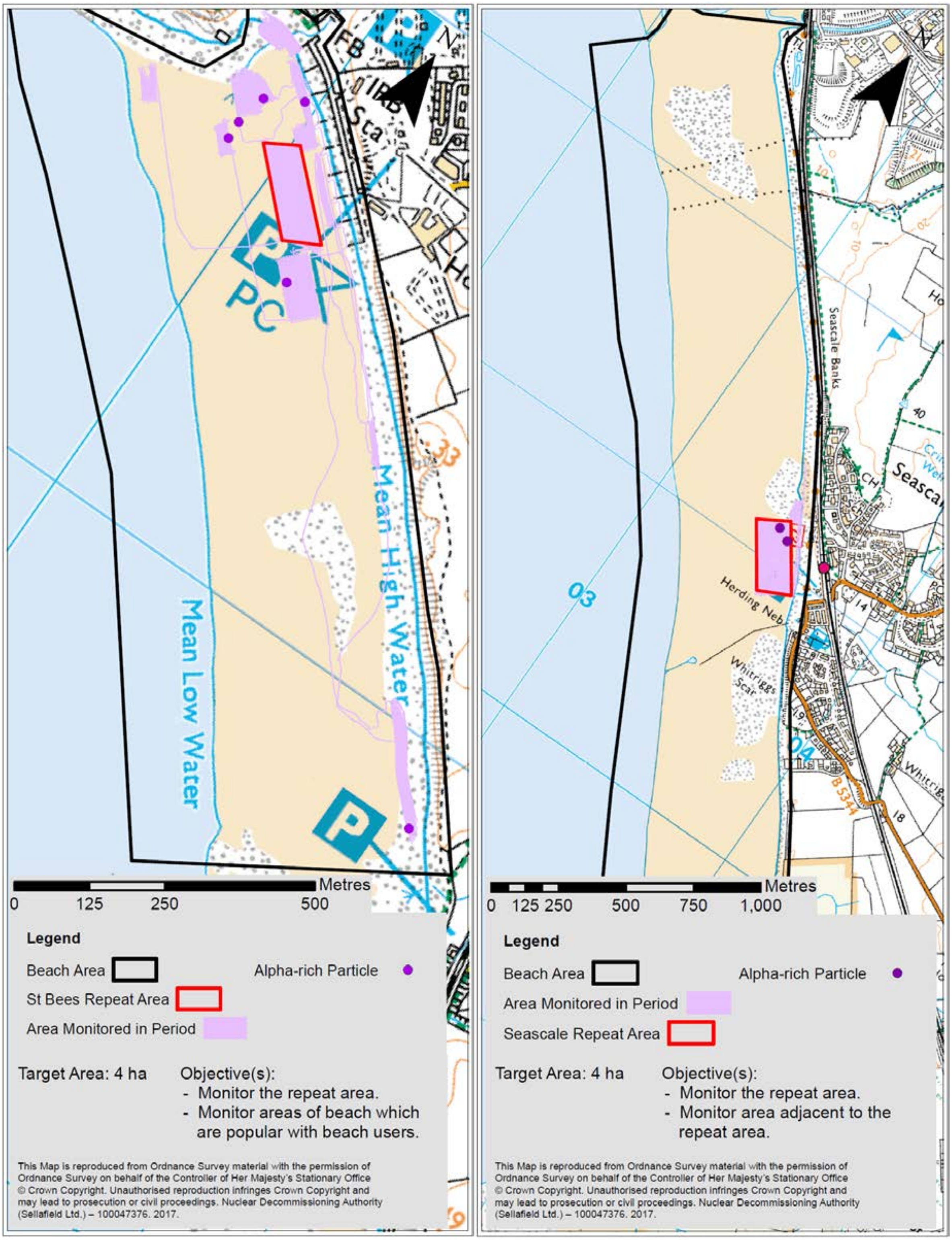

Figure A1.6 St. Bees and Seascale beach visits in April and May 2017.

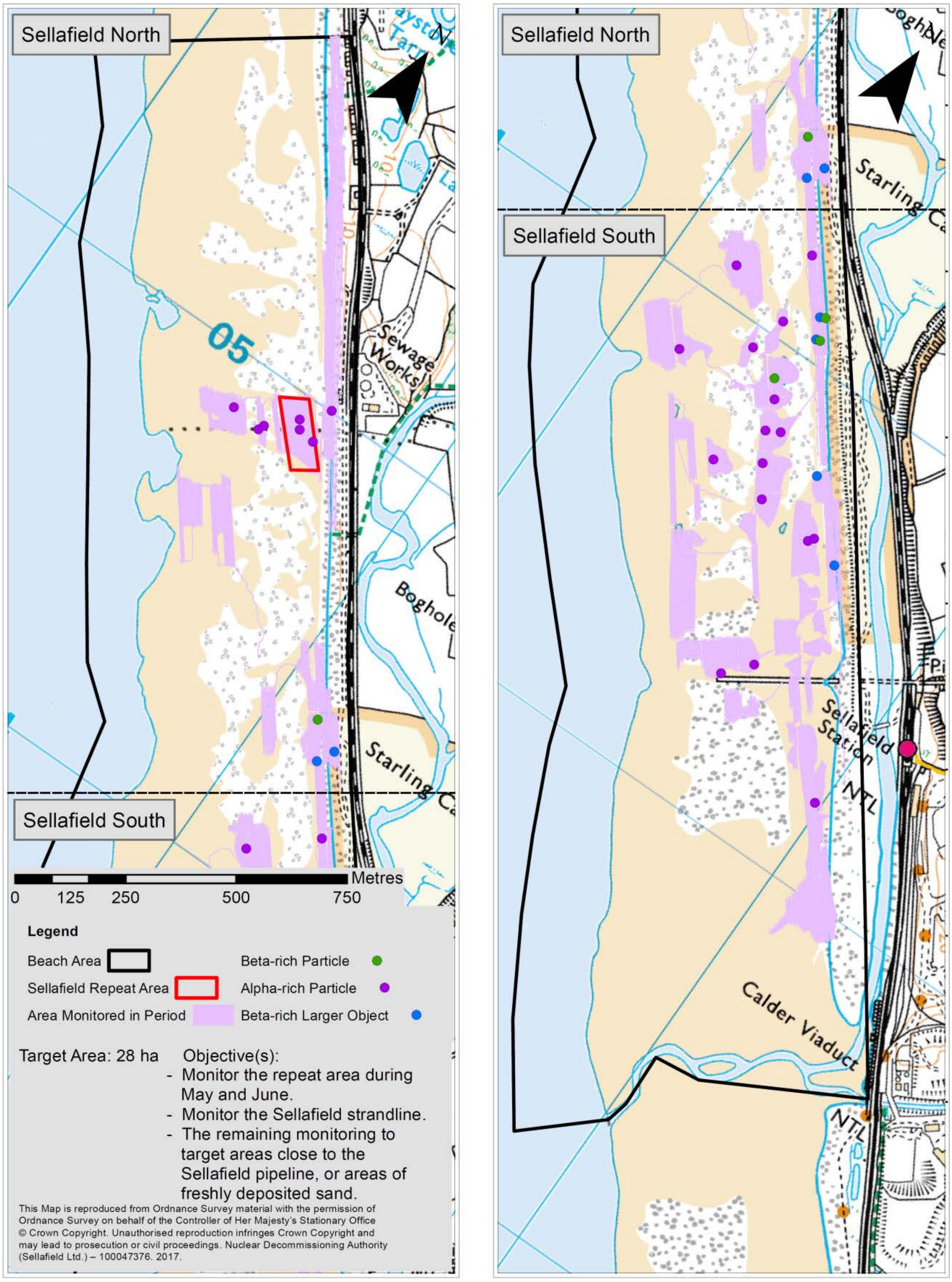

Figure A1.7 Sellafield beach visit in May and June 2017.

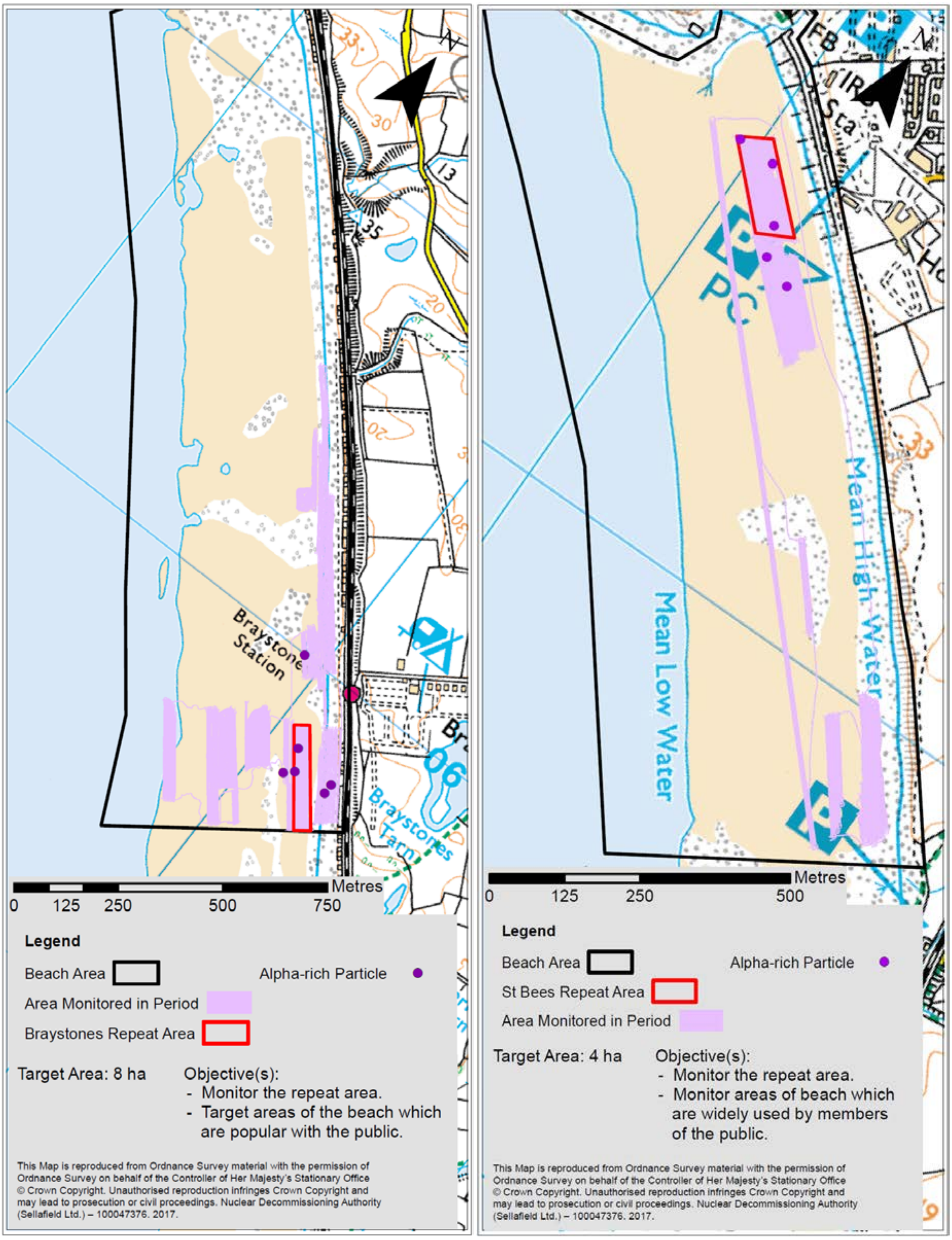

Figure A1.8 Braystones and St. Bees beach visits in June and July 2017.

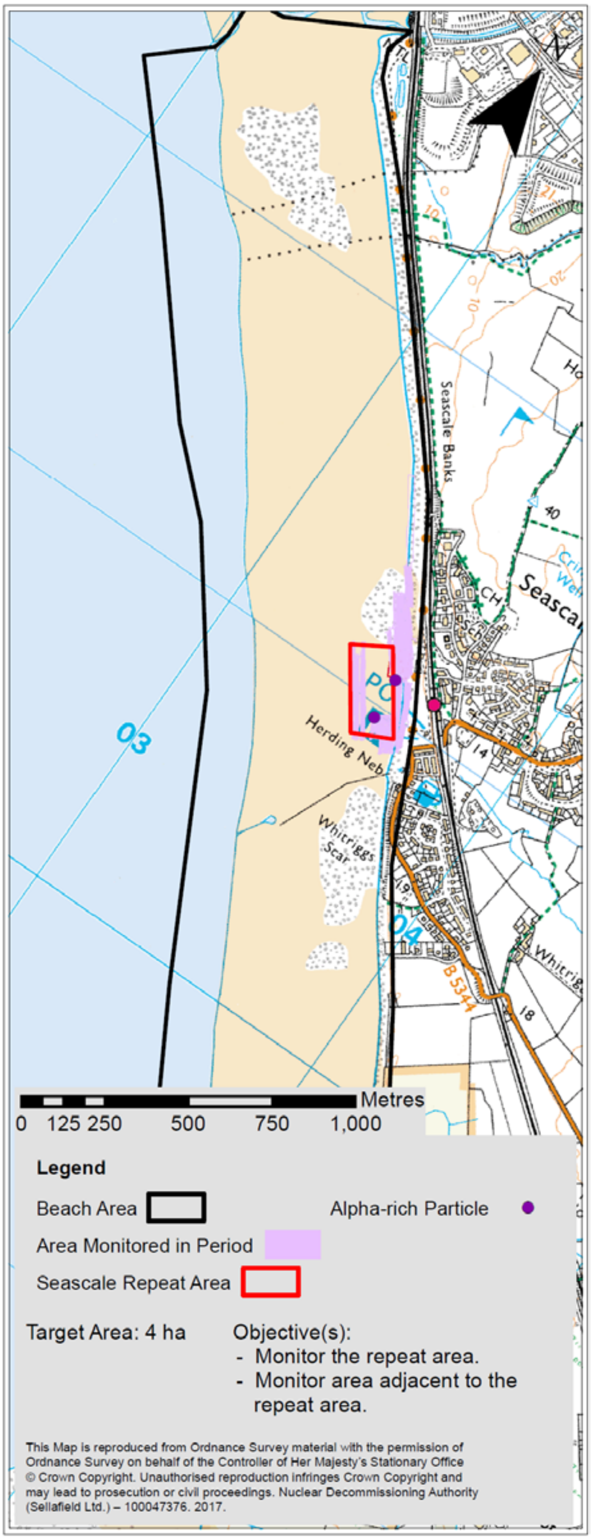

Figure A1.9 Seascale beach visit in July 2017.

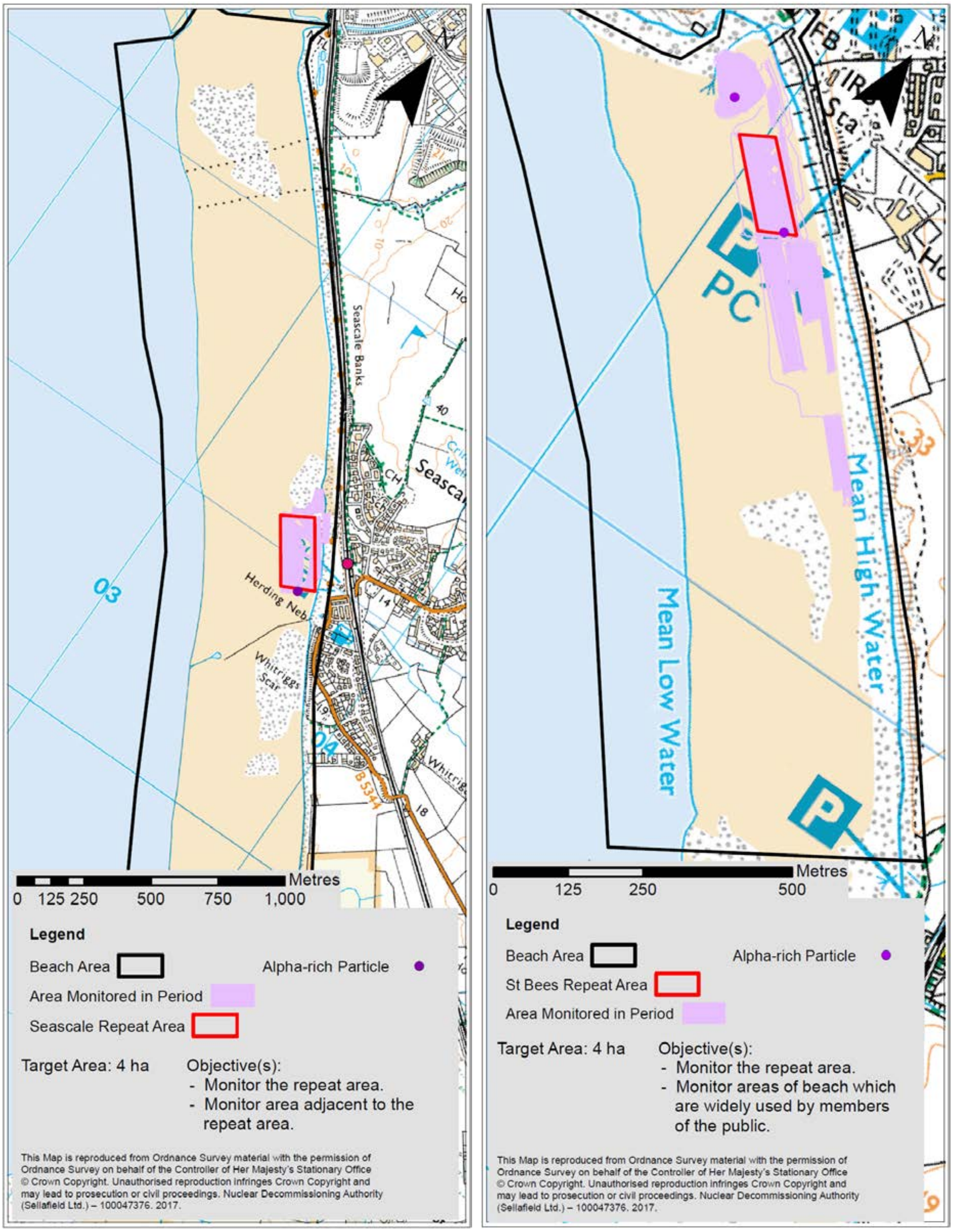

Figure A1.10 Seascale and St. Bees beach visits in September 2017.

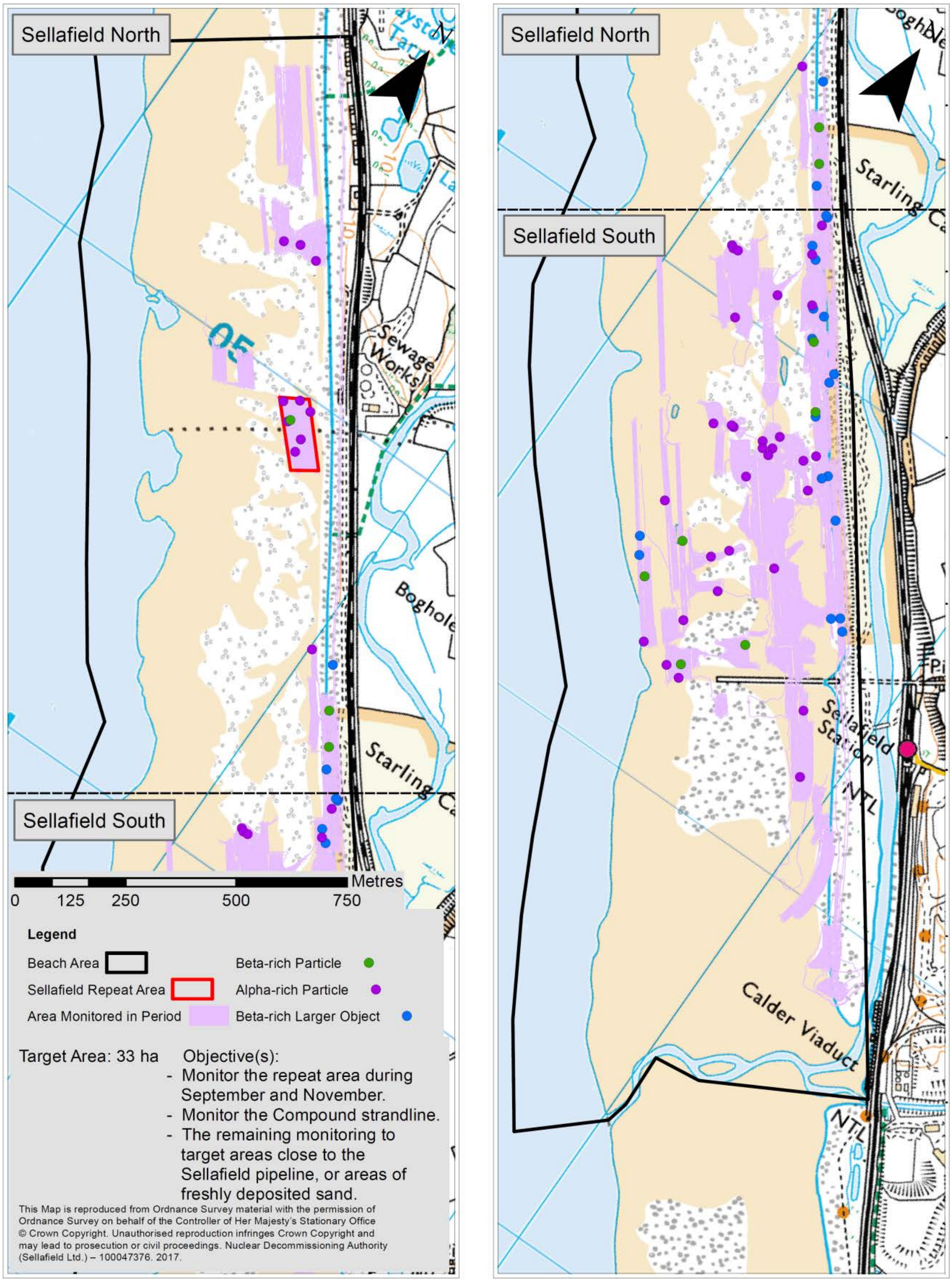

Figure A1.11 Sellafield beach visit in September, October, November and December 2017.

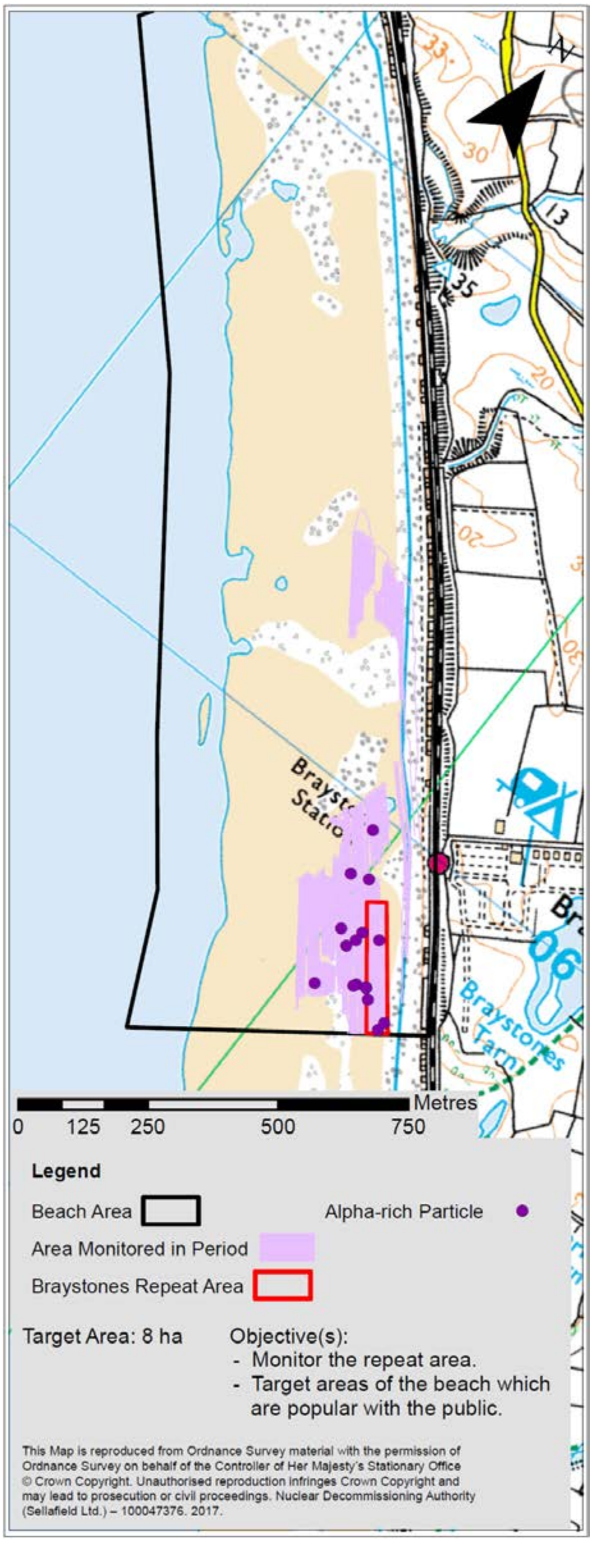

Figure A1.12 Braystones beach visit in December 2017.

Appendix 2: Summary Monitoring Data to the end of December 2017

Table A2.1 Total area monitored and finds by category and beach to the end of December 2017.

Beach location	Area covered ha	Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	^{60}Co rich particle	^{60}Co rich larger object	Total particles found	Total larger objects found
Allonby	88.1	14	0	2	1	0	0	16	1
Workington	24.0	5	0	1	1	0	0	6	1
Harrington	8.6	4	0	0	0	0	0	4	0
Whitehaven	8.8	8	0	1	0	0	0	9	0
St. Bees	360.6	246	0	15	0	2	0	263	0
Braystones	357.3	424	0	35	0	4	0	463	0
Sellafield	666.8	1098	6	312	683	8	2	1418	691
Seascale	347.6	68	0	23	3	0	1	91	4
Drigg	142.6	25	0	2	1	0	1	27	2
TOTAL [1]	2004.3	1892	6	391	689	14	4	2297	699

Note 1:The total area excludes monitoring from other beach areas (Southerness 14.3 ha, Goatwell Bay 5.8 ha, Parton 1.9 ha, Nethertown 2.5 ha and Silecroft 12.1 ha). Including this additional area gives an overall total of 2040.8 ha.

Table A2.2 Particle and larger object activity summary by category and monitoring system to the end of December 2017.

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	854	599	206	275	11	6	1
No. of particles	59	980	854	190	103	98	7	6	1
No. of larger objects	3	3	0	409	103	177	4	0	0
Particle Mean Am-241	7.82E+04	3.00E+04	2.58E+04	3.72E+02	5.45E+02	2.22E+02	-	-	-
Particle Max. Am-241	6.34E+05	2.52E+05	1.46E+05	1.15E+03	1.63E+03	7.17E+02	-	-	-
Number of Particles Containing Am-241	59	980	854	17	11	15	0	0	0
Larger Object Mean Am-241	1.74E+04	2.40E+05	-	7.62E+02	4.15E+02	5.81E+02	4.48E+03	-	-
Larger Object Max. Am-241	3.54E+04	6.18E+05	-	4.99E+03	1.17E+03	5.27E+03	4.48E+03	-	-
Number of Larger Objects Containing Am-241	3	3	0	59	14	43	1	0	0
Particle Mean Cs-137	4.09E+01	1.99E+01	3.02E+02	1.51E+04	1.81E+04	2.29E+04	-	8.41E+01	-
Particle Max. Cs-137	6.09E+01	3.36E+01	7.38E+03	6.52E+04	2.92E+05	1.86E+05	-	8.41E+01	-
Number of Particles Containing Cs-137	2	7	25	190	103	98	0	1	0
Larger Object Mean Cs-137	7.04E+03	5.46E+01	-	3.94E+04	5.94E+04	8.39E+04	8.17E+01	-	-
Larger Object Max. Cs-137	7.20E+03	5.46E+01	-	8.75E+05	1.04E+06	3.73E+06	8.17E+01	-	-
Number of Larger Objects Containing Cs-137	2	1	0	409	103	177	1	0	0
Particle Mean Co-60	8.85E+00	1.03E+01	-	7.91E+01	-	-	1.37E+04	7.35E+03	1.09E+04
Particle Max. Co-60	8.85E+00	1.65E+01	-	2.42E+02	-	-	1.97E+04	2.38E+04	1.09E+04
Number of Particles Containing Co-60	1	7	0	4	0	0	7	6	1
Larger Object Mean Co-60	- [1]	-	-	1.06E+02	-	-	1.37E+04	-	-
Larger Object Max. Co-60	-	-	-	5.33E+02	-	-	2.35E+04	-	-
Number of Larger Objects Containing Co-60	0	0	0	7	0	0	4	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

Table A2.3 Total area monitored and finds by category, beach and calendar year (years reported only when monitoring has been performed).

Beach Location	Calendar Year	Area Monitored in Hectares	Find category & Type							
			Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	^{60}Co rich particle	^{60}Co rich larger object	Excess beta particle	Excess beta larger object
Allonby	2008	10.9	0	0	1	0	0	0	0	0
	2010	7.5	0	0	0	0	0	0	0	0
	2011	8.7	1	0	0	0	0	0	0	0
	2012	10.5	2	0	0	0	0	0	0	0
	2013	8.5	1	0	0	0	0	0	0	0
	2014 Synergy	2.8	2	0	0	0	0	0	0	0
	2014 Synergy 2	10.9	7	0	1	0	0	0	0	0
	2015	12.6	0	0	0	0	0	0	0	0
	2016	10.7	0	0	0	0	0	0	0	0
	2017	5.1	1	0	0	1	0	0	0	0
Workington	2008	10.5	0	0	1	0	0	0	0	0
	2012	3.2	1	0	0	0	0	0	0	0
	2013	5.8	1	0	0	0	0	0	0	0
	2014 Synergy 2	3.4	2	0	0	1	0	0	0	0
	2015	1.0	1	0	0	0	0	0	0	0
Harrington	2010	2.5	2	0	0	0	0	0	0	0
	2011	2.0	1	0	0	0	0	0	0	0
	2012	1.5	1	0	0	0	0	0	0	0
	2014 Synergy	0.9	0	0	0	0	0	0	0	0
	2014 Synergy 2	0.8	0	0	0	0	0	0	0	0
	2015	0.9	0	0	0	0	0	0	0	0
Whitehaven	2008	1.5	0	0	0	0	0	0	0	0
	2010	5.3	8	0	1	0	0	0	0	0
	2011	2.0	0	0	0	0	0	0	0	0

Beach Location	Calendar Year	Area Monitored in Hectares	Find category & Type							
			Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	^{60}Co rich particle	^{60}Co rich larger object	Excess beta particle	Excess beta larger object
St. Bees	2007	26.0	2	0	4	0	0	0	1	0
	2008	43.1	1	0	2	0	0	0	0	0
	2009 Pre-Synergy	38.6	1	0	2	0	1	0	0	0
	2009 Post-Synergy	14.5	0	0	0	0	0	0	0	0
	2010	37.8	45	0	2	0	0	0	0	0
	2011	30.4	42	0	2	0	0	0	0	0
	2012	30.3	14	0	1	0	0	0	0	0
	2013	37.8	31	0	0	0	0	0	0	0
	2014 Synergy	10.7	6	0	0	0	0	0	0	0
	2014 Synergy 2	26.5	33	0	1	0	0	0	0	0
	2015	20.6	30	0	1	0	0	0	0	0
	2016	22.1	25	0	0	0	1	0	0	0
	2017	22.2	16	0	0	0	0	0	0	0
Braystones	2007	18.7	1	0	4	0	0	0	0	0
	2008	19.2	0	0	3	0	0	0	0	0
	2009 Pre-Synergy	21.4	2	0	2	0	0	0	0	0
	2009 Post-Synergy	15.1	25	0	2	0	0	0	0	0
	2010	63.7	131	0	11	0	2	0	0	0
	2011	45.1	46	0	3	0	0	0	0	0
	2012	42.2	38	0	4	0	1	0	0	0
	2013	35.5	51	0	3	0	1	0	0	0
	2014 Synergy	12.4	8	0	2	0	0	0	0	0
	2014 Synergy 2	16.6	48	0	0	0	0	0	0	0
	2015	20.6	21	0	1	0	0	0	0	0
	2016	25.3	26	0	0	0	0	0	0	0
	2017	21.6	27	0	0	0	0	0	0	0

Beach Location	Calendar Year	Area Monitored in Hectares	Find category & Type							
			Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	^{60}Co rich particle	^{60}Co rich larger object	Excess beta particle	Excess beta larger object
Sellafield	2006	4.8	0	0	2	7	0	0	0	0
	2007	34.8	19	1	52	162	1	1	5	0
	2008	113.8	17	1	67	192	3	0	9	0
	2009 Pre-Synergy	41.6	9	1	31	44	2	1	4	0
	2009 Post-Synergy	14.3	31	1	3	8	0	0	0	0
	2010	50.9	141	2	17	41	0	0	0	0
	2011	43.4	118	0	15	20	0	0	0	0
	2012	37.0	77	0	16	16	1	0	0	0
	2013	43.6	101	0	15	13	1	0	0	0
	2014 Synergy	13.1	6	0	2	5	0	0	0	0
	2014 Synergy 2	27.1	150	0	27	36	0	0	0	0
	2015	79.7	198	0	22	38	0	0	0	0
	2016	82.3	117	0	19	67	0	0	0	0
	2017	80.4	114	0	24	34	0	0	0	0
Seascale	2007	23.7	0	0	6	0	0	1	2	0
	2008	53.3	3	0	5	3	0	0	1	0
	2009 Pre-Synergy	49.6	1	0	6	0	0	0	3	0
	2009 Post-Synergy	20.4	2	0	3	0	0	0	2	0
	2010	32.7	14	0	0	0	0	0	0	0
	2011	35.7	3	0	0	0	0	0	0	0
	2012	14.7	6	0	0	0	0	0	0	0
	2013	12.7	6	0	1	0	0	0	0	0
	2014 Synergy	8.6	4	0	0	0	0	0	0	0
	2014 Synergy 2	30.7	14	0	2	0	0	0	0	0
	2015	16.2	7	0	0	0	0	0	0	0
	2016	27.7	1	0	0	0	0	0	0	0
	2017	21.6	7	0	0	0	0	0	0	0

Beach Location	Calendar Year	Area Monitored in Hectares	Find category & Type							
			Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	^{60}Co rich particle	^{60}Co rich larger object	Excess beta particle	Excess beta larger object
Drigg	2007	19.0	2	0	1	1	0	1	0	0
	2008	34.5	1	0	1	0	0	0	0	0
	2009 Pre-Synergy	0.01	0	0	0	0	0	0	0	0
	2009 Post-Synergy	0.02	0	0	0	0	0	0	0	0
	2010	49.8	10	0	0	0	0	0	0	0
	2011	4.7	1	0	0	0	0	0	0	0
	2012	14.9	2	0	0	0	0	0	0	0
	2013	4.9	0	0	0	0	0	0	0	0
	2014 Synergy	4.3	0	0	0	0	0	0	0	0
	2014 Synergy 2	4.9	4	0	0	0	0	0	0	0
	2015	3.4	1	0	0	0	0	0	0	0
	2016	1.1	2	0	0	0	0	0	0	0
	2017	1.1	2	0	0	0	0	0	0	0
Total	2007 - 2017	2004.3	1892	6	391	689	14	4	27	0

Table A2.4 Find rates by category, beach and calendar year (years reported only when monitoring has been performed)

Beach Location	Financial Year	Find rate by Find category & Type (per ha)			
		Area Monitored in Hectares	Alpha rich particle	Beta rich particle	Beta rich larger object
Allonby	2008	10.9	No Finds	<0.1	No Finds
	2010	7.5	IA	IA	IA
	2011	8.7	IA	IA	IA
	2012	10.5	<1	No Finds	No Finds
	2013	8.5	IA	IA	IA
	2014 Synergy	2.8	IA	IA	IA
	2014 Synergy 2	10.9	<1	<0.1	No Finds
	2015	12.6	No Finds	No Finds	No Finds
	2016	10.7	No Finds	No Finds	No Finds
	2017	5.1	IA	IA	IA
Workington	2008	10.5	No Finds	<0.1	No Finds
	2012	3.2	IA	IA	IA
	2013	5.8	IA	IA	IA
	2014 Synergy 2	3.4	IA	IA	IA
	2015	1.0	IA	IA	IA
Harrington	2010	2.5	IA	IA	IA
	2011	2.0	IA	IA	IA
	2012	1.5	IA	IA	IA
	2014 Synergy	0.9	IA	IA	IA
	2014 Synergy 2	0.8	IA	IA	IA
	2015	0.9	IA	IA	IA
Whitehaven	2008	1.5	IA	IA	IA
	2010	5.3	IA	IA	IA
	2011	2.0	IA	IA	IA
St. Bees	2007	26.0	<0.1	<1	No Finds
	2008	43.1	<0.1	<0.1	No Finds
	2009 Pre-Synergy	38.6	<0.1	<0.1	No Finds
	2009 Post-Synergy	14.5	No Finds	No Finds	No Finds
	2010	37.8	1	<0.1	No Finds
	2011	30.4	1	<0.1	No Finds
	2012	30.3	<1	<0.1	No Finds
	2013	37.8	<1	No Finds	No Finds
	2014 Synergy	10.7	<1	No Finds	No Finds
	2014 Synergy 2	26.5	1	<0.1	No Finds
	2015	20.6	1	<0.1	No Finds
	2016	22.1	1	No Finds	No Finds
	2017	22.2	<1	No Finds	No Finds

Beach Location	Financial Year	Find rate by Find category & Type (per ha)			
		Area Monitored in Hectares	Alpha rich particle	Beta rich particle	Beta rich larger object
Braystones	2007	18.7	<0.1	<1	No Finds
	2008	19.2	No Finds	<1	No Finds
	2009 Pre-Synergy	21.4	<0.1	<0.1	No Finds
	2009 Post-Synergy	15.1	2	<1	No Finds
	2010	63.7	2	<1	No Finds
	2011	45.1	1	<0.1	No Finds
	2012	42.2	<1	<0.1	No Finds
	2013	35.5	1	<0.1	No Finds
	2014 Synergy	12.4	<1	<0.1	No Finds
	2014 Synergy 2	16.6	3	No Finds	No Finds
	2015	20.6	1	<0.1	No Finds
	2016	25.3	1	No Finds	No Finds
	2017	21.6	1	No Finds	No Finds
Sellafield	2006	4.8	IA	IA	IA
	2007	34.8	<1	1	5
	2008	113.8	<1	<1	2
	2009 Pre-Synergy	41.6	<1	<1	1
	2009 Post-Synergy	14.3	2	<1	<1
	2010	50.9	3	<1	<1
	2011	43.4	3	<1	<1
	2012	37.0	2	<1	<1
	2013	43.6	2	<1	<1
	2014 Synergy	13.1	<1	<1	<1
	2014 Synergy 2	27.1	6	<1	1
	2015	79.7	2	<1	<1
	2016	82.3	1	<1	<1
	2017	80.4	1	<1	<1

Beach Location	Financial Year	Find rate by Find category & Type (per ha)			
		Area Monitored in Hectares	Alpha rich particle	Beta rich particle	Beta rich larger object
Seascale	2007	23.7	No Finds	<1	No Finds
	2008	53.3	<0.1	<0.1	<0.1
	2009 Pre-Synergy	49.6	<0.1	<1	No Finds
	2009 Post-Synergy	20.4	<0.1	<1	No Finds
	2010	32.7	<1	No Finds	No Finds
	2011	35.7	<0.1	No Finds	No Finds
	2012	14.7	<1	No Finds	No Finds
	2013	12.7	<1	<0.1	No Finds
	2014 Synergy	8.6	IA	IA	IA
	2014 Synergy 2	30.7	<1	<0.1	No Finds
	2015	16.2	<1	No Finds	No Finds
	2016	27.7	<0.1	No Finds	No Finds
	2017	21.6	<1	No Finds	No Finds
Drigg	2007	19.0	<1	<0.1	<0.1
	2008	34.5	<0.1	<0.1	No Finds
	2009 Pre-Synergy	0.01	IA	IA	IA
	2009 Post-Synergy	0.02	IA	IA	IA
	2010	49.8	<1	No Finds	No Finds
	2011	4.7	IA	IA	IA
	2012	14.9	<1	No Finds	No Finds
	2013	4.9	IA	IA	IA
	2014 Synergy	4.3	IA	IA	IA
	2014 Synergy 2	4.9	IA	IA	IA
	2015	3.4	IA	IA	IA
	2016	1.1	IA	IA	IA
	2017	1.1	IA	IA	IA

Notes: IA - Insufficient area coverage to estimate finds rates (<10 ha). "<1" denotes values between 0.1 and 0.99, "<0.1" denotes values between zero and 0.099.

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