Sellafield Ltd

Particles in the Environment

Annual Report for 2018 and Forward Programme

June 2019 **EM/2019/15**

This page is intentionally blank

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 2018 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 2019, summarises the forward strategy and presents the proposed monitoring programme for 2020 onwards including a reduction in the area monitored.

A total area of 159 hectares (ha) of Cumbrian beaches was surveyed in 2018, meeting the programme's specification. This identified 145 radioactive items, of which 128 were classified as particles (less than 2 mm in size) and 17 as larger objects (greater than 2 mm in size). A total of 121 of the finds were designated alpha rich, with higher ^{241}Am activity than ^{137}Cs activity and 24 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 (77%).

An analysis of the trends in find rates on the beaches identified that find rates for beta rich particles and larger objects have reduced over time on Sellafield beach. Further monitoring at this location is required in order to establish whether the reduction in find rates will be sustained. No statistically significant trends were identified for alpha rich particles. A detailed analysis of the influence of storm events established that peaks in particle and larger object find rates were not strongly influenced by storms.

The distributions of caesium-137 (^{137}Cs) and americium-241 (^{241}Am) activities for particles and larger objects recovered in 2018 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 2018 that exceeded the characterisation criteria specified by the EA and therefore required further detailed laboratory analysis. This characterisation identified the particle contained iron, aluminium and carbon, 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 current health risk assessment.

The work conducted during 2018 provides further evidence that the conclusions 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).

Table of Contents

List of Tables

List of Figures

1 Introduction

The overall objective of the Sellafield Ltd Particles in the Environment programme is to understand the nature of radioactive 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 2018 on the Particles in the Environment programme and sets out the schedule of work for 2019 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 and the agreed programme aims.

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

Section 4 details the progress made in 2018 on the beach monitoring programme.

Section 5 provides the analysis of the monitoring and find data gathered up to the end of the 2018.

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

Section 10 outlines the work programme and objectives for 2019 and the proposed programme for 2020 onwards.

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 during the beach visits and the location and broad categories of the beach finds.

Appendix 2 provides tabulated data from the beach monitoring programme compiled since the programme began in 2006.

2 Environment Agency Requirements

2.1 Radioactive Substance Act Permit

The Environment Agency (EA) has 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 EA requirements is included in the Compilation of Environment Agency Requirements, Approvals and Specifications (CEAR) which includes the following.

> *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 for 2018.

2.2 Intervention

The EA, Public Health England (PHE), the Food Standards Agency (FSA), Allerdale Borough Council (ABC) and Copeland Borough Council (CBC), 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 EA 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)

2.4 Programme aims and objectives

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 (Brown & Etherington, 2011; Etherington, et al., 2012; Oatway & Brown, 2015b) 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)

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

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

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

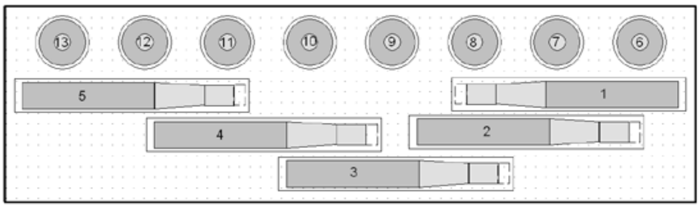
- Assess whether the conclusions of the health risk assessment remain valid (as detailed in Section 9).
- Monitor for abnormal radioactive material and remove in line with the principle of As Low As Reasonably Practicable (ALARP).

3 Detection Systems

The Groundhog Evolution system is used for particle detection on the beaches at Dounreay and was used at Sellafield up to August 2009. It was primarily designed to detect particles containing the radionuclides caesium-137 (^{137}Cs) and cobalt-60 (^{60}Co) as it has an array of five 76 x 400 mm sodium iodide (NaI) detectors which provide a continuous monitoring swathe of two metres.

The Groundhog Synergy system (used between August 2009 and May 2014) improved radiation transmission through the use of 2 mm thick carbon fibre detector cases and through the introduction of an additional eight low-energy Field Instrument for the Detection of Low Energy Radiation (FIDLER) detectors for the detection of americium-241 (^{241}Am). Each detector was mounted in a carbon fibre case which had a 0.4 mm thick detection window.

In May 2014 Nuvia Ltd commissioned the Groundhog Synergy2 system (Figure 1). The Synergy2 system was designed to further improve detection of ^{241}Am and strontium-90 / yttrium-90 (^{90}Sr/^{90}Y). The detection system of Synergy2 is physically the same as Synergy, except that it includes a thinner window of carbon fibre below the NaI detectors to improve the transmission of beta radiation. The Synergy2 system also includes additional ^{90}Sr alarms both for the NaI 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 quantitatively be achieved because detection of both beta particles and Bremsstrahlung radiation was possible.



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

Figure 1: Synergy2 detector layout.

The line of wind-blown debris or highest tideline (referred to as the strandline) between Drigg and St. Bees[1] is also surveyed. These surveys are conducted biannually and have been part of the wider environmental monitoring programme since 1983, applying a variety of detection techniques. These surveys were previously conducted using hand-held equipment however the Best Available Technique (BAT) was re-evaluated and identified that monitoring should be conducted using the Synergy2 vehicle based system (Sellafield Ltd, 2018a). The Environment Agency supported the revised BAT case and hence for 2018 the strandline was monitored using the vehicle-based detection system.

Monitoring of 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, was discontinued for the 2018 programme as there was no evidence of any increase in find rates within this area (Sellafield Ltd, 2018b).

[1] Monitoring is not conducted on Nethertown beach as the rocky foreshore cannot be safely monitored.

4 Monitoring Conducted During 2018

Information is presented in this section on the areas monitored; the number and types of finds recovered and their geographical distribution. The results from the 2018 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 Synergy2 monitoring are ^{137}Cs and ^{241}Am and to a lesser extent cobalt-60 (^{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.

A small number of radium-226 (^{226}Ra) finds have been detected since the beach monitoring programme began. All 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 2018

A programme of 152 hectares (ha) was developed and agreed with the EA to meet the objectives detailed in Section 2.4 (Sellafield Ltd, 2018b).

The 152 ha programme was split as follows:

- Sellafield programme (totalling 80 ha);
- Near-field programme (totalling 62 ha); and
- Far-field programme (totalling 10 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 2018.

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

Table 1: Planned area coverage (ha) for each beach in 2018.

Programme	Beach	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

4.2.1 Sellafield programme

A programme of 80 ha of 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 20 ha and 30 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
- Past monitoring efforts have seen a reduction in find numbers following the introduction of the various developments of the Groundhog system. 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 beach.

Regular monitoring of the 1 ha repeat area was discontinued on Sellafield beach for the 2018 programme as it was demonstrated that monitoring of a larger area closer to the pipeline would provide more useful information. This is particularly the case for beta rich finds as the repeat area was outside the zone they are found (Sellafield Ltd, 2018b).

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 regularly 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. 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 the high water mark 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 supports the statistical analysis of longer term trends as well as the characterisation of the finds. The results are discussed in Section 5.

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 of the beaches that are readily accessible.

4.2.3 Far-field programme

The far-field programme, totalling 10 ha, targets beaches with historically lower find rates. For 2018 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, although for 2018 a popular southerly area of Allonby beach was surveyed in order to check that find rates did not vary significantly along the beach.

4.2.4 Additional programme aims

Two periods of vehicle driven strandline monitoring were included to address the requirement to monitor the accessible areas between St. Bees Head and Drigg Point. This monitoring was conducted in March and September 2018.

The sequence of the beach monitoring programmes also considers 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 and to provide coverage of the high occupancy beaches close to the school holidays.

	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 2: Beach monitoring programme for 2018.

4.3 Beach Areas Monitored in 2018

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. 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 files that can be displayed on a map and provide 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. 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. All areas and find rates reported in this document use the Sellafield methodology.

4.3.2 Areas monitored in 2018

The beach monitoring programme for the 2018 calendar year was completed with a total area of 159 ha, against a programme target of 152 ha (Table 2, Figure 3 to Figure 6, Appendix 1 and Appendix 2).

Table 2 presents the area monitored in 2018 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 mark, excluding rocks and other inaccessible areas of the beach, and is provided purely for comparative purposes.

Comparing the information in Table 2 with Figure 2 illustrates that the total area monitored was higher than that originally included in the programme, with slightly more area being monitored at Sellafield, Braystones, Seascale and St. Bees 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 2018.

Programme	Monitoring area	Number of days	Area covered (ha)	Available area[$] (ha)	Monitoring as % of available
Sellafield	Sellafield	80	81	53	**152%**
Near-Field	Braystones	24	23	19	**122%**
	St. Bees	19	21	29	**74%**
	Seascale	19	22	82	**27%**
Far-Field	Allonby	7	10	137	**7%**
	Drigg	3	3	197	**2%**
Total		**152**	**159**	**516**	**31%**

[$] The "available area" is a simple estimate of the maximum area that could be monitored on each beach by the monitoring vehicle.

4.4 Finds Recovered in 2018

A total of 145 finds were recovered during the 2018 monitoring programme from along the Cumbrian coast (Table 3). Of these, 128 were classified as particles and the remaining 17 were classified as larger objects. The locations of these finds are shown in Figure 3 to Figure 6. The maps included in Appendix 1 show the distribution of beach finds for all beaches and the areas monitored during the visits.

Most beach finds were recovered from Sellafield (77%), Braystones (8%) and St. Bees (8%) beaches during 2018. More than 123 ha of beach area were monitored at these three locations, accounting for more than 77% of the total area surveyed in 2018. Of the 128 particles recovered, the majority were detected on Sellafield beach, with most of the others being from Braystones and St. Bees. A total of 17 radioactive larger objects were detected and all of these were recovered from Sellafield beach (Table 3 and Figure 3).

Over 83% of all finds recovered in 2018 were classified as alpha rich. There were 24 finds classified as beta rich in 2018. None of the finds that were recovered were classified as cobalt rich.

Table 3: Particle and larger object beach finds recovered during 2018.

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	88	6	0	0	17	0	111
Near-field	Braystones	10	1	0	0	0	0	11
	St. Bees	12	0	0	0	0	0	12
	Seascale	9	0	0	0	0	0	9
Far-field	Allonby	1	0	0	0	0	0	1
	Drigg	1	0	0	0	0	0	1
Total		**121**	**7**	**0**	**0**	**17**	**0**	**145**

4.4.1 Sellafield beach finds

A total of 111 finds (94 particles, 17 larger objects) were recovered from Sellafield beach during 2018, compared with 172 finds in 2017. Of the particle finds, 88 were classified as alpha rich and 6 as beta rich. All 17 of the larger objects recovered were classed as beta rich. The area monitored (81 ha) is comparable with that monitored in 2017 (80 ha).

Monitoring of Sellafield beach during 2018 continued to focus on areas identified as having the highest rates of alpha and beta rich finds, to establish if intensive monitoring of these areas can impact the find rates. The number of beta rich finds detected on Sellafield beach in 2018 reduced when compared with the previous year. Compared to previous years there were reductions in the numbers of beta rich particles (6 in 2018, 24 in 2017, 19 in 2016) and larger objects (17 in 2018, 34 in 2017, 67 in 2016). The find rates at Sellafield beach are analysed in more detail in Section 5.2.

4.4.2 Near-field beach finds

A total of 23 ha was monitored at Braystones, with 10 alpha rich particles and one beta rich particle (the first beta rich particle since 2015 on this beach) detected in 2018. Alpha rich particle find rates at Braystones were lower than the previous years (0.4 finds/ha in 2018, 1.3 finds/ha in 2017 and 1.0 finds/ha in 2016).

Five separate surveys were scheduled for St. Bees throughout 2018, with 19 days of monitoring completed during this period. A total of 21 ha of beach were surveyed with 12 alpha rich particles detected. There was a reduction in the number of finds detected at St. Bees in 2018 when compared with the previous year (16 particles were recovered in 2017). Finds rates at St. Bees are at the lowest levels since the introduction of Synergy2.

Monitoring at Seascale was conducted over 19 days during 2018 with 9 alpha rich particles being detected from a monitoring area of 22 ha. Find rates at Seascale were slightly higher than those from 2017 (7 finds from 22 ha).

4.4.3 Far-field beach finds

A single survey took place at Allonby during April 2018. This was conducted as part of the far-field programme to provide reassurance for areas where the general public spend the majority of their time (Figure 6). A total of 10 ha was monitored during the survey with one find being detected (an alpha rich particle). This find rate is in line with long term find rates at this beach.

There was a single alpha rich particle recovered from Drigg beach during the annual vehicle driven strandline monitoring in September 2018. 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).

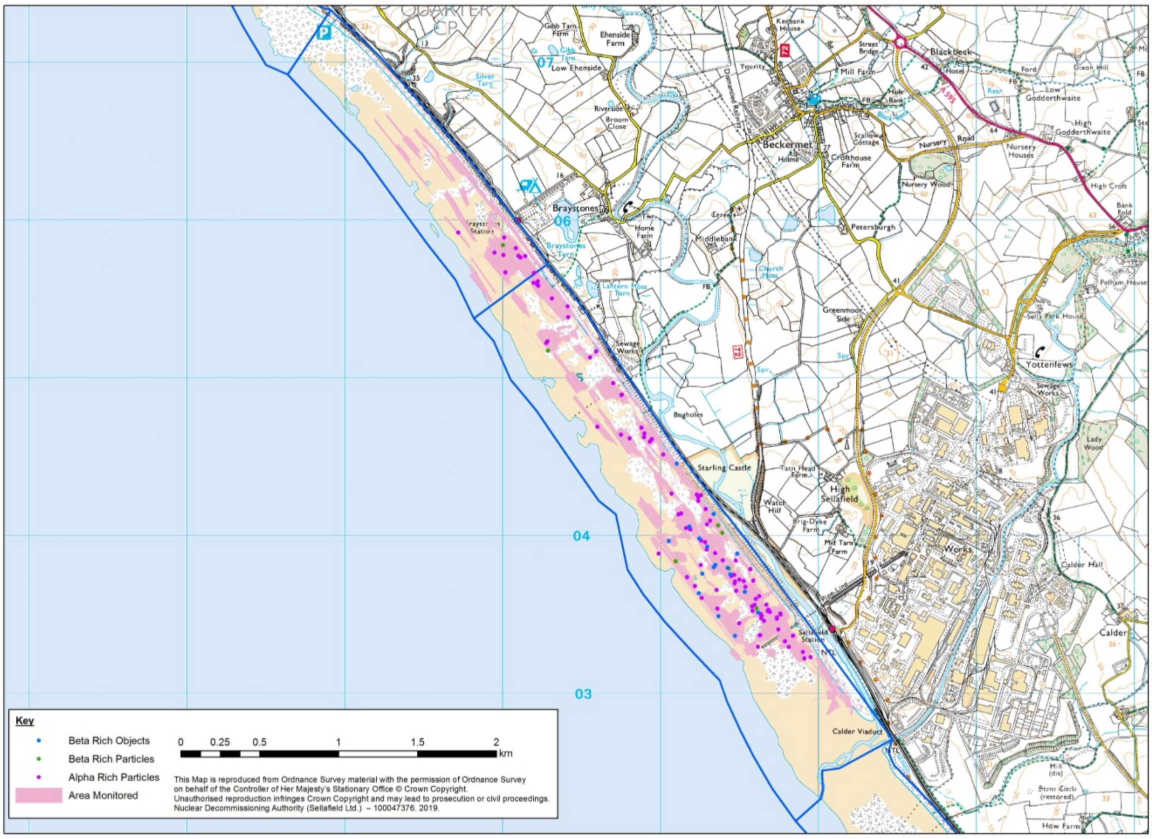


Figure 3: Sellafield and Braystones beach find locations and areas monitored in 2018.

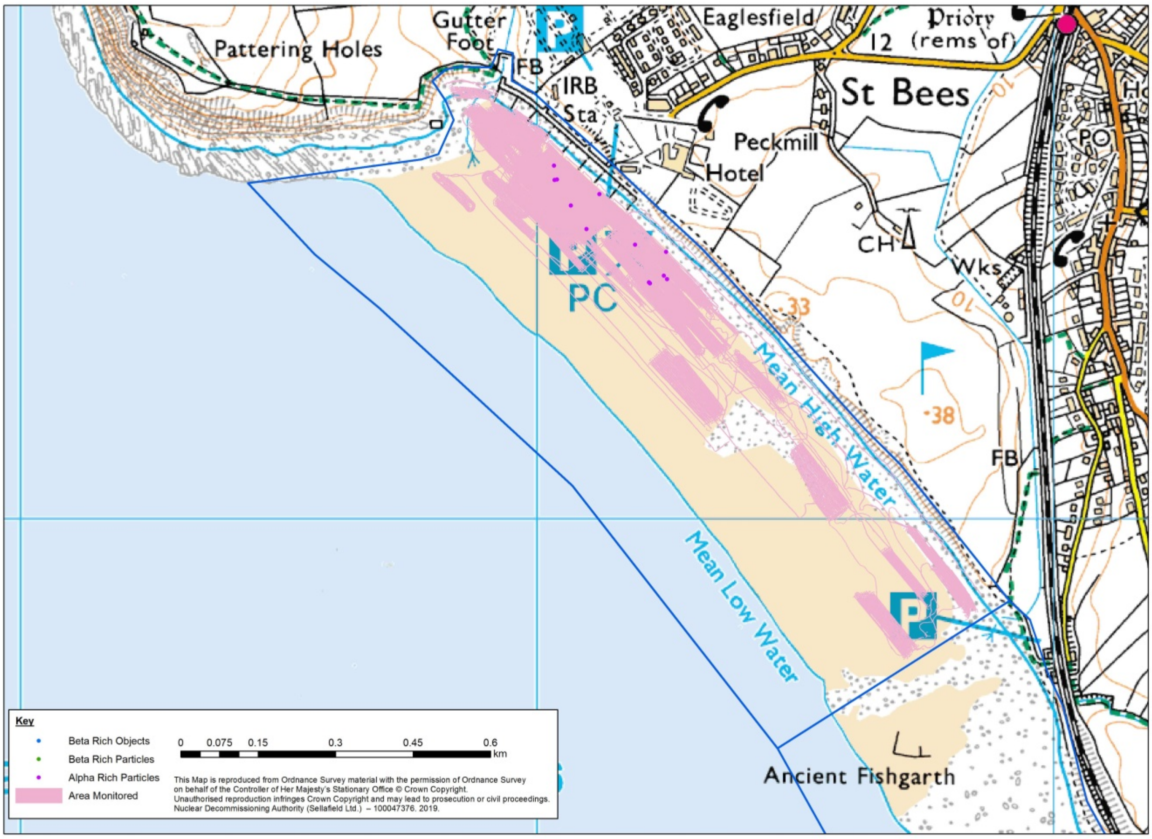


Figure 4: St. Bees beach find locations and areas monitored in 2018.

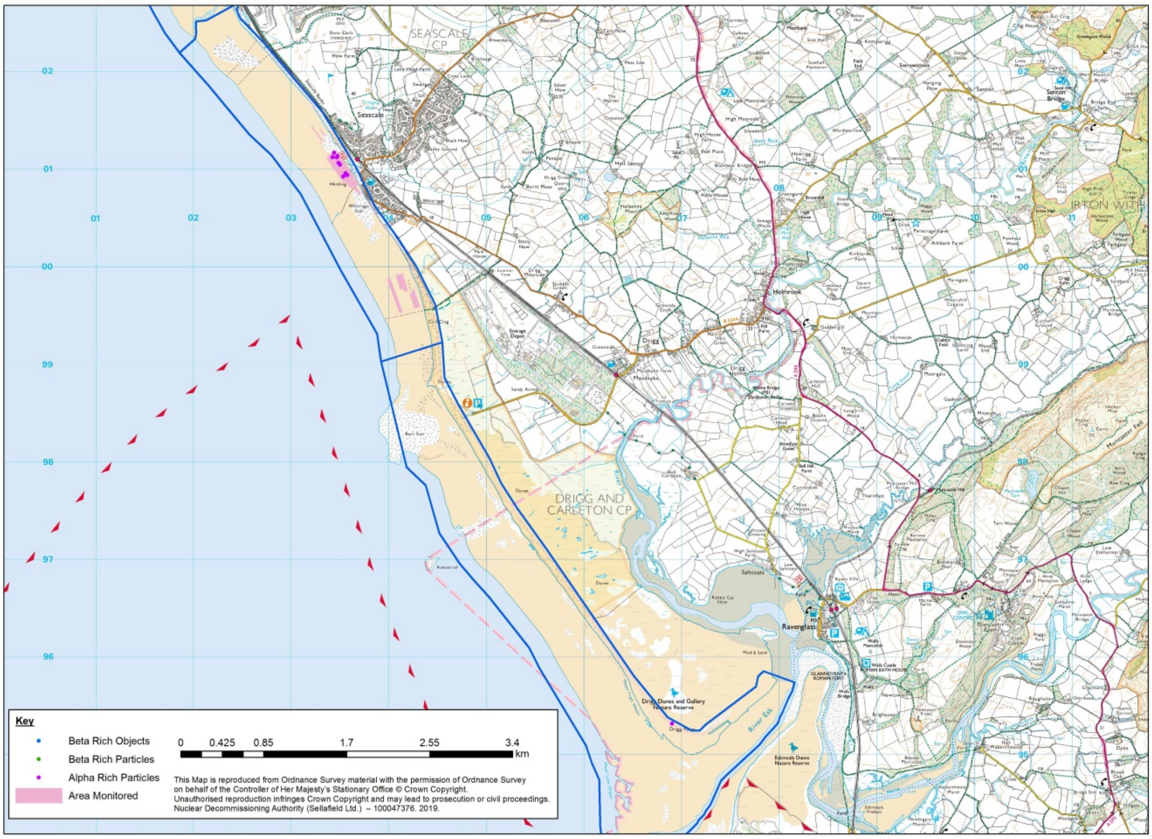


Figure 5: Seascale and Drigg beach find locations and areas monitored in 2018.

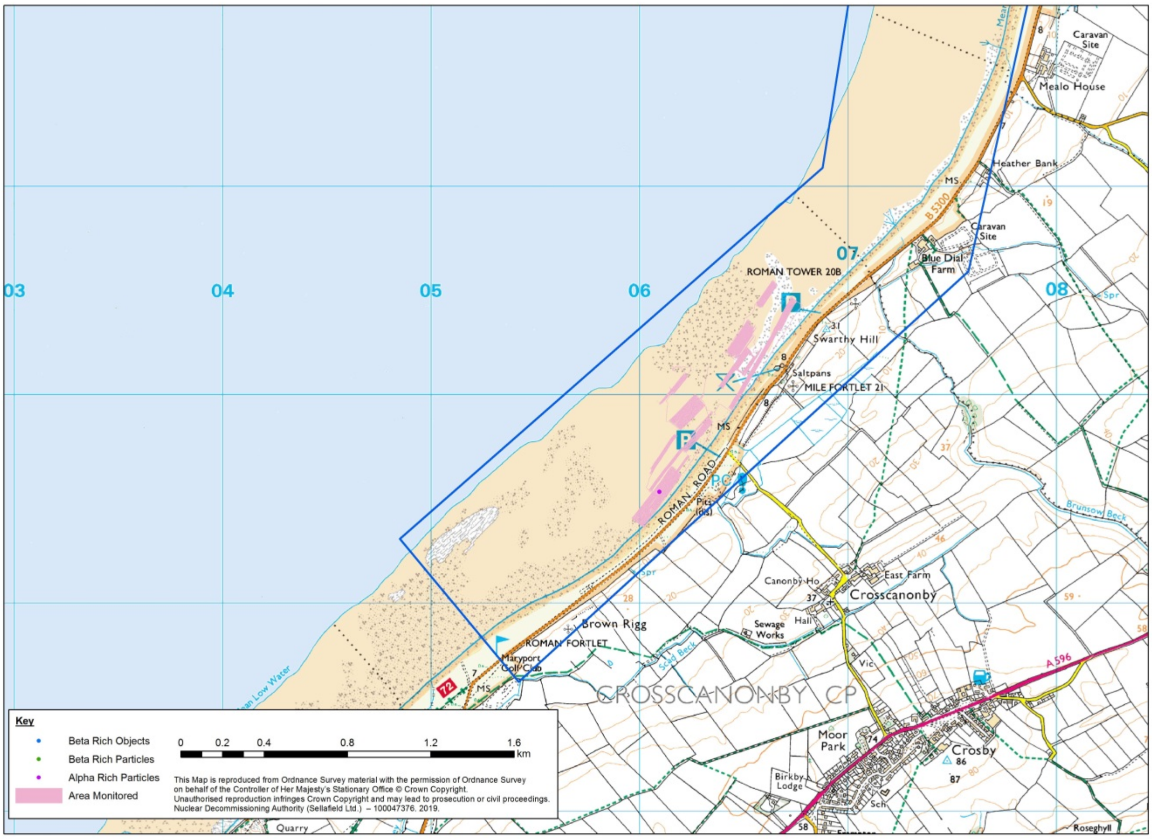


Figure 6: Allonby beach find locations and areas monitored in 2018.

4.5 Activity Distributions Measured In 2018

The distributions of ^{241}Am and ^{137}Cs activities for particles recovered from Sellafield beach are shown in Figure 7 and Figure 8 respectively. These figures present data from Sellafield beach as this beach has the highest find rates for alpha rich and beta rich particles. The shapes of the distributions were analysed and found to be well represented by log-normal distributions, hence data are presented as log transformed (further details are provided in the figure notes).

As noted in the Particles Annual Report for 2015/16 (Sellafield Ltd, 2016), the introduction of Synergy2 appears to have impacted on the distributions of the activity of particles being recovered. Figure 7 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 rates 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 8 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 a slight increase in the mean activity of finds and a reduction in the standard deviation, although neither of these changes were statistically significant. The mean ^{137}Cs activity also increased when going from Synergy to Synergy2 and there was a further reduction in the standard deviation of the distribution, with the change in the mean being statistically significantly different from the means of either Evolution or Synergy. The most likely cause for these changes in the activity distributions was identified as being associated with improvements to the standardisation of detector heights on the Synergy2 monitoring equipment.

The distribution of ^{137}Cs and ^{241}Am activities, shown in Figure 7 and Figure 8, 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 eight 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 cobalt rich finds were recovered in 2018. The last recovery of a cobalt rich find was in 2016 (see Appendix 2, Table A2.3).

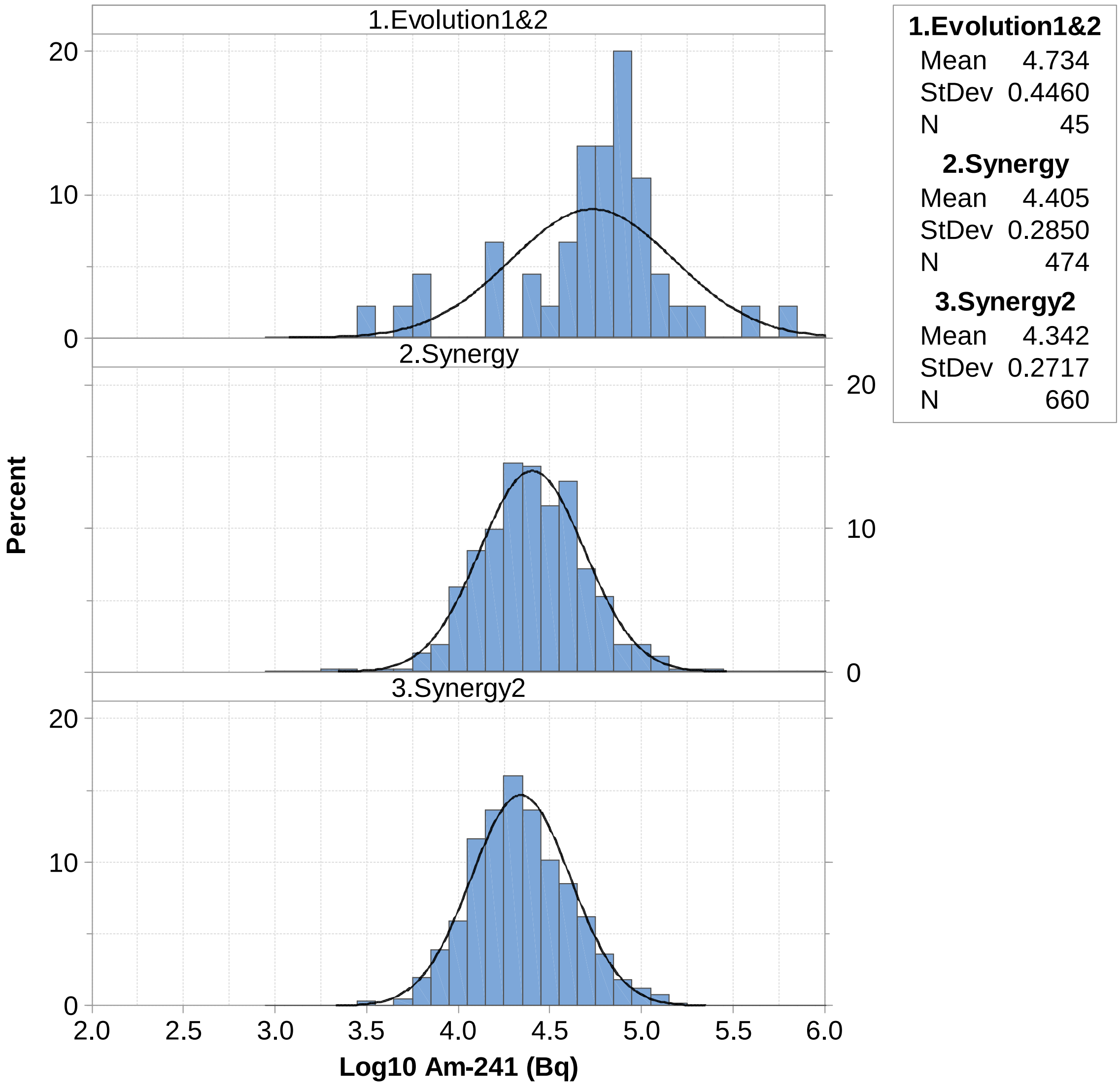


Figure 7: Distribution of ^{241}Am activity of alpha rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.

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

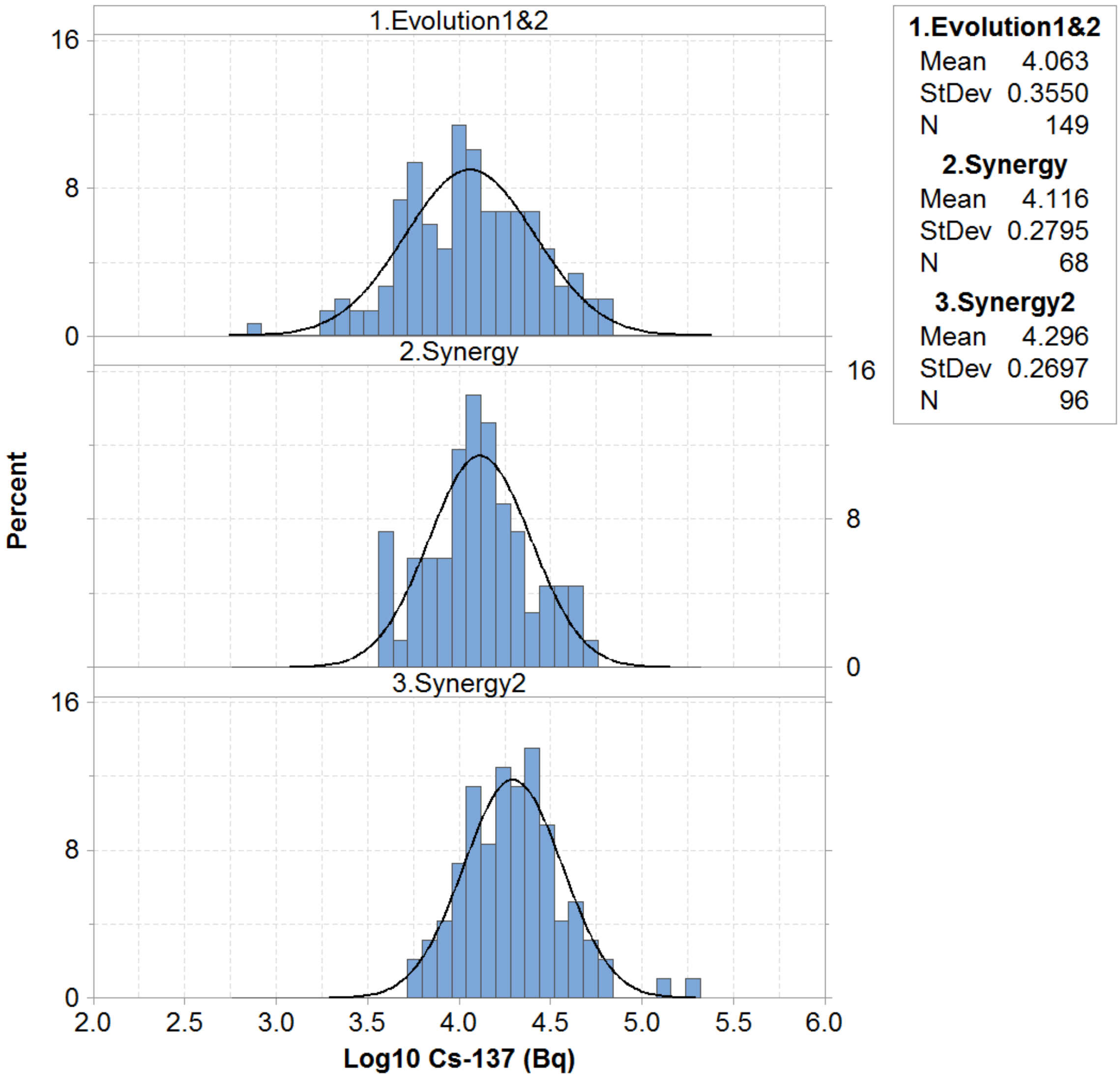


Figure 8: Distribution of ^{137}Cs activity of beta rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.

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

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 exceedances of the EA intervention criteria in 2018 (as specified in Section 2.2). Find rates from the programme have consistently been several orders of magnitude below the intervention criteria thresholds.

In May 2018, a beta rich beach find (LSN2233820) with a ^{137}Cs activity of 1.03E+05 Bq was recovered from Sellafield beach from a depth of 22 cm. The ^{137}Cs:^{134}Cs ratio of the beach find indicated that it was related to historical operations at the site earlier than 1993 although an exact age could not be determined. An initial visual characterisation of the recovered material suggested that the activity was associated with a particle and as it exceeded the EA characterisation criteria (specified in Section 2.3) it was sent for further detailed analysis. Initial laboratory analysis confirmed the ^{137}Cs activity to be greater than the characterisation criteria. Isolation and identification procedures confirmed that the beach find had dimensions of 3.3 mm x 2.4 mm x 1.5 mm and therefore was a larger object rather than a particle. The EA confirmed that no further analysis was required, as the activity of this beach find was within the range of other larger objects and as larger objects pose lower health risks than particles.

In October 2018, a beta rich beach find (LSN2256635) with a ^{137}Cs activity of 1.23E+05 Bq was retrieved from Sellafield beach from a depth of 7 cm. The ^{137}Cs:^{134}Cs ratio of the beach find indicated that it was related to historical operations at the site earlier than 1994 although an exact age could not be determined. An initial visual inspection identified that the sample was likely to be a particle and it was sent for further analysis. Scanning Electron Microscopy (SEM) on the sample confirmed that the radioactivity was associated with a particle which had dimensions of 0.32 mm x 0.24 mm x 0.12 mm. This particle had a radioactivity content that was within the range of previous measurements and therefore did not require immediate further consideration and did not challenge the health risk assessment. However, the results of further detailed laboratory analysis of this particle are reported in Section 5.4.

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 cobalt rich finds could not be analysed statistically due to the low number recovered. As the differences between the Synergy and Synergy2 monitoring systems are small, the data were combined for this analysis. Find rates are highly uncertain when they relate to small amounts of monitoring area 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 9 and are summarised in Figure 10. These illustrate 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 9 and Figure 10 as monitoring cannot be conducted between the northerly edge of Braystones beach and the southerly edge of St. Bees beach due to the nature of the beach. Beta rich particles and larger objects were found to be more tightly clustered than alpha rich particles, with the peak of the beta rich particle and larger object distributions being approximately 700 m to the north of the pipeline.

The Conceptual Site Model (CSM) is detailed in Section 7 and illustrates that the northerly movement of particles would be expected based on coastal processes (Atkins, 2018). Furthermore, 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 10, 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) where the gradient in find rate along the beach is lower and where beta rich finds are rarely recovered.

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.

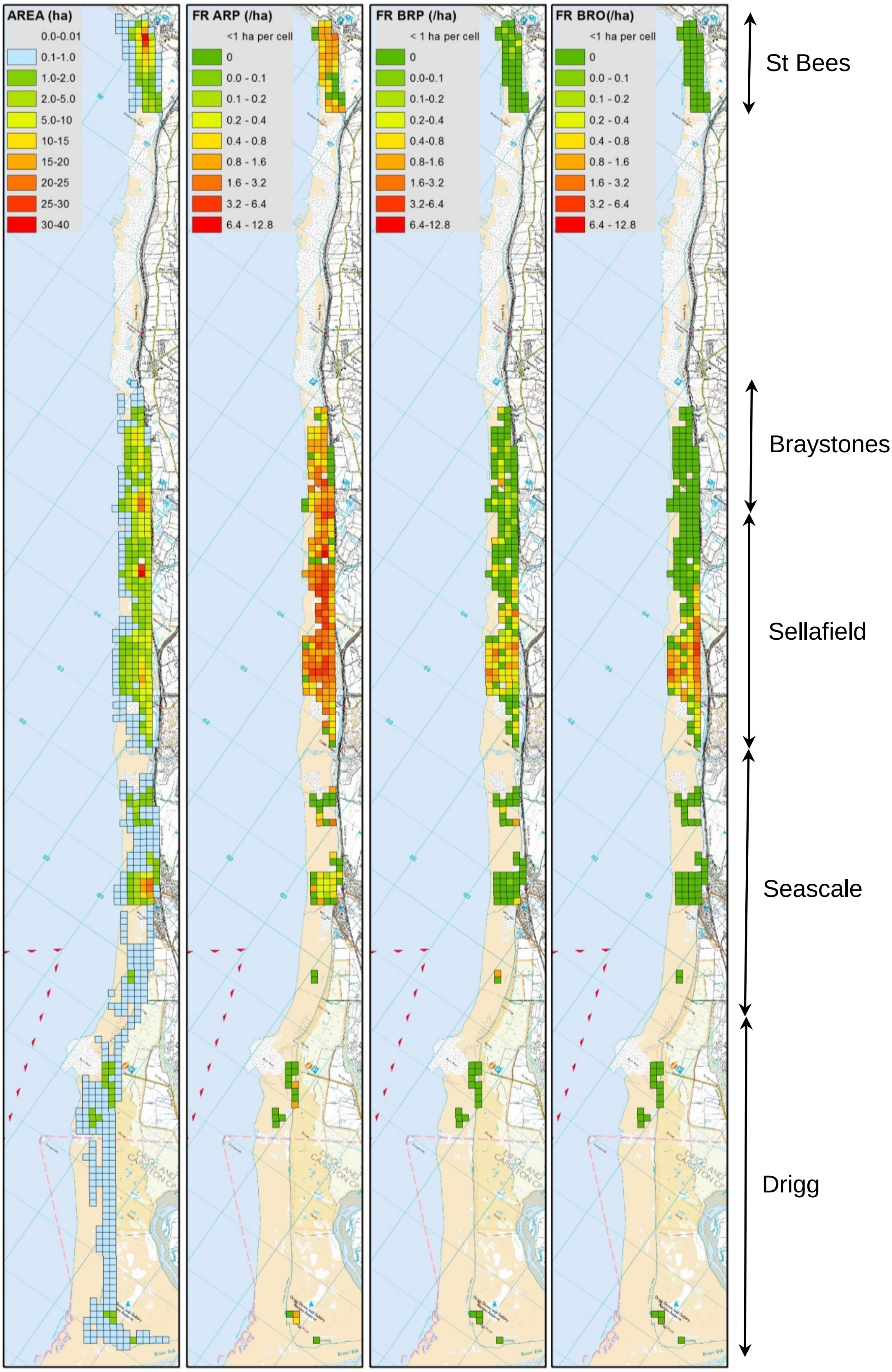


Figure 9: Find rate map for the Synergy and Synergy2 monitoring periods.

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.

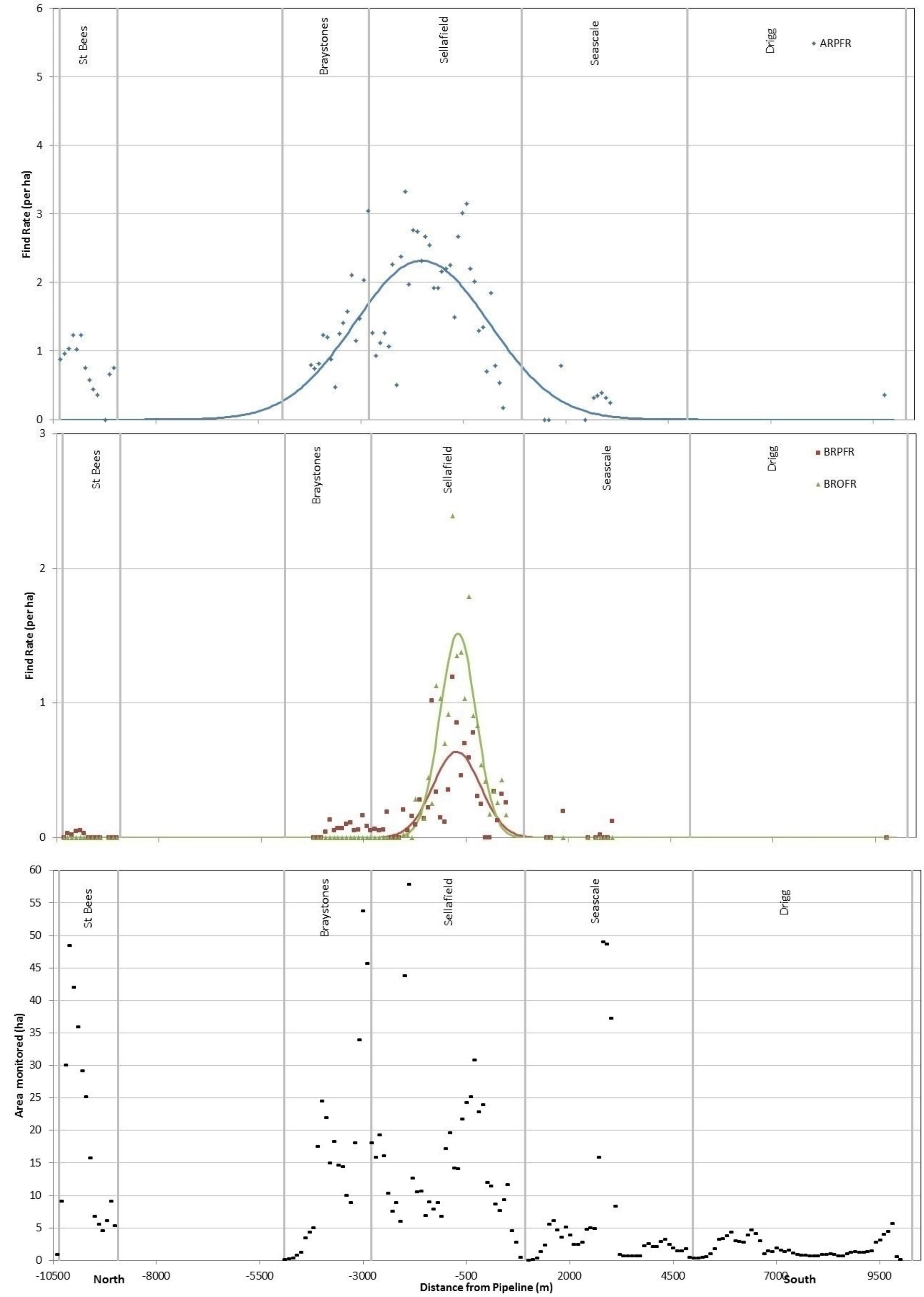


Figure 10: Spatial distribution of find rates.

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. All data are for the Synergy and Synergy2 monitoring periods only.

The resulting graphs are shown in Figure 11 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 Synergy2 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. Data over the last 3 years (2016 - 2018) have been reasonably consistent with no statistically significant trend in find rates at the 95% confidence level. There was however some evidence of a trend towards declining find rates at the 90% statistical confidence level, hence further monitoring is required in this area.

- Beta rich particle find rates peaked at 3 finds/ha (averaged over a 10 ha area) when monitoring began with the Evolution System. Find rates then reduced within a few months to a relatively consistent baseline of approximately 1 find/ha. A second peak (2.2 finds/ha) occurred following the introduction of Synergy2 in 2014, with find rates again declining quickly to a baseline of around 0.5 finds/ha. Overall, beta rich particle find rates have shown a statistically significant decline ($R^2 = 0.48$), at the 95% confidence level, over the 3 year period 2016 - 2018.

- As found with beta rich particles, beta rich larger object find rates peaked following the start of wide area beach monitoring using the Evolution System (7 finds/ha, averaged over a 10 ha area) and there was a rapid subsequent reduction (to around 3 finds/ha). The highest find rates for the Synergy and Synergy2 monitoring periods occurred following the introduction of Synergy2 in 2014, however this peak (3.7 finds/ha) was close to the typical find rates measured during the earlier period where the Evolution system was applied. Beta rich larger object find rates have shown a statistically significant decline ($R^2 = 0.75$), at the 95% confidence level, over the 3 year period 2016 - 2018.

It should be noted that a similar analysis of find rates (averaged over 10 ha areas) was applied for data from St Bees and Seascale beaches over the period 2015 - 2018 and identified no statistically significant trends (either increases or reductions).

Monitoring during 2018 focused on the peak areas of alpha rich and beta rich finds to determine whether a concerted monitoring effort could deplete find rates. The statistically significant declines in beta rich particles and larger objects provide some evidence that depletion in find rates has occurred (to the end of 2018). Further monitoring of the area of peak beta rich finds is required in 2019 in order to establish whether the observed rate of depletion is a sustained response to the recovery of finds.

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 Synergy2, are shown in Figure 12, Figure 13 and Figure 14 as well as Table A2.4 in Appendix 2. These data illustrate that 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 (also shown in Figure 11). Find rates at Sellafield, Braystones and St Bees beaches during 2018 were at historically low levels whilst alpha rich particle find rates at Seascale and Allonby beaches were well within the typical ranges previously observed for all beaches. 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 11).

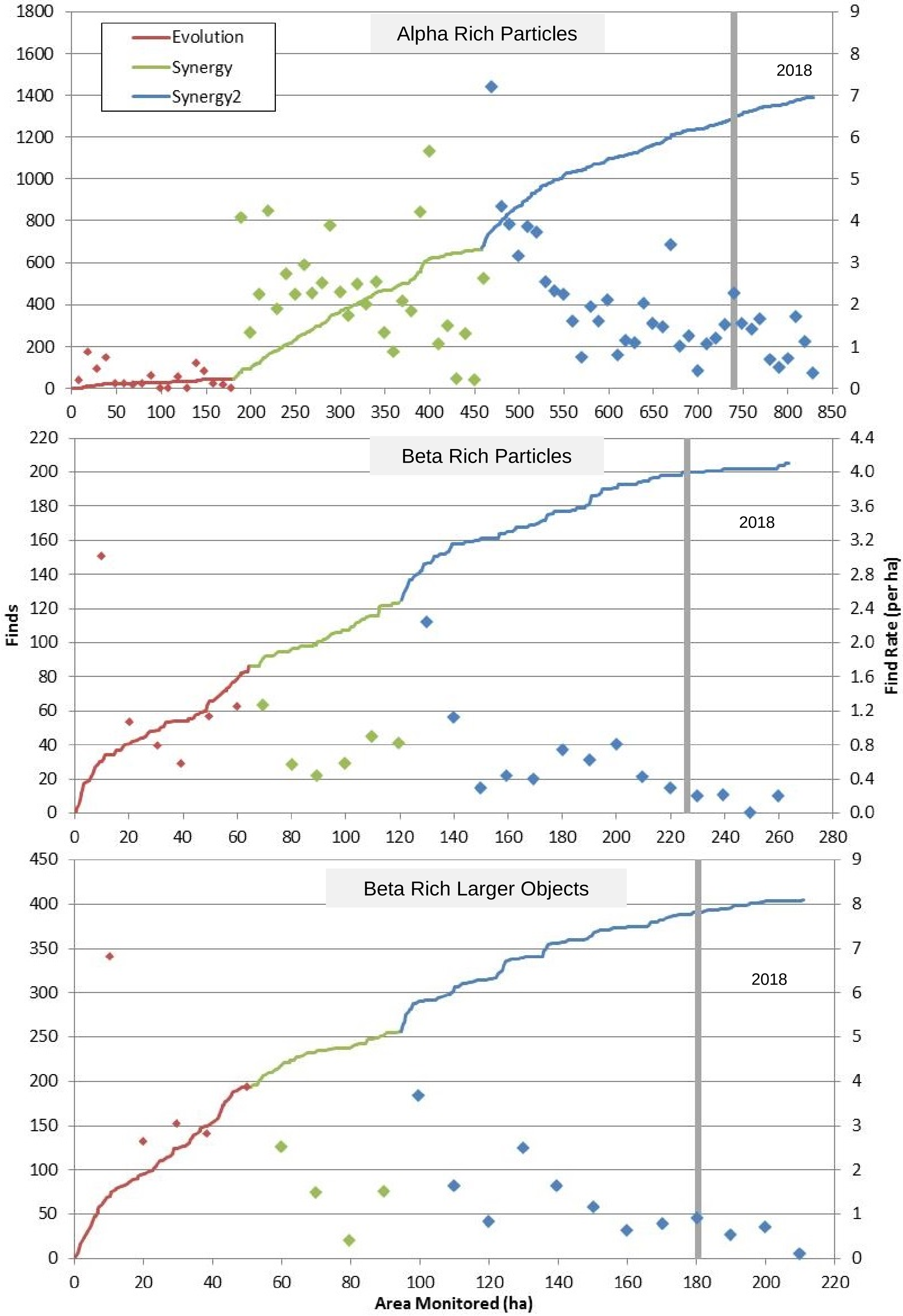


Figure 11: Trends in finds with area monitored and 10 ha averaged find rates.

Notes: Data are taken from 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 2018 monitoring period.

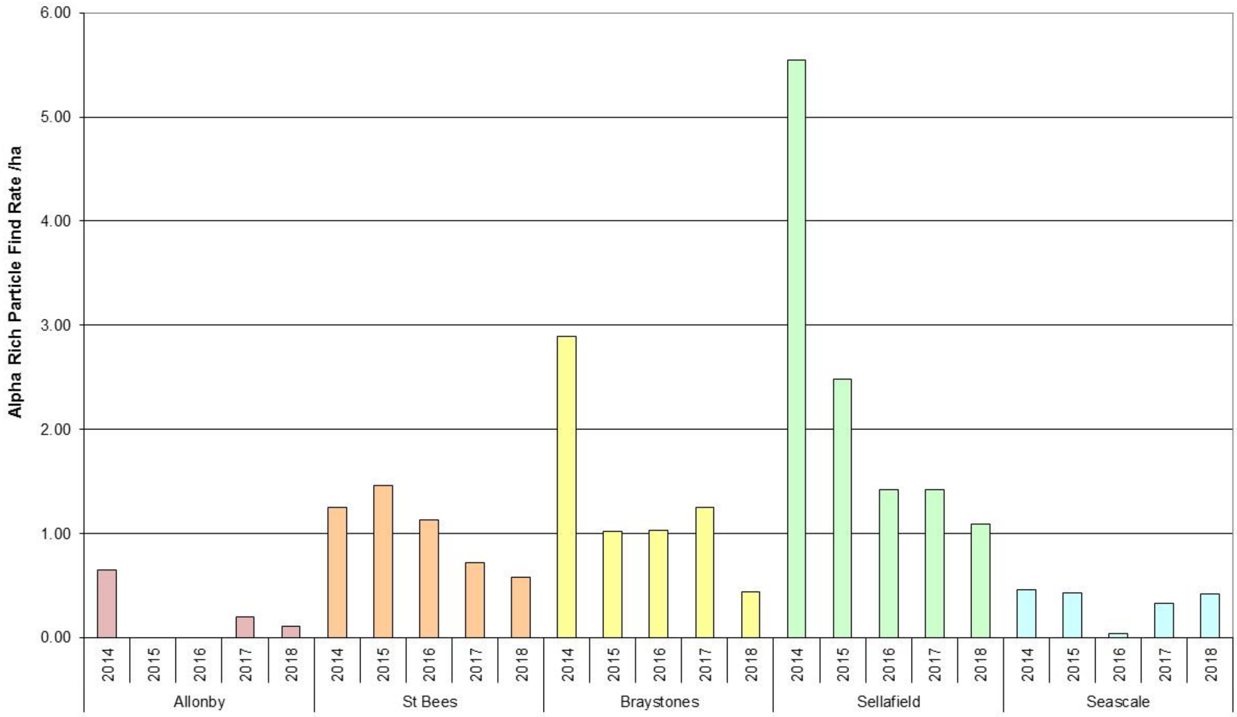


Figure 12: Alpha rich particle find rates since the introduction of Synergy2.

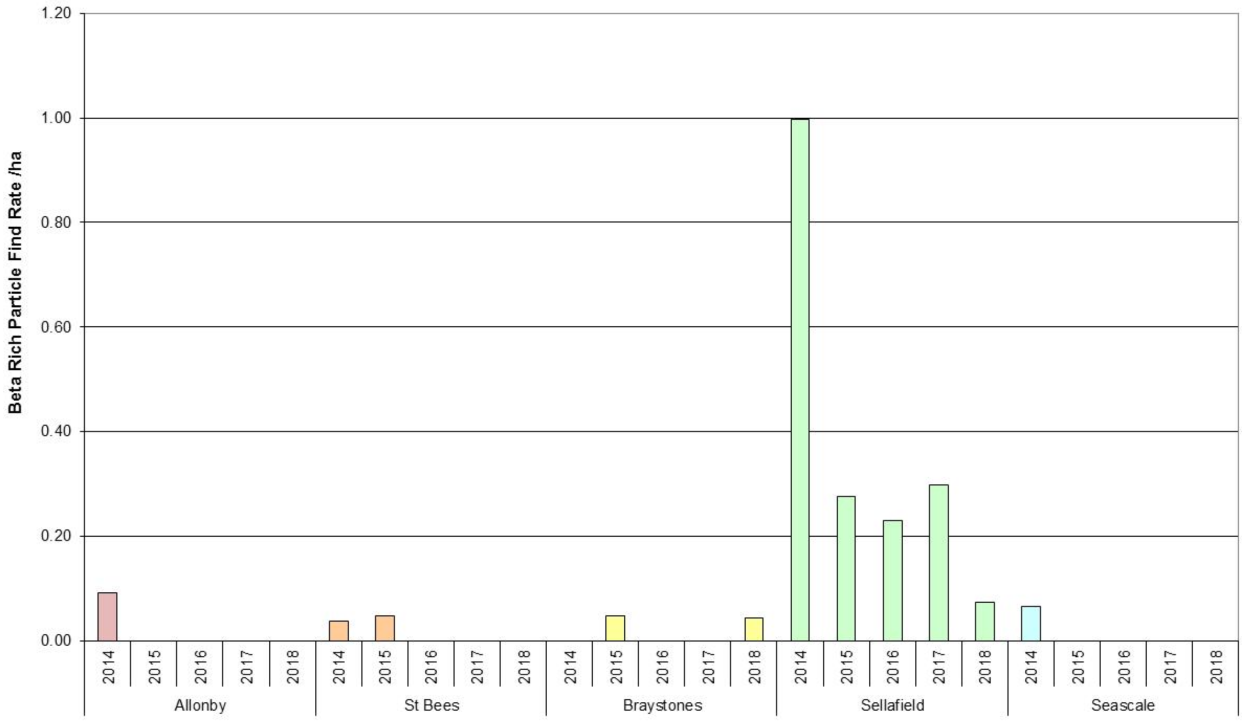


Figure 13: Beta rich particle find rates since the introduction of Synergy2.

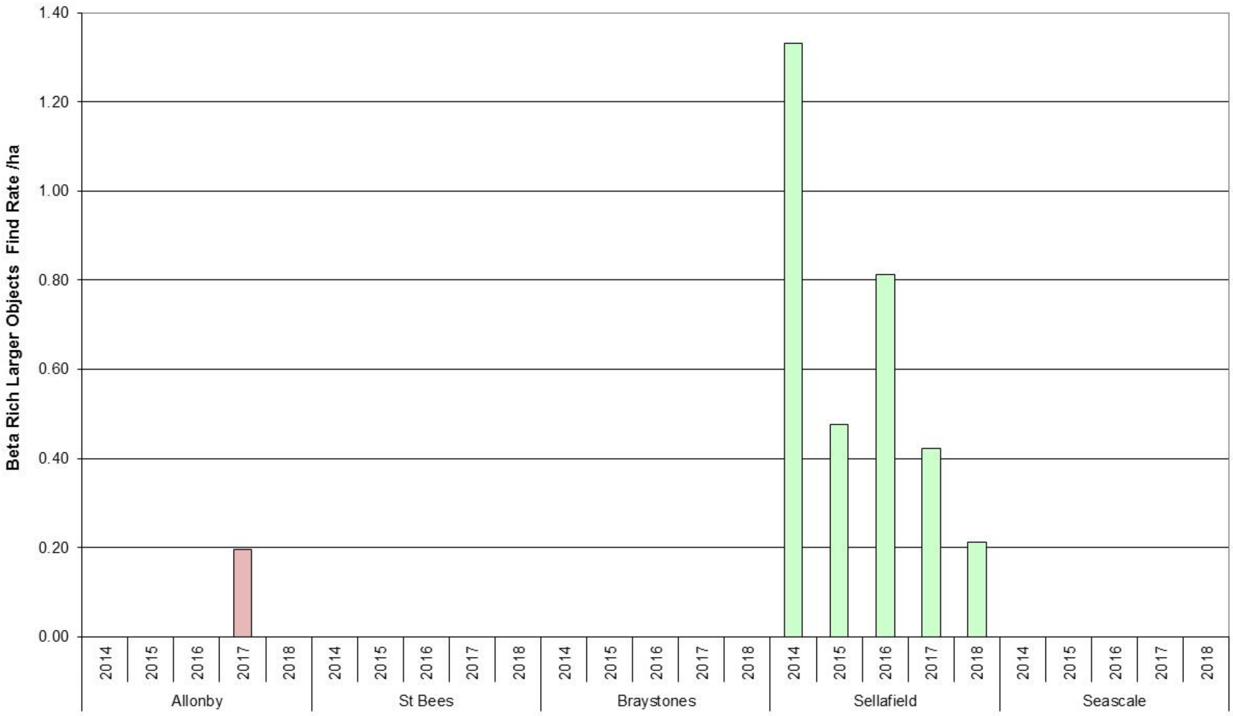


Figure 14: Beta rich larger object find rates since the introduction of Synergy2.

The number of larger objects recovered during 2018 decreased when compared with the previous three years, with almost all larger objects being recovered from Sellafield beach since the introduction of Synergy2. A notable exception is the larger object recovered from Allonby in 2017 (see Figure 14).

5.3 Investigation Monitoring

5.3.1 Storm Analysis

The CSM (see Section 7) highlighted the importance of storm events in the dispersion of sand and sediment and therefore beach particles in the environment. The transport of material depends on the intensity and the prevailing wave and current directions during a storm (Atkins, 2018). However, whether this impacts on the population of particles on the beaches also depends on how well dispersed particles are within their environmental matrix (*e.g.* sands) and whether the storms move material onshore or offshore. Atkins (2018) noted that there is likely to be movement of materials onshore during moderate storms and for offshore transport during severe storms.

The impact of storms on particle populations was investigated by comparing particle find rates to stormy episodes identified by Atkins (2019). The frequency of stormy episodes along the West Cumbrian Coast was found to show a strong seasonal variation, with the highest frequency of storm events occurring during autumn and winter months.

The find rates for alpha rich particles, beta rich particles and beta rich larger objects in the peak geographical areas used in Figure 11, were analysed to determine monthly average find rates. For beta rich particles and larger objects these were for the period 2006 - 2018 as the changes to monitoring equipment over this time (Section 3) has not significantly affected the detection characteristics for ^{137}Cs. For alpha rich particles this analysis was only applied to the Synergy and Synergy2 data due to the equipment changes discussed in

Section 3. Find rates for months where less than 1 ha of beach area was monitored were excluded. The averages of these monthly find rates were calculated. In addition, 95% confidence limits were also calculated for months where five or more datapoints contributed to the mean value. This enabled the analysis to account for the variability in find rates.

The results of this analysis are shown in Figure 15 and illustrate that whilst storms show a very strong variation by month (with January, October, November and December showing the highest frequency of storms) there is no evidence of any corresponding monthly variation in particle or larger object find rates.

A further time-series analysis was undertaken to establish whether there was evidence that storms had contributed to a sustained (seasonal) increase in particle find rates. It should be noted that for a change in particle find rates to impact on public health risk then the increase would need to be sustained over a significant period of time rather than being a short term transitory response (Oatway, et al., 2019). An analysis of the seasonally averaged time series of alpha rich particle find rates and the occurrence of storms was conducted for the peak area of Sellafield Beach (as defined in Figure 10) and also for St Bees beach as a comparator. The results are shown in Figure 16 and demonstrate that the occurrence of storms did not lead to a sustained increase in alpha rich particle find rates on a seasonal timescale on either of the beaches evaluated. A similar analysis could not be performed for beta rich particles or larger objects due to the smaller peak areas (Figure 10) restricting the available monitoring data.

Three periods are shown in Figure 16 where there were either peaks in find rates or peaks in the occurrence of storms. A time-series analysis of these periods was used to establish whether storms could cause a temporary (short term) increase in find rates that was not observable in the seasonal analysis of data. Find rate data were analysed accounting for the duration of monitoring campaigns and accumulating up to 5 ha of monitoring for each data point. This analysis provided an optimal compromise between achieving high time resolution data whilst maximising the area monitoring to reduce statistical variability. The results of this analysis are shown in Figure 17 and demonstrate that there were no consistent increases in alpha rich particle find rates that occurred when monitoring was conducted following a storm.

In conclusion, whilst it is undisputed that storms can move sands and silts along the Cumbrian coast, they do not appear to have a strong influence on the find rates of beach particles and larger objects. From an analysis of particle and larger object find rates there was no evidence that these followed a similar monthly variation to that found for storm events. In addition, time-series analyses demonstrated that storm events do not result in short term or long term (seasonal) increases in alpha rich particle find rates. The lack of a strong response to storms indicates that beach finds are relatively well mixed in the environment, particularly between offshore and onshore zones.

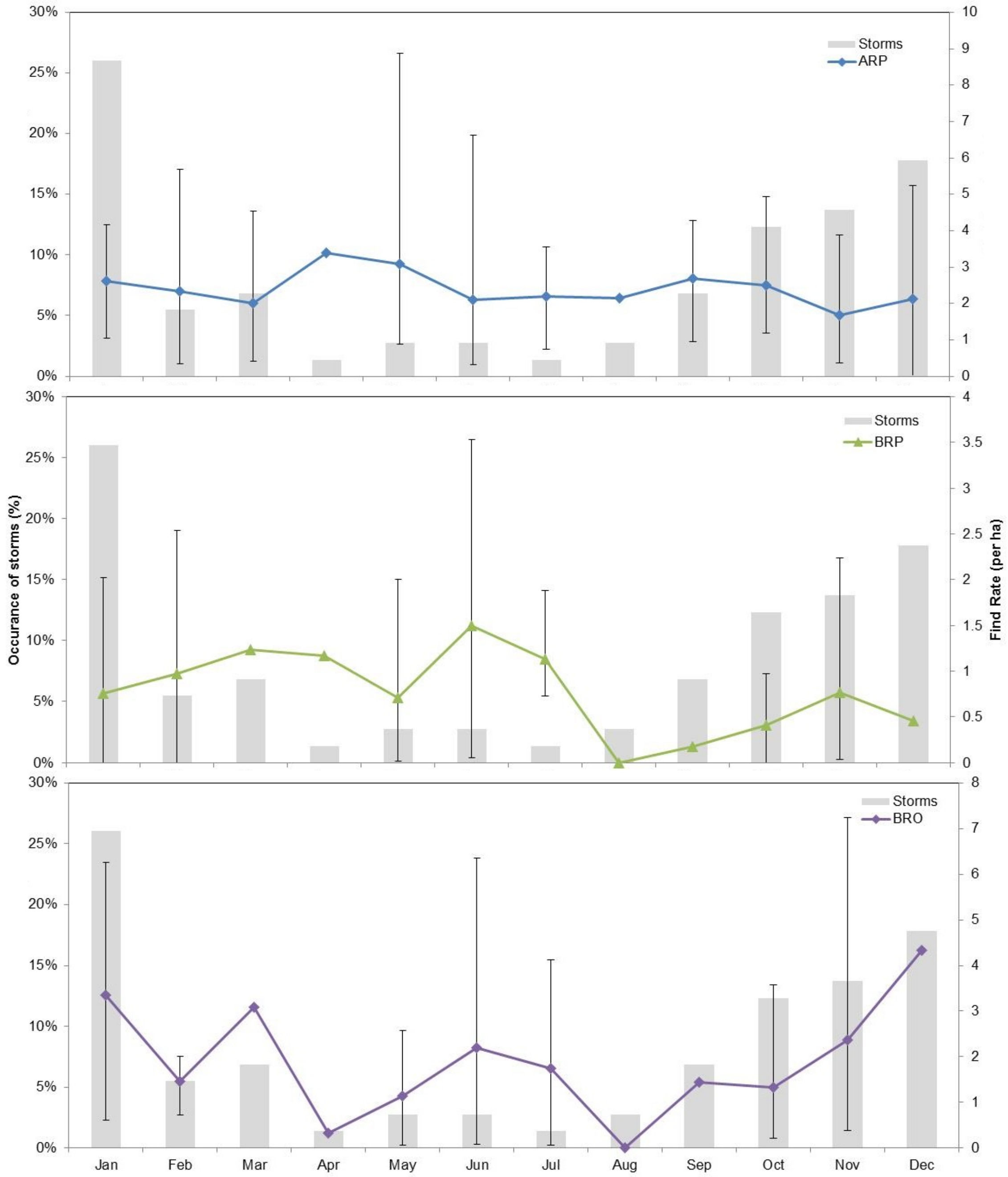


Figure 15: Comparison between monthly averaged find rates and the monthly frequency of storms at the spatial peak areas.

Notes: ARP= Alpha Rich Particle find rate for Synergy and Synergy2 only; BRP: Beta Rich Particle find rate for all monitoring systems; BRO: Beta Rich Larger Object find rate for all monitoring systems. Error bars show the 95% confidence limits and are shown where five or more datapoints are available to estimate the monthly averaged find rates.

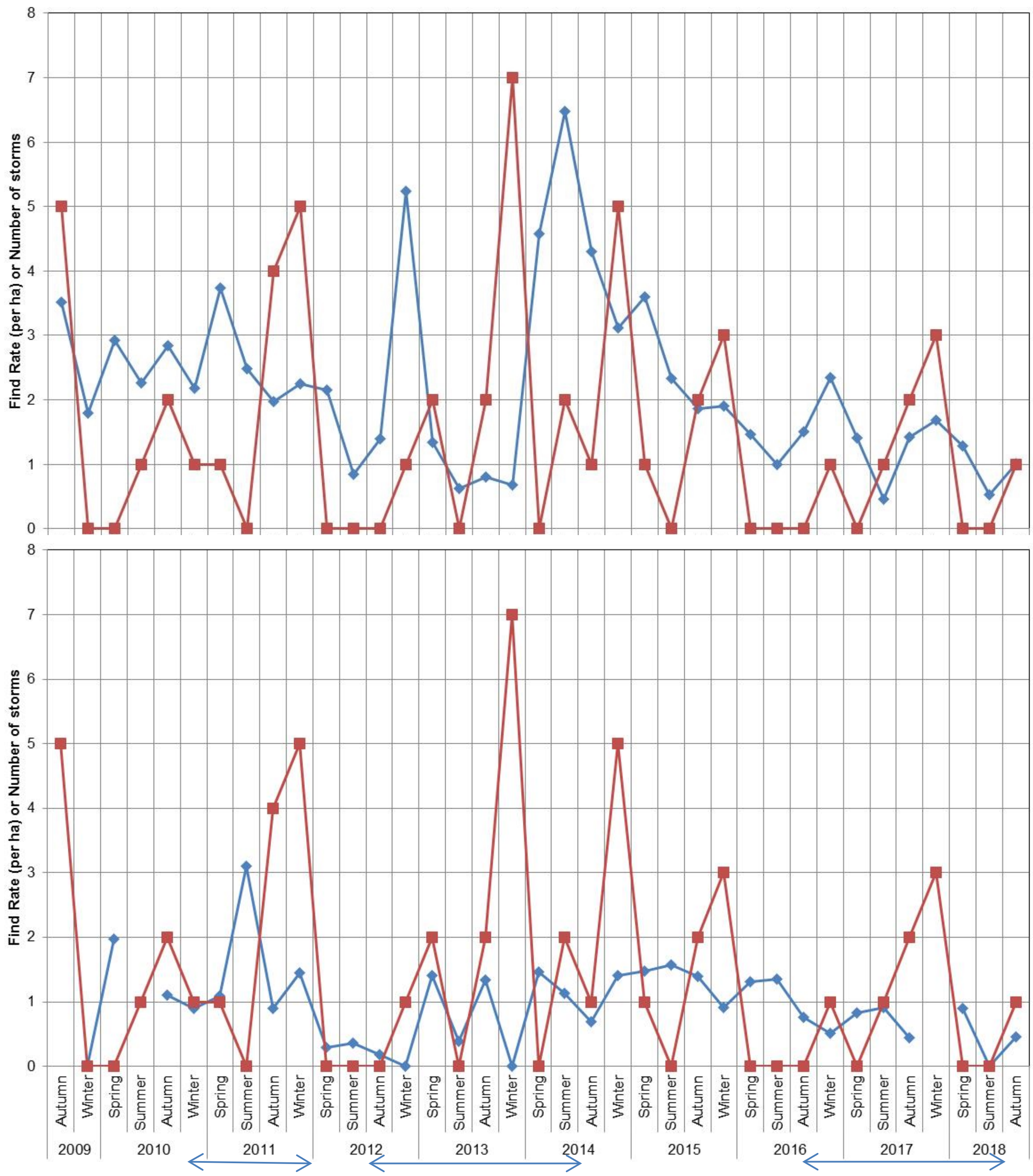


Figure 16: Time-series of seasonally averaged alpha rich particle find rates (blue) and the frequency of occurrence of storms (red) for: (upper) the peak area of alpha rich particle finds; and (lower) St Bees beach.

Notes: spatial peaks in find rates are as defined in Figure 10 ; horizontal markers denote periods for further study.

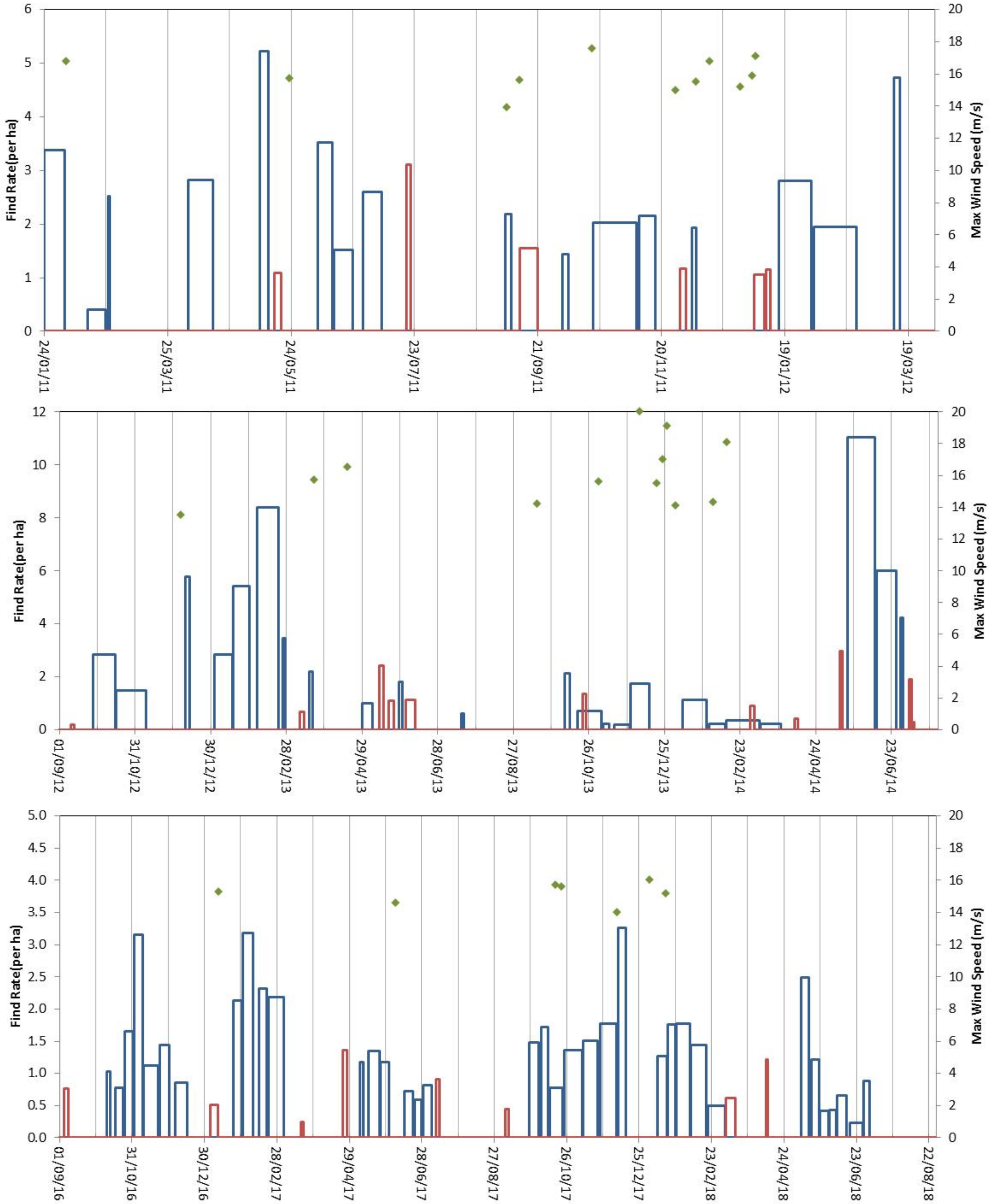


Figure 17: Time-series of period averaged alpha rich particle find rates at the peak area of alpha rich particle finds (see Figure 10) (blue bars) and St Bees beach (red bars) compared with the maximum wind speed during a storm event (green markers).

5.4 Further Analysis of Beach Finds

Further laboratory analyses were performed on beach finds in order to provide information on their physical and radiological properties to meet the programme aim of understanding and monitoring the behaviour of radionuclides in the environment (Section 2.4).

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, 2018b).

5.4.1 Laboratory analysis of finds as required through the EA Characterisation protocol

A beta rich particle (LSN2256635) was recovered from Sellafield beach in October 2018 which had a ^{137}Cs activity that exceeded the EA Characterisation criteria of 1E+05 Bq (see Sections 2.3 and 4.6) and was sent for further detailed analysis. Based on SEM with an Energy Dispersive X-Ray Analyser (EDXA), the particle was considered to be anthropogenic (see Figure 18). It was a subangular particle with patchy dark grey and brown surface colours. Between sample preparation and SEM analysis, incipient cracks were identified to have opened, most likely through drying-related shrinkage. The bulk of the sample interior was found to comprise of iron, aluminium and carbon. Brown surfaces were thought to comprise of a thin layer of iron oxide/hydroxide. Caesium was only detected in the interior of the particle. The observed incipient cracks indicate a high chance of further fragmentation.

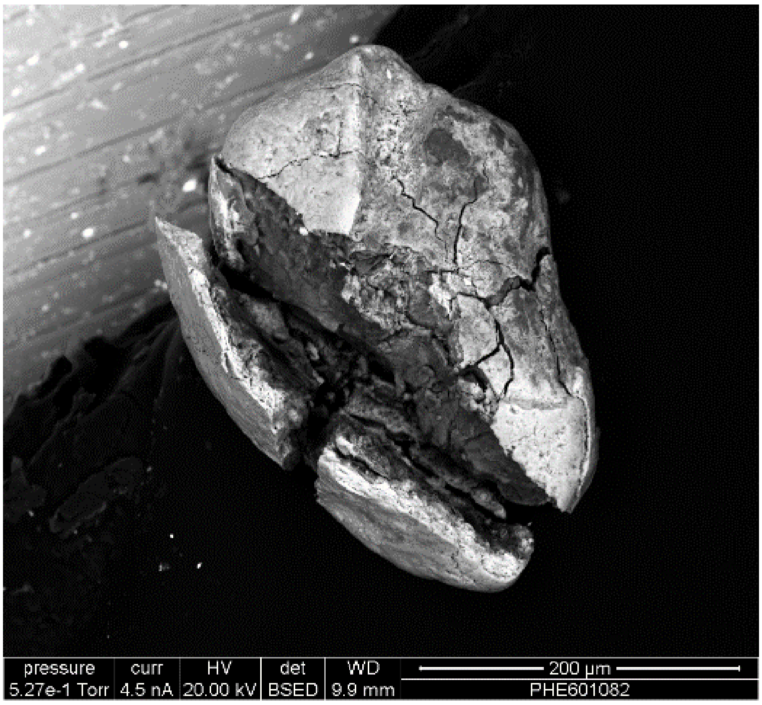


Figure 18: Scanning electron micrograph of particle LSN2256635.

Details of the radionuclide activities of the beta rich particle are given in Table 4. The principal beta emitter present was found to be ^{137}Cs (1.29E+05 Bq) with a much smaller contribution from ^{90}Sr (4.32E+01 Bq). This confirms that dose contributions from ^{90}Sr will be much lower than those from the ^{137}Cs present in this find. The individual alpha-emitting radionuclides were not analysed in detail as less than 30 Bq of total alpha activity was reported to be present.

Table 4: Radiochemical analysis of particle LSN2256635.

Area	Type	Total Beta	^{90}Sr	^{137}Cs	Total Alpha
Sellafield	Fe-Al-C (A)	144000 Bq	43.2 Bq	129000 Bq	<30 Bq

(A) – Anthropogenic; Total Beta measurement applies a Sr-90 reference source.

Skin contact dose rate measurements of beach finds have been conducted since 2015 by PHE (Eakins, et al., 2017; Tanner, et al., 2017a; Tanner, et al., 2017b). Three techniques were applied to the beach find: thermoluminescent detectors (EXTRAD® TLD); radiochromic dye film; and a PTW 23344W type ionization chamber (IC) connected to a PTW Unidos E electrometer (Eakins, et al., 2019). The annual report for 2016/17 provides a summary of these techniques (Sellafield Ltd, 2017c).

The mean skin contact dose rate measurement results for particle LSN2256635 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 milli-sieverts per hour (mSv/h). 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 milli-grays per hour (mGy/h).

Table 5: Skin dose rate estimates for particle LSN2256635.

EXTRAD TLD	IC 23344W	Radiochromic Dye Film	Average Dose Rate
175 ± 17 mSv/h	94 ± 6 mSv/h	146 ± 44 mSv/h	138 mSv/h

Data provided by PHE (Eakins, et al., 2019). Uncertainties are shown as standard deviations.

The maximum measured skin contact dose rate at the upper 95% confidence limit was determined to be 209 mSv/h (209 mGy/h) using EXTRAD®TLD. 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 10 hours. The contact dose rate is below the 300 mSv/h threshold previously recommended by PHE (Brown & Etherington, 2011) for an urgent review of the health risk assessment. A detailed report on the skin dose from this particle concluded that it was unlikely to pose a serious health risk from external exposure (Eakins, et al., 2019).

It is notable that this result, obtained from a detailed laboratory investigation, is similar to the result obtained from the initial analysis of this particle (221 mSv/h). This provides confidence in the dose factors (Serco, 2011) that were applied to the measured ^{137}Cs activity as a reliable method for initial skin dose assessment.

5.4.2 Supplementary analysis of beach finds

During 2018, nine beach finds were identified for further characterisation to meet the programme aim of understanding the behaviour of radionuclides in the environment (Section 2.4). The following finds were selected for further analysis:

- Two beta rich larger objects that were found outside the areas that beta rich larger objects are usually recovered (Workington: LSN2044039: and Allonby: LSN2173412).
- Three beta rich finds recovered from Braystones and Sellafield beaches to evaluate whether there are physical differences between finds recovered from different beaches (Braystones: LSN 2219281; Sellafield: LSN 2235874 and Sellafield: LSN2164229).
- Four alpha rich particles to evaluate whether there are physical differences between finds recovered from different beaches (Allonby: LSN2173413; Drigg: LSN2161224; Seascale: LSN2161772; and Sellafield: LSN2213918).

The petrographic analysis was performed by the British Geological Survey (BGS) using optical and environmental scanning electron microscopes, the latter being equipped with an EDXA system, to enable physical, chemical and mineralogical characterisation. The results showed that the finds were classified as rock fragments, anthropogenic plutonium/iron rich and anthropogenic zirconium rich. The classifications of these beach finds provide further validation of the CSM (as discussed in Section 7).

Rock fragments

A total of four beta rich finds were characterised as being natural materials containing man-made radioactivity. All these finds were silicate rock types, three of which were igneous and one of which was of metamorphic origin. Two of the beta rich finds were >2 mm in size as was expected as they had been classed as larger objects. These larger objects were from Workington beach (LSN2044039) and from Allonby beach (LSN2173412) and were found to be physically similar in terms of size, shape and composition (Figure 19). A further find (LSN2235874) was initially thought to be a particle but was reclassified as a larger object as its dimensions were over 2mm.

Scanning electron micrographs of the four beta rich rock fragments, encompassing three larger objects and a particle rock fragment are shown in Figure 19. Three of the rock fragments (LSN2164229, LSN2044039 & LSN2173412) were found to have fine to medium crystal sizes with tightly interlocking crystal mosaic structures and are considered to have low risks of further fragmentation. The remaining rock fragment, a larger object (LSN2235874), was found to be metamorphic and had a mica-dominant composition. The weak foliation and pre-existing fractures of LSN2235874 indicated that it had a slightly higher risk of fragmentation than the other igneous rock fragments.

The mica minerals present in all of these rock fragments are potential sites for caesium fixation through near-irreversible cation-exchange with potassium, and this is considered the most likely mechanism and source of their radioactivity (as previously identified in the CSM, see Section 7). Some naturally occurring radioactive minerals (*e.g.* monazite, apatite, zircon) are also present in some of these rock fragments.

Anthropogenic plutonium/iron rich

All four of the alpha rich particles that were sent for laboratory analysis were characterised as anthropogenic. These were found to have discrete plutonium-rich and iron-rich parts. Three comprised of a plutonium-rich core with an iron-rich coating (LSN2161224; LSN2161772 and LSN2213918) and all these particles showed that the coating was fractured and has been partially knocked or peeled off. The fourth particle (LSN2173413) comprised of a plutonium-rich layer on an iron-rich flake substrate. The iron-rich material is likely to be an indeterminate iron oxide / hydroxide. The plutonium-rich part is also likely to be an oxide / hydroxide. Fragmentation is considered a high risk with all the particles in this group. Analysis of the ratio of ^{241}Pu:^{241}Am demonstrated that these particles were aged materials and the absence of fission products, such as ^{137}Cs, illustrates that they have been reprocessed and are not fuel fragments.

The activity of alpha rich particle finds is strongly related to their physical size, as shown in Figure 20. Based on previously analysed metallic / iron containing alpha rich particles a statistically significant linear relationship was determined between the volume of a particle and its ^{241}Am activity, explaining 82% of the variation in activity (an R^2 value of 0.82). The four alpha rich particles detailed in this section were compared with the previous data and show a good agreement with the expected activity based on their estimated volumes. This confirms that the current analysis of alpha rich particles agrees well with the previous analyses used in the in the Conceptual Site Model (Atkins, 2018).

Anthropogenic Zirconium-rich

A single beta rich particle (0.37 mm x 0.31 mm x 0.15 mm) was identified to be anthropogenic in origin (Braystones: LSN2219281). This particle was grey with patches of yellow, and had a rough, pitted surface and a fine spongy porosity. The main detectable elements associated with the dominant zirconium are phosphorous and oxygen. Small niobium-bearing elements are embedded in the zirconium-rich matrix. The angular form of the particle suggested that it has recently fragmented and it was expected to be prone to further fragmentation.

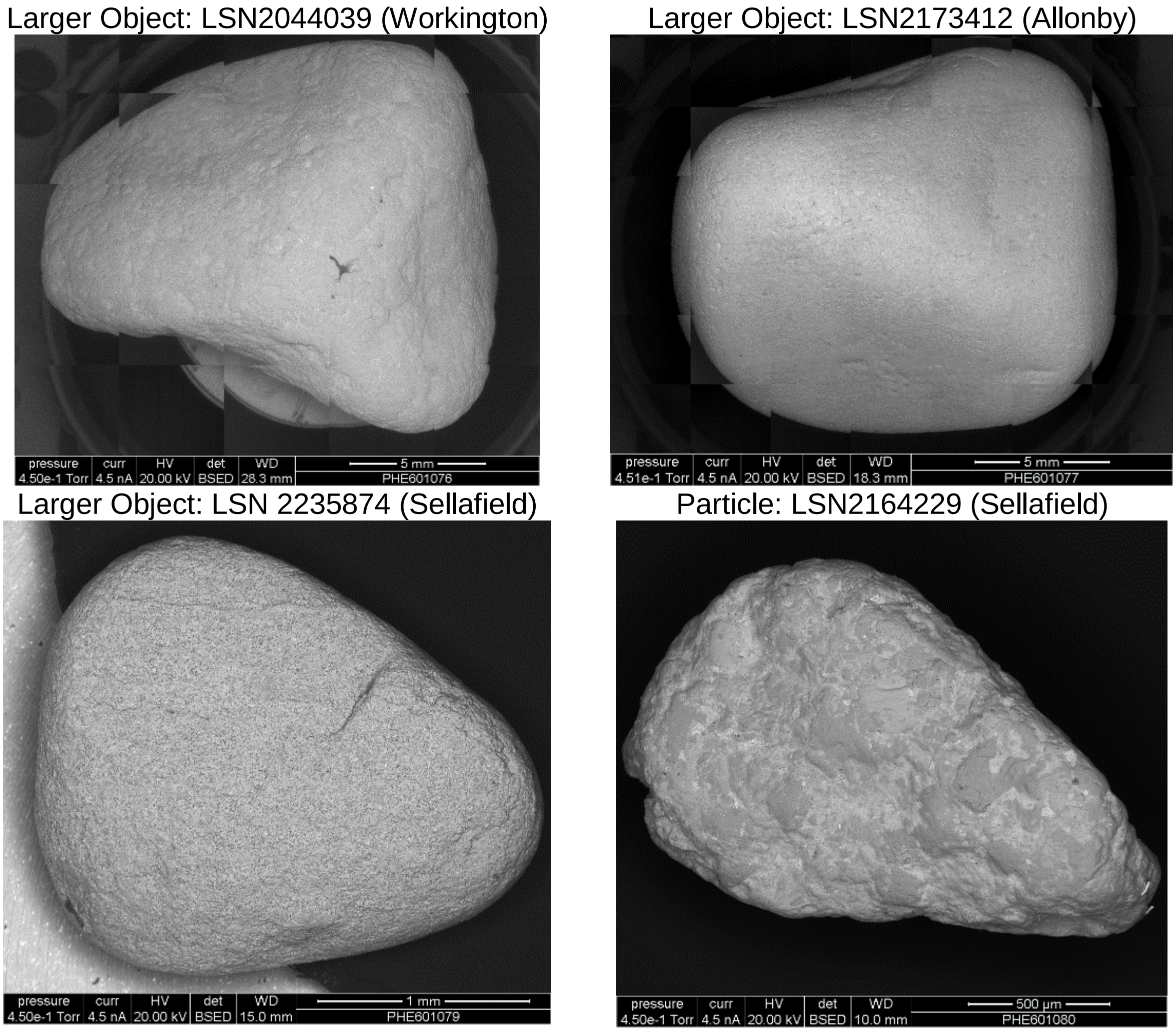


Figure 19: Scanning electron micrographs of larger object and particle rock fragments.

5.4.3 Summary of the further analysis

The classification of alpha rich particles as plutonium-iron rich, beta rich larger objects as rock fragments and beta rich particles as a mixture of anthropogenic (in this case zirconium rich) or rock fragments is in-line with the sources identified in the CSM (Atkins, 2018) as described in Section 7 and previous characterisation work (Sellafield Ltd, 2018b).

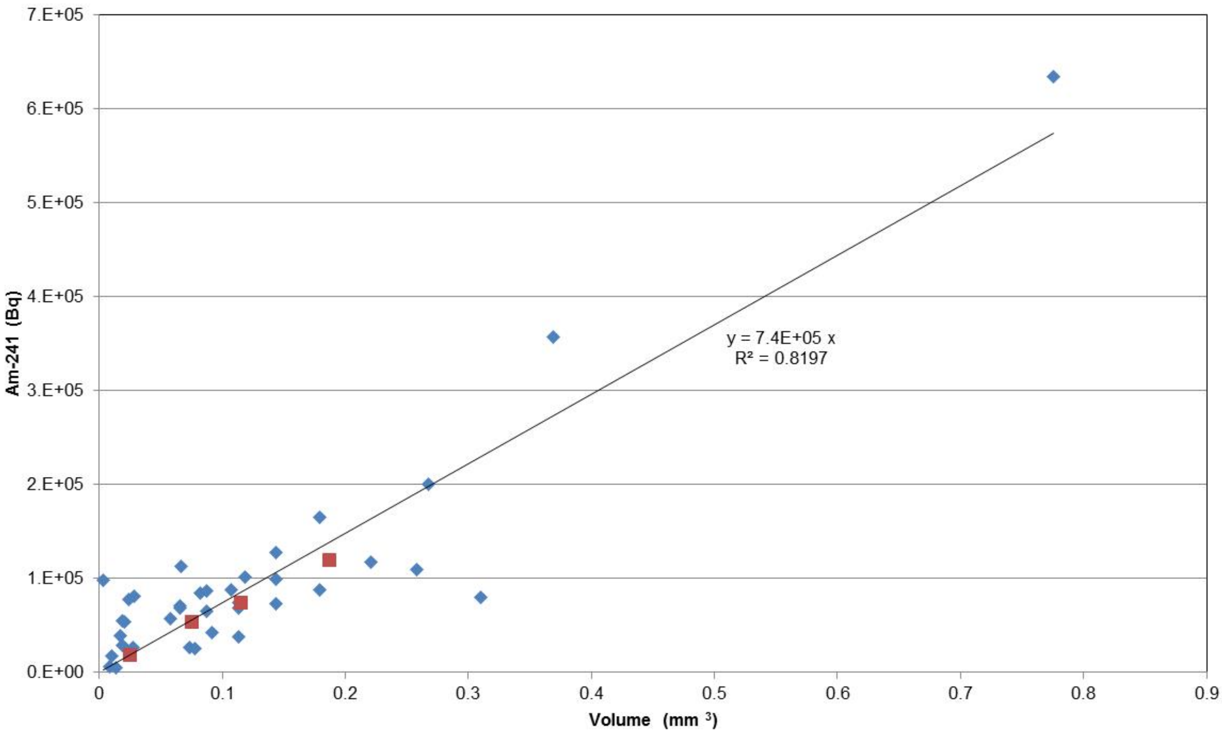


Figure 20: Relationship between size and activity for alpha rich metal containing particles for particles previously analysed (in blue) and detailed in this report (in red).

Notes: Line fit is based on previous data and shows that the current measurements of particle activities are in a good agreement with the expected relationship based on their volume.

5.5 Beach Monitoring Programme Conclusions

The 2018 programme has provided data that remains consistent with the health risk assessment and the CSM. The types of material being recovered during 2018 remained consistent with those retrieved since the start 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 EA requirements, detailed in Section 2, is that the Particles in the Environment programme must apply BAT for the monitoring and detection of environmental radioactivity. The definition of BAT encompasses both the monitoring equipment and the programme design.

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 EA in September 2017 (Sellafield Ltd, 2017b), developing on the considerations in the 2014 BAT review report (Sellafield Ltd, 2014b).

6.2 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 EA 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)

6.3 BAT Assessment Update

A further review was completed following the production of the 2017 BAT Case focussing on the optimisation of the strandline monitoring (Sellafield Ltd, 2018a). The recommendations of this review are detailed in the annual report for 2017 (Sellafield Ltd, 2018b). The review was shared with the EA and no objections were raised to the modification of the programme. Hence, strandline monitoring for 2018 (and for future programmes) was conducted using the Synergy2 vehicle.

Recent scientific papers (Connor, et al., 2018a; Connor, et al., 2018b) have applied thallium activated caesium iodide scintillator radiation detectors (Kromek, SIGMA-50) to study radioactivity at waste storage facilities in Japan. These facilities are used to temporarily hold surface soils contaminated following the accident at the Fukushima Daiichi Nuclear Power Plant (March 2011). The Kromek SIGMA-50 detector is capable of providing a well resolved gamma spectrum and utilises a crystal measuring 34.5 mm x 34.5 mm x 130 mm. This enables the analysis of specific energy windows for isotope identification, although monitoring at Fukushima (Connor, et al., 2018a) applied 20-minute stationary periods to collected sufficient counts to obtain a spectrum.

The SIGMA-50 detectors have been applied for walking surveys and for surveys using an Unmanned Aerial Vehicle (UAV) travelling at a speed of 1 m/s and an altitude of 5 m (Connor, et al., 2018a; Connor, et al., 2018b). These papers identified that both the walked survey and UAV could make measurements corresponding to ^{137}Cs activities of the order of 4E+05 Bq m^{-2} based on data integrated over one second and provided spatial data with a resolution of the order of around a metre.

A comparison was also made of the advantages and disadvantages of walked surveys compared to those conducted using a UAV. This highlighted the improved reproducibility, reduced survey time, and lower worker doses of the UAV whilst the walked surveys have the advantage of being able to carry larger and heavier detectors that provide better spectral information (Connor, et al., 2018b).

SIGMA-50 detectors and UAVs are a useful technology for mapping the high levels of radioactivity around Fukushima. Recent media reports[2] also highlight similar work being done close to Chernobyl, where gamma doses of up to 1 mSv per hour were reported. A dose of 1 mSv per hour would correspond to a ^{137}Cs activity of around 4E+08 Bq m^{-2} based on the conversion factors applied in other UAV studies (Connor, et al., 2018b). The applicability of this technology to a beach environment for the rapid detection and retrieval of discrete particles would require careful consideration as beach particle activities are typically orders of magnitude lower than the activities considered in the UAV studies and there would not be time for detailed post-processing and analysis of data as particles must be recovered from the beach before the next tidal inundation occurs.

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.	Completed. See Section 10.
2. Provide analysis and input data for PHE to use for their review of the risk assessment.	Completed.
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. See Section 6.3.
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.	Completed.
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.	Completed. See Section 10.
6. Conduct laboratory characterisation on finds only as required by the characterisation criteria developed by the Environment Agency following PHE advice.	Completed. See Section 5.4.
7. Continue statistical work to underpin the monitoring programmes and sampling arrangements for the beach environment.	Completed. See Sections 5 and 10.

[2] http://www.bristol.ac.uk/physics/news/2019/iac-drones-chernobyl-research.html

7 Transport and Dispersion

The CSM for particles in the environment was updated in 2018 (Atkins, 2018) and details were provided in the annual report for 2017 (Sellafield Ltd, 2018b). 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).

An analysis was conducted on the transport and dispersion of particles and larger objects in the Irish Sea (Atkins, 2018), including the dominant coastal mechanisms transferring particles from the offshore environment to the beach. These can be summarised as follows:

- The most likely transport direction in the offshore coastal environment would be for northward transport parallel to the coast.
- 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.
- 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 21, 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.

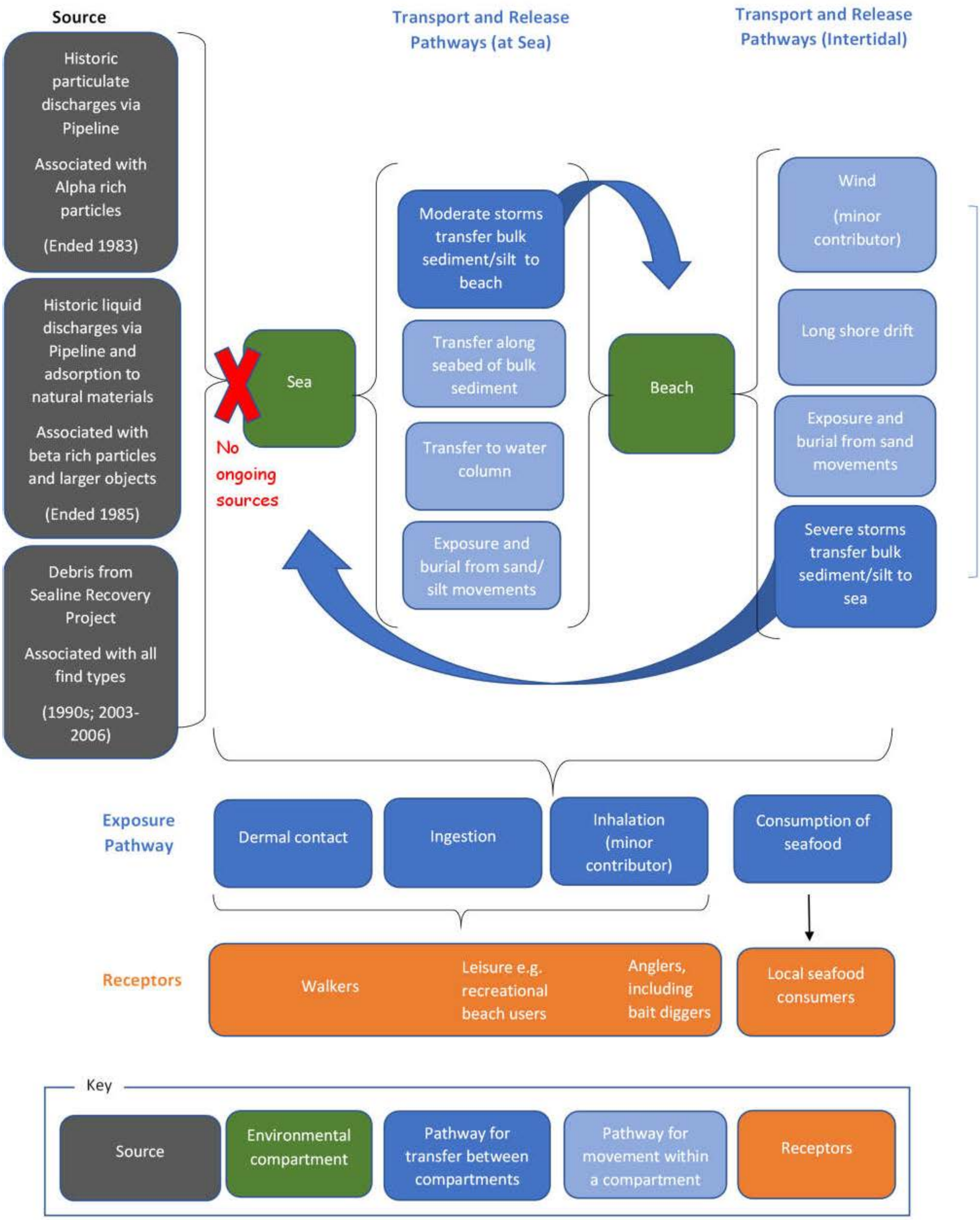


Figure 21: Schematic diagram of the Conceptual Site Model.

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 2).

Communications and engagement with the EA are 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 (*e.g.* 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). Work in 2018 focussed on the ongoing revision to the risk assessment work that is currently being conducted by PHE (Oatway, et al., 2019).

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

The PHE Centre for Radiation, Chemical and Environmental Hazards is responsible for the health risk assessment for Particles in the Environment.

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 (Oatway & Brown, 2015b). They concluded that the risks from seafood consumption were similar to those encountered by beach users.

The highest overall risks are shown in Table 7, 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.

PHE has been requested by the EA 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 work on the updated risk assessment is nearing completion. The key conclusions of the current draft of the updated health risk assessment (Oatway, et al., 2019) are as follows:

- *Radiological risks posed by radioactive objects on the beaches near the Sellafield site are very low and measures to control these risks are not warranted on public health grounds.*
- *There is little justification to continue with the current beach monitoring programme on public health grounds. A reduction in the scope of the beach monitoring programme could be achieved to focus the programme on providing reassurance that the assumptions made in the risk assessment remain valid.*

(Oatway, et al., 2019)

It is expected that the 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 published during 2019.

Table 7: Risks of fatal cancer associated with encountering radioactive particles on the Cumbrian coast.

Find type	Beach user risk (per year)		Seafood consumer risk (per year)*	
	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).

10 Forward Programme

10.1 Proposed Beach Monitoring Programme for 2019

For 2019, a programme of 150 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 150 ha split into three: Sellafield (totalling 80 ha); near-field (totalling 60 ha) and far-field (totalling 10 ha). The near-field programme focuses on the beaches at Seascale, Braystones and St. Bees, whereas the far-field programme will focus solely on the beach at Allonby.

Preliminary conclusions from the draft PHE risk assessment (Oatway, et al., 2019) have identified that risks to the public from Particles in the Environment are very low and that risks on Braystones and St Bees Beaches and Seascale and Drigg Beaches cannot be meaningfully disaggregated. Consequently the 2019 monitoring programme groups the beaches as Northern Beaches (Braystones and St Bees Beaches) and Southern Beaches (Seascale and Drigg Beaches). Sellafield beach and Allonby beach remain included in the programme as individual beaches.

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.

The BAT assessment for the Particles in the Environment programme (Sellafield Ltd, 2017b) identified that the programme shown in Table 8 and Figure 22 meets the programme objectives detailed in Section 2.4. The programme exceeds the current PHE 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 for the 2019 programme was discussed at the October 2018 meeting of the Sellafield Particles Working Group and was agreed with the EA in November 2018. The 2019 scheduled target areas for each beach are given in Table 8 and full details of the programme are included in Figure 22.

Table 8: Planned area coverage for each beach in 2019.

Programme	Area to be monitored (ha)			
	Sellafield	Near-Field	Far-Field	Total
Northern beaches	-	40	-	40
Sellafield	80	-	-	80
Southern beaches	-	20	-	20
Allonby	-	-	10	10
Total	80	60	10	150

	Week Starting	Beach Monitoring	Target Area (ha)
Q1 2019	31-Dec-18	No Monitoring	
	07-Jan-19	Sellafield	20
	14-Jan-19		
	21-Jan-19		
	28-Jan-19		
	04-Feb-19		
	11-Feb-19	Northern Beaches (St Bees or Braystones)	6
	18-Feb-19		
	25-Feb-19	Allonby	10
	04-Mar-19		
	11-Mar-19	Strandline Monitoring	
	18-Mar-19	Southern Beaches (Seascale or Drigg)	4
	25-Mar-19	Northern Beaches (St Bees or Braystones)	4
Q2 2019	01-Apr-19	No Monitoring (Easter Holidays)	
	08-Apr-19		
	15-Apr-19		
	22-Apr-19	Northern Beaches (St Bees or Braystones)	4
	29-Apr-19	Southern Beaches (Seascale or Drigg)	4
	06-May-19	Sellafield	30
	13-May-19		
	20-May-19		
	27-May-19		
	03-Jun-19		
	10-Jun-19		
	17-Jun-19		
	24-Jun-19	Northern Beaches (St Bees or Braystones)	8
Q3 2019	01-Jul-19		
	08-Jul-19	Southern Beaches (Seascale or Drigg)	4
	15-Jul-19	Northern Beaches (St Bees or Braystones)	4
	22-Jul-19	No Monitoring (Summer Holidays)	
	29-Jul-19		
	05-Aug-19		
	12-Aug-19		
	19-Aug-19		
	26-Aug-19		
	02-Sep-19		
	09-Sep-19	Northern Beaches (St Bees or Braystones)	4
	16-Sep-19	Southern Beaches (Seascale or Drigg)	4
	23-Sep-19	Strandline Monitoring	
	30-Sep-19	Sellafield	30
Q4 2019	07-Oct-19		
	14-Oct-19		
	21-Oct-19		
	28-Oct-19		
	04-Nov-19		
	11-Nov-19		
	18-Nov-19		
	25-Nov-19	Northern Beaches (St Bees or Braystones)	10
	02-Dec-19		
	09-Dec-19		
	16-Dec-19	Southern Beaches (Seascale or Drigg)	4
	23-Dec-19	No Monitoring (Winter Break)	
	30-Dec-19		
		Total ==>	**150 ha**

Figure 22: Beach monitoring programme for 2019.

10.2 Proposed Investigation Programme for 2019

Two items of further research are to be conducted in 2019, these are:

- The update of the health risk assessment.
- 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 (Atkins, (2018); 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) has 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 nearing completion and has reviewed:

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

Engagement with key stakeholders is ongoing and it is anticipated that the finalised risk assessment review will be published during 2019.

10.2.2 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 (Connor, et al., 2018a; Connor, et al., 2018b). 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 2019.

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 statuses are shown in Table 9. It should be noted that the list in Table 9 has been optimised so some of the listed tasks meet several of the requirements detailed in the workplan.

Table 9: Strategy tasks that were assessed as medium and high priority.

Tasks	Status
Synergy2 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 Synergy2 trials.	Nearing completion (see Section 9).
Evaluate the detection efficiency of Synergy2 for buried particles.	Completed (Sellafield Ltd, 2017c).
Design of beach monitoring programme to focus on high find rate beaches.	Completed (see Section 10).
Analysis of beach monitoring repeat areas to understand repopulation rates.	Completed (Sellafield Ltd, 2017c).
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.	Completed (see Section 5.3.1).
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 5.4).
Sellafield Ltd to develop staged proposals on optimising the sentinel monitoring programme.	Completed (Section 10.4).
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.

10.4 Potential Routine Beach Monitoring Programme (2020+)

Monitoring programmes for the beaches in and around Sellafield need to be risk based. The draft conclusions of the revised PHE risk assessment (Oatway, et al., 2019), as detailed in Section 9, allow the programme objectives (Section 2.4) to be modified to reduce, or indeed remove, requirements related to public health protection. Furthermore, the completion of the Particles in the Environment Forward Strategy (Section 10.3) allows the removal of the monitoring objectives related to understanding the behaviour of radioactivity in the environment and the assessment of the dose to wildlife.

Consequently, the monitoring objectives for a future routine programme would be limited to the following (Sellafield Ltd, 2019):

- Provide public and stakeholder reassurance.
- Assess long term trends (as an indicator).
- Assess whether the conclusions of the PHE Health Risk Assessment remain valid.
- Monitor for abnormal radioactive material and remove in line with the principle of As Low As Reasonably Practicable (ALARP).

The programme requirements of assessing long term trends and determining whether the conclusions of the PHE Health Risk Assessment remain valid can be used to estimate the monitoring area required. The highest recent long term (annual) alpha rich particle find rates are of the order of 1 - 6 finds/ha. Beta rich particles are rarely found at locations other than Sellafield beach (where find rates are less than one find per hectare). Hence, an increase in long term find rates by at least two orders of magnitude would be required to challenge the EA Sellafield radioactive objects intervention plan (Section 2.2) noting that risks at these find rates would still be likely to be considerably less than one in a million.

A monitoring programme focussed on demonstrating compliance with the above limits would require monitoring of an area of less than 1 ha in order to obtain an estimate of a change in find rate by two orders of magnitude (Sellafield Ltd, 2019). Practical limitations in dealing with such a number of finds would present the main monitoring constraint and early identification that intervention by the regulator may be required. Intervention criteria related to high activity alpha rich finds (1MBq ^{241}Am) also do not require monitoring of more than a few hectares as such high activities would be readily detected by the Synergy2 monitoring system (Section 3). Again, logistical considerations would provide the main limitations to the area able to be monitored.

It is not possible to quantify the area required for meeting the programme aims of stakeholder reassurance and monitoring for abnormal radioactive material. A practical programme, accounting for current commercial/ contractual issues, could have an annual target around 105 ha whilst still meeting these programme aims.

The areas covered by a 105 ha programme are shown in Table 10 and Figure 23. It should be noted that around 50% of the monitoring effort would be focussed on Sellafield beach as this beach has the highest rate of alpha rich particle finds and is the only location where beta rich particles and larger objects are typically found. Hence, monitoring at this location is required to meet the programme aim of assessing long-term trends.

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

Programme	Area to be monitored (ha)			
	Sellafield	Near-Field	Far-Field	Total
Northern Beaches	-	32	-	32
Sellafield	52	-	-	52
Southern Beaches	-	16	-	16
Allonby	-	-	5	5
Total	52	48	5	105

	Week	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near Field Programme: Target Area (ha)	Far Field Programme: Target Area (ha)
	1				
	2	No Monitoring (Winter Break)			
	3	Biannual Maintenance			
	4				
	5				
	6				
Q1	7				
	8	Sellafield	5		
	9				
	10	Northern Beaches (Braystones and/or St. Bees)		5	
	11				
	12	Strandline Monitoring			
	13				
	14	No Monitoring (Easter Holidays)			
	15				
	16				
	17				
	18				
Q2	19				
	20	Northern Beaches (Braystones and/or St. Bees)		2	
	21	Southern Beaches (Drigg and/or Seascale)		2	
	22	Sellafield	5		
	23				
	24	Allonby			5
	25				
	26	Northern Beaches (Braystones and/or St. Bees)		3	
	27	Southern Beaches (Drigg and/or Seascale)		3	
	28				
	29				
	30	No Monitoring (Summer Holidays)			
Q3	31	Biannual Maintenance			
	32				
	33				
	34				
	35				
	36				
	37	Northern Beaches (Braystones and/or St. Bees)		2	
	38	Strandline Monitoring			
	39	Sellafield	5		
	40				
	41	Northern Beaches (Braystones and/or St. Bees)		3	
	42				
	43				
Q4	44				
	45				
	46				
	47				
	48				
	49	No Monitoring (Winter Break)			
	50				
	51				
	52				
		Cumulative Totals ==>	**15 ha**	**20 ha**	**5 ha**
		OVERALL TOTAL ==>	**40 ha**		

Figure 23: Potential beach monitoring programme for 2020 and onwards.

References

Atkins, 2018. *Review of Conceptual Site Model for Particles in the Environment, 5163065-301-0001 Rev 2.0,* Moor Row: Atkins Ltd.

Atkins, 2019. *Environmental Service Support for Sellafield Meteorological Data Collectio: Sellafield Annual Meteorological Report 2018,* Westminster: Atkins Limited.

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

Connor, D. et al., 2018a. Application of airborne photogrammetry for the visualisation and assessment or contamination migration arising from a Fukishima waste storage facility. *Environmental Pollution,* Volume 234, pp. 610 - 615.

Connor, D. et al., 2018b. Radiological comparison of a FDNNP waste storage site during and after construction. *Environmental Pollution,* Volume 243, pp. 582 - 590.

Davies, M., 2014. *Radionuclide specific alarms for Am-241 and Sr-90/ Y-90, Report 87257/TR020,* Harwell: Nuvia Ltd.

Eakins, J., Hager, L., Ibrahimi, F. & Tanner , R., 2019. *Report for measurements made at PHE, CRCE, Chilton, on Sellafield particle LSN 2256635 (PHE601082),* Chilton: Public Health England.

Eakins, J., Hager, L., Ibrahimi, Z.-F. & Tanner, R., 2017. *Measurement of dose rates to skin for the December 2016 batch of ESR-199 beach finds.,* Chilton: CRCE-DSD-003-2017 Public Health England.

Environment Agency, 2017a. *Notice of variation with introductory note: The Environmental Permitting (England & Wales) Regulations 2016 Variation notice number EPR/KP3690SX/V008 Permit number KP3690SX,* Penrith: Environment Agency.

Environment Agency, 2017b. *Compilation of Environment Agency Requirements, Approvals and Specifications,* Warrington: EAR 4.2.2P2/V010 Condition 12, Issue 13, Permit KP3690SX, Environment Agency.

Environment Agency, 2017c. *Sellafield radioactive objects intervention plan: available online at https://www.gov.uk/government/publications/sellafield-radioactive-objects-intervention-plan,* Penrith: Environment Agency.

Environment Agency, 2018. *RSR Compliance Assessment Report, RASCAR-SEL-18-001,* Penrith: Environment Agency.

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

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

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

Oatway, W., Cabianca, T. & Jones, A., 2019. *Health risks from radioactive objects in the environment in the vicinity of the Sellafield site: Summary Report. Draft.,* Chilton: Public Health England.

Sellafield Ltd, 2014a. *Particles in the Environment Annual Report for 2013/14 and Forward Programme SSEM/2014/20,* Moor Row: Nuclear Decommissioning Authority.

Sellafield Ltd, 2014b. *BAT assessment for monitoring particles in the environment. June 2014,* Whitehaven: SSEM/2014/22, Nuclear Decommissioning Authority.

Sellafield Ltd, 2016. *Particles in the Environment, Annual Report for 2015/16 and Forward Programme, June 2016,* Moor Row: Nuclear Decommissioning Authority.

Sellafield Ltd, 2017a. *Particles in the Environment Forward Strategy. EM/2016/37, January 2017.,* Moor Row: Nuclear Decommissioning Authority.

Sellafield Ltd, 2017b. *BAT Assessment of Monitoring for Particles in the Environment, SSEM/2017/29.,* Whitehaven: Nuclear Decommissioning Authority.

Sellafield Ltd, 2017c. *Particles in the Environment, Annual Report for 2016/17 and Forward Programme, June 2017.,* Moor Row: Nuclear Decommissioning Authority.

Sellafield Ltd, 2018a. *Proposed revisions to the Strandline and Stormline Monitoring, EM/2018/01,* Moor Row: Nuclear Decommissioning Authority.

Sellafield Ltd, 2018b. *Particles in the Environment, Annual Report for 2017 and Forward Programme, EM/2018/07, June 2018,* Moor Row: Nuclear Decommissioning Authority.

Sellafield Ltd, 2019. *Proposed Particle Monitoring Programmes EM/2019/03.,* Moor Row: Nuclear Decommissioning Authority.

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

Tanner, R., Eakins, J. & Ibrahimi, Z.-F., 2017b. *Measurement of dose rates to skin for the May 2016 batch of beach finds.,* Chilton: CRCE-DED-02-2017 Public Health England.

Tanner, R. et al., 2017a. *Measurement of dose rates to skin made on Sellafield particle S1164/SEA.,* Chilton: CRCE-DSD-07 Public Health England.

For further information please contact:

Government Relations Officer
Sellafield Limited
Banna Court
Westlakes Science and Technology Park
Ingwell Drive
Moor Row
Cumbria
CA28 3HW

E-mail: enquiries@sellafieldsites.com
Telephone: 01946 775 656

Appendix 1: Beach Monitoring and Find Maps

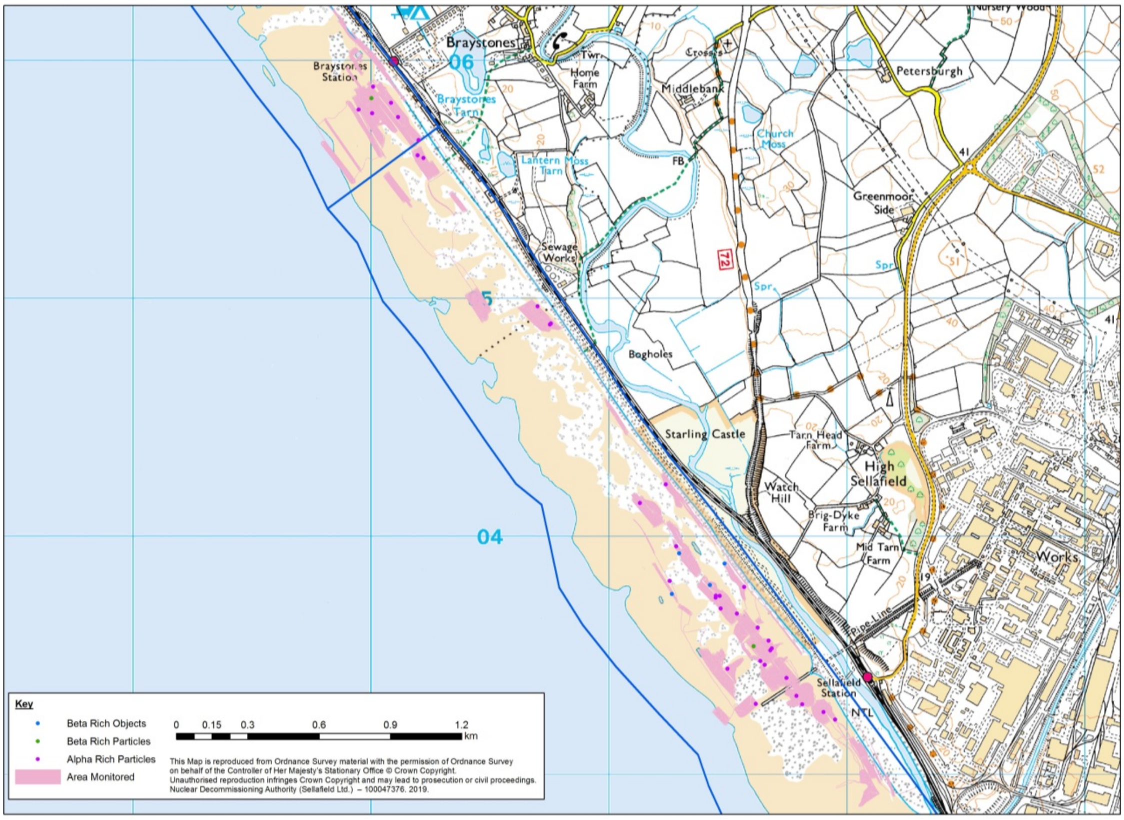


Figure A1.1 Sellafield and Braystones beach visits in January and February 2018.

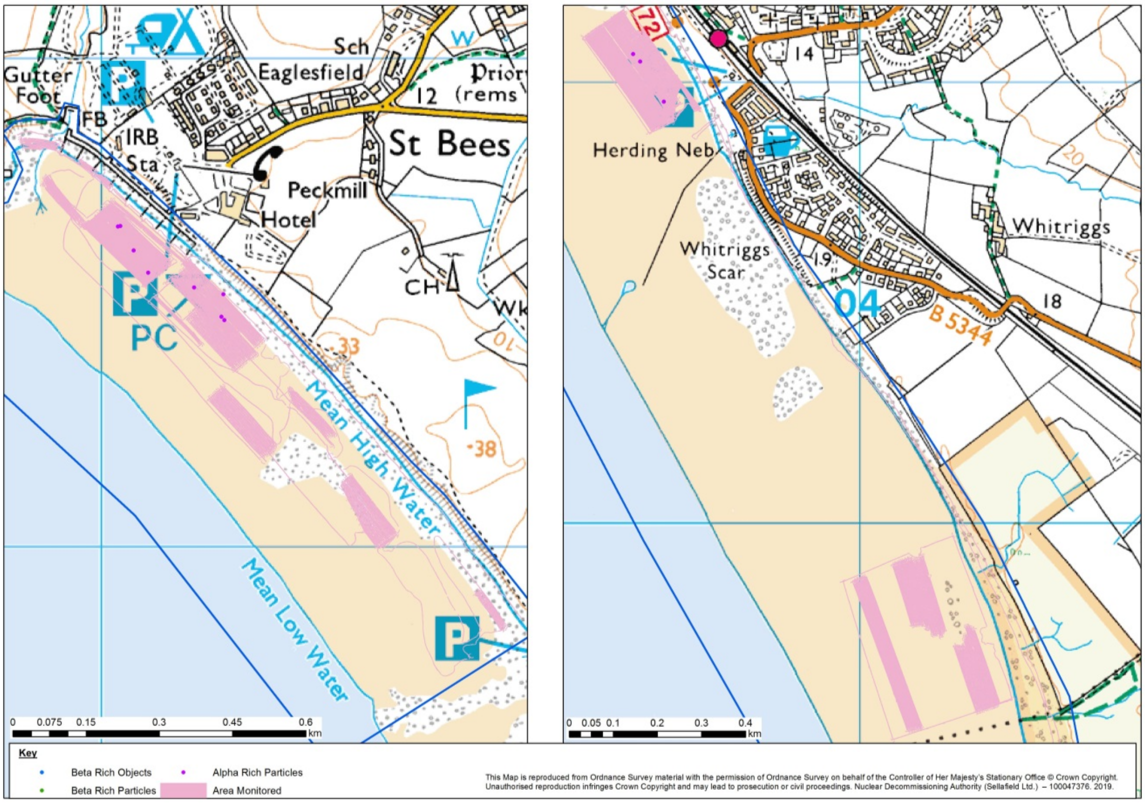


Figure A1.2 St. Bees (left) and Seascale (right) beach visits in March and April 2018.

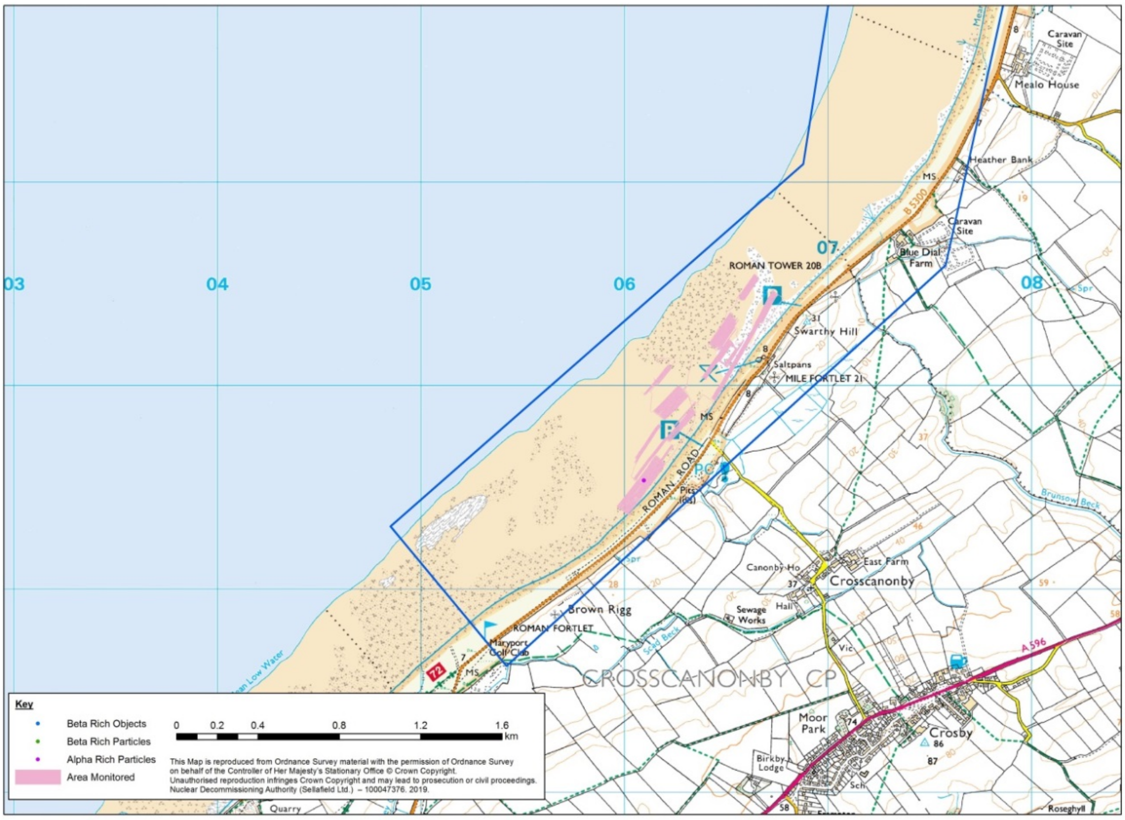


Figure A1.3   Allonby beach visit in April 2018.

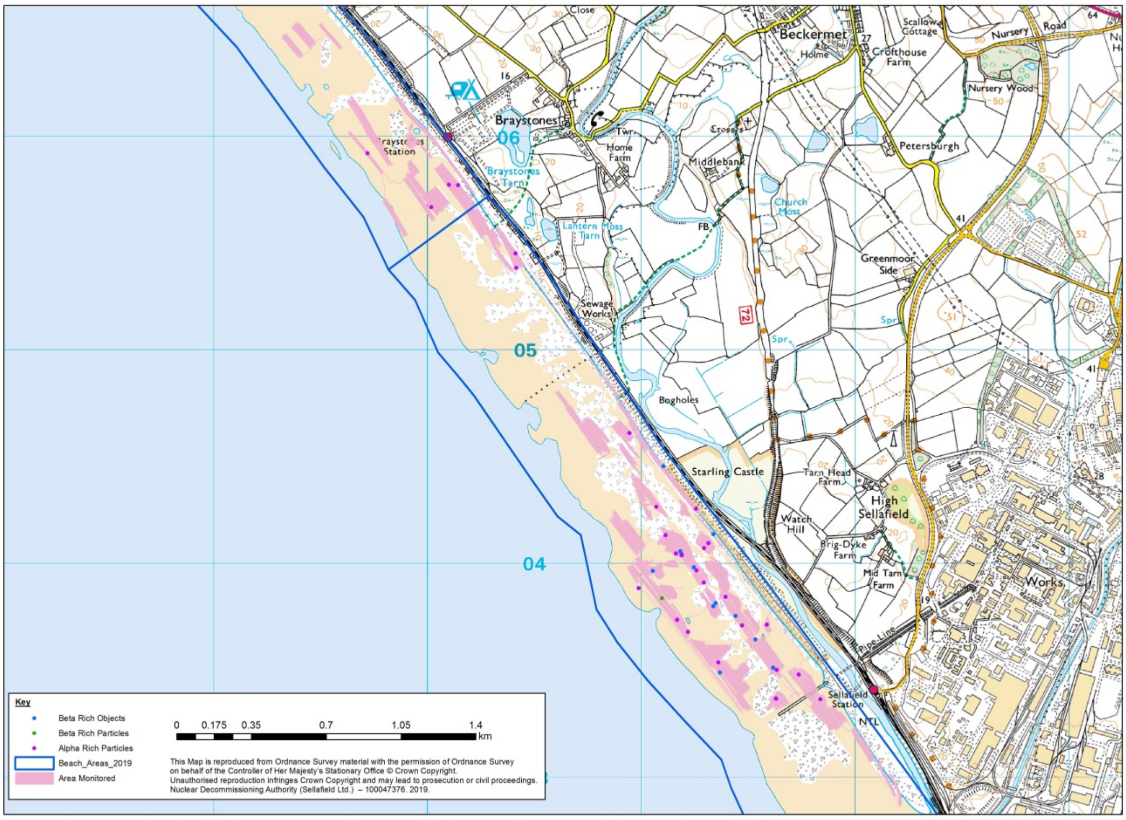


Figure A1.4   Sellafield and Braystones beach visits in May - July 2018.

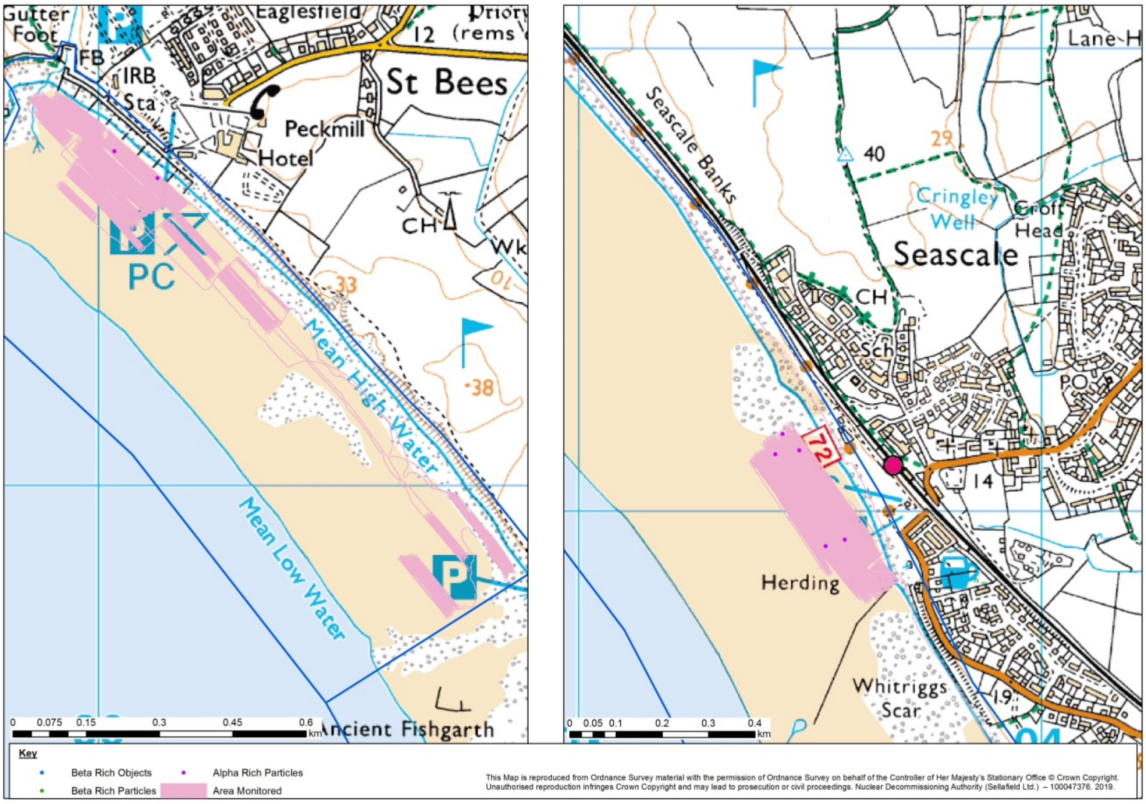


Figure A1.5 St. Bees (left) and Seascale (right) beach visits in July and September 2018.

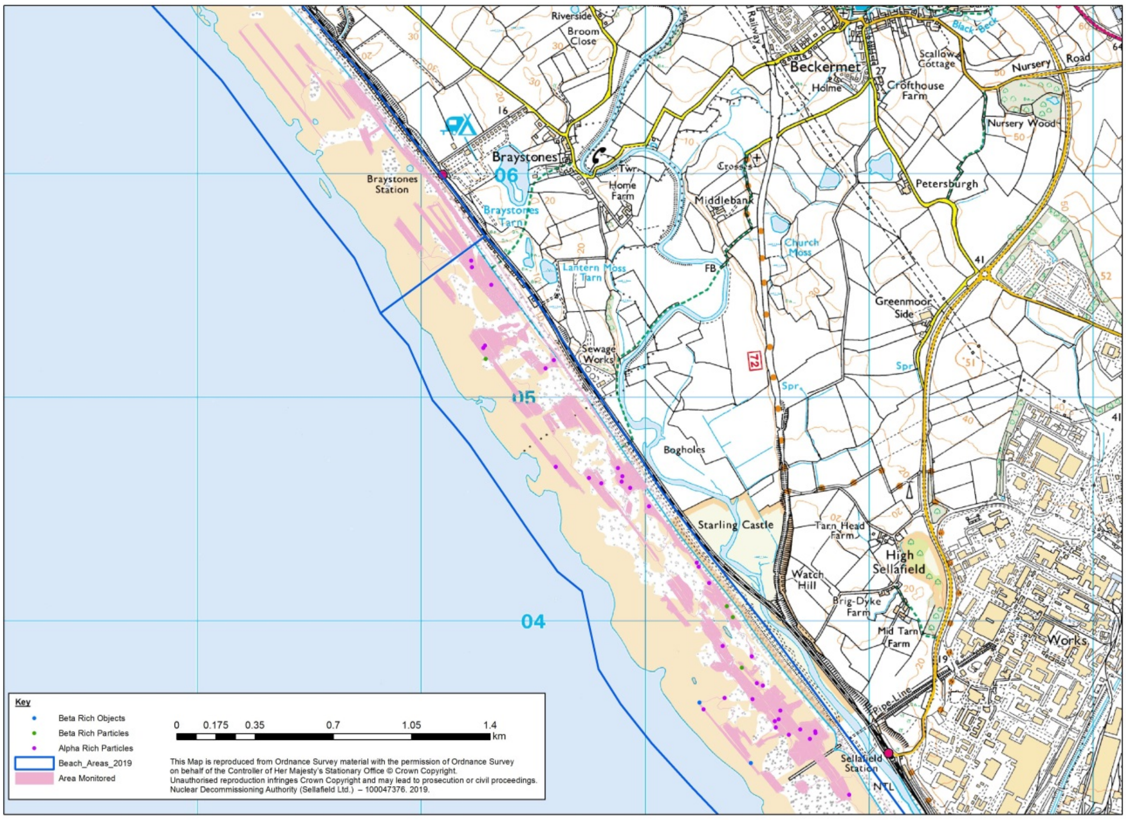


Figure A1.6 Sellafield and Braystones beach visits in September - November 2018.

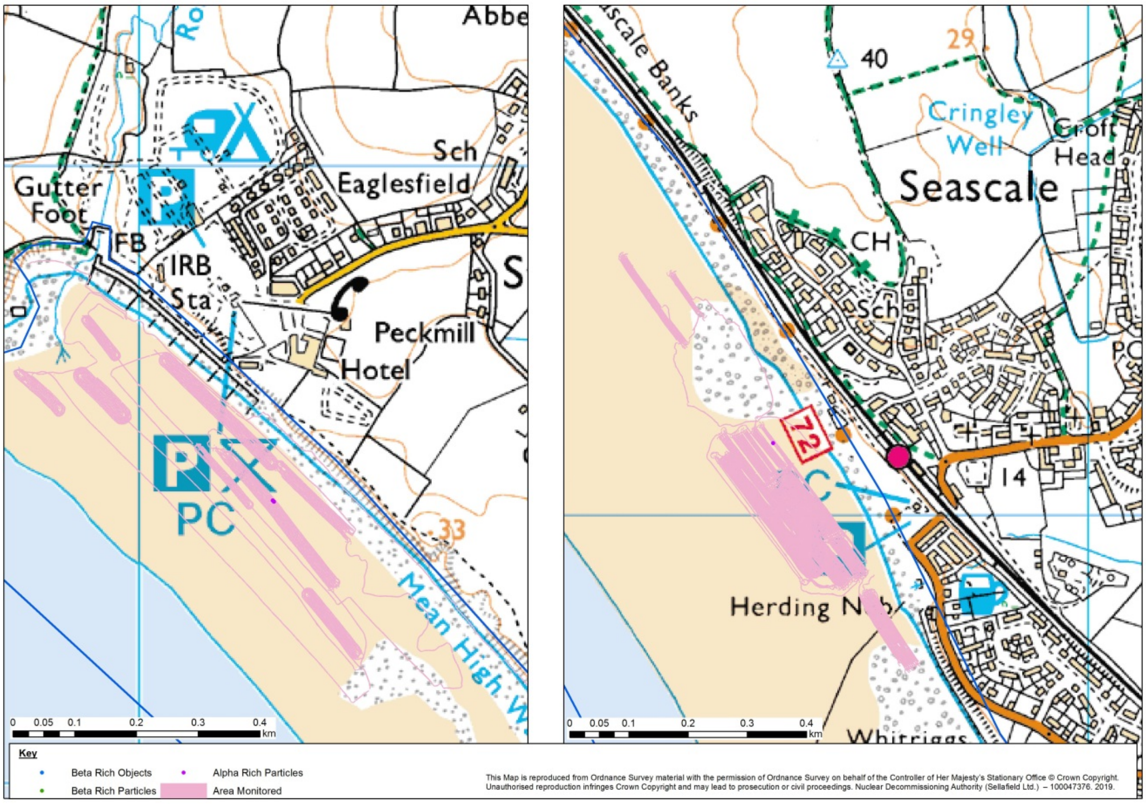


Figure A1.7 St Bees (left) and Seascale (right) beach visits in December 2018.

Appendix 2: Summary Monitoring Data to the end of December 2018

Table A2.1 Total area monitored and finds by category and beach to the end of December 2018.

Beach	Area (ha)	Alpha rich		Beta rich		Cobalt rich		Total particles	Total larger objects
		Particles	Larger objects	Particles	Larger objects	Particles	Larger objects		
Allonby	98	15	0	2	1	0	0	17	1
Workington	24	5	0	1	1	0	0	6	1
Harrington	9	4	0	0	0	0	0	4	0
Whitehaven	9	8	0	1	0	0	0	9	0
St. Bees	381	258	0	15	0	2	0	275	0
Braystones	380	434	0	36	0	4	0	474	0
Sellafield	747	1186	6	318	700	8	2	1512	708
Seascale	369	77	0	23	3	0	1	100	4
Drigg	146	26	0	2	1	0	1	28	2
TOTAL [1]	2163	2014	6	398	706	14	4	2426	716

Note 1: The total area excludes monitoring from other beach areas where no finds were recovered (Southerness 14 ha, Goatwell Bay 6 ha, Parton 2 ha, Nethertown 2 ha and Silecroft 12 ha). Including this additional area gives an overall total of 2200 ha.

Table A2.2 Particle and larger object activity summary by category and monitoring system to the end of December 2018.

	Alpha rich			Beta rich			Cobalt rich		
	Evolution	**Synergy**	**Synergy2**	**Evolution**	**Synergy**	**Synergy2**	**Evolution**	**Synergy**	**Synergy2**
Total number	62	983	975	599	206	299	11	6	1
No. of particles	59	980	975	190	103	105	7	6	1
No. of larger objects	3	3	0	409	103	194	4	0	0
Particle Mean ^{241}Am (Bq)	7.82E+04	3.00E+04	2.56E+04	3.72E+02	5.45E+02	2.07E+02	-	-	-
Particle Max. ^{241}Am (Bq)	6.34E+05	2.52E+05	1.46E+05	1.15E+03	1.63E+03	7.17E+02	-	-	-
Number of Particles Containing ^{241}Am	59	980	975	17	11	17	0	0	0
Larger Object Mean ^{241}Am (Bq)	1.74E+04	2.40E+05	-	7.62E+02	4.15E+02	1.14E+03	4.48E+03	-	-
Larger Object Max. ^{241}Am (Bq)	3.54E+04	6.18E+05	-	4.99E+03	1.17E+03	2.89E+04	4.48E+03	-	-
Number of Larger Objects Containing ^{241}Am	3	3	0	59	14	48	1	0	0
Particle Mean ^{137}Cs (Bq)	4.09E+01	1.99E+01	2.70E+02	1.51E+04	1.81E+04	2.35E+04	-	8.41E+01	-
Particle Max. ^{137}Cs (Bq)	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 ^{137}Cs	2	7	28	190	103	105	0	1	0
Larger Object Mean ^{137}Cs (Bq)	7.04E+03	5.46E+01	-	3.94E+04	5.94E+04	8.01E+04	8.17E+01	-	-
Larger Object Max. ^{137}Cs (Bq)	7.20E+03	5.46E+01	-	8.75E+05	1.04E+06	3.73E+06	8.17E+01	-	-
Number of Larger Objects Containing ^{137}Cs	2	1	0	409	103	194	1	0	0
Particle Mean ^{60}Co (Bq)	8.85E+00	1.03E+01	-	7.91E+01	-	-	1.37E+04	7.35E+03	1.09E+04
Particle Max. ^{60}Co (Bq)	8.85E+00	1.65E+01	-	2.42E+02	-	-	1.97E+04	2.38E+04	1.09E+04
Number of Particles Containing ^{60}Co	1	7	0	4	0	0	7	6	1
Larger Object Mean ^{60}Co (Bq)	- [1]	-	-	1.06E+02	-	-	1.37E+04	-	-
Larger Object Max. ^{60}Co (Bq)	-	-	-	5.33E+02	-	-	2.35E+04	-	-
Number of Larger Objects Containing ^{60}Co	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	Year	System	Area (ha)	Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	Cobalt rich particle	Cobalt rich larger object
Allonby	2008	Evolution	11	0	0	1	0	0	0
	2010	Synergy	7	0	0	0	0	0	0
	2011	Synergy	9	1	0	0	0	0	0
	2012	Synergy	11	2	0	0	0	0	0
	2013	Synergy	8	1	0	0	0	0	0
	2014	Synergy	3	2	0	0	0	0	0
	2014	Synergy2	11	7	0	1	0	0	0
	2015	Synergy2	13	0	0	0	0	0	0
	2016	Synergy2	11	0	0	0	0	0	0
	2017	Synergy2	5	1	0	0	1	0	0
	2018	Synergy2	10	1	0	0	0	0	0
Workington	2008	Evolution	11	0	0	1	0	0	0
	2012	Synergy	3	1	0	0	0	0	0
	2013	Synergy	6	1	0	0	0	0	0
	2014	Synergy2	3	2	0	0	1	0	0
	2015	Synergy2	1	1	0	0	0	0	0
Harrington	2010	Synergy	3	2	0	0	0	0	0
	2011	Synergy	2	1	0	0	0	0	0
	2012	Synergy	2	1	0	0	0	0	0
	2014	Synergy	1	0	0	0	0	0	0
	2014	Synergy2	1	0	0	0	0	0	0
	2015	Synergy2	1	0	0	0	0	0	0
Whitehaven	2008	Evolution	2	0	0	0	0	0	0

Beach	Year	System	Area (ha)	Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	Cobalt rich particle	Cobalt rich larger object
Whitehaven	2010	Synergy	5	8	0	1	0	0	0
	2011	Synergy	2	0	0	0	0	0	0
St Bees	2007	Evolution	26	2	0	4	0	0	0
	2008	Evolution	43	1	0	2	0	0	0
	2009	Evolution	39	1	0	2	0	1	0
	2009	Synergy	14	0	0	0	0	0	0
	2010	Synergy	38	45	0	2	0	0	0
	2011	Synergy	30	42	0	2	0	0	0
	2012	Synergy	30	14	0	1	0	0	0
	2013	Synergy	38	31	0	0	0	0	0
	2014	Synergy	11	6	0	0	0	0	0
	2014	Synergy2	26	33	0	1	0	0	0
	2015	Synergy2	21	30	0	1	0	0	0
	2016	Synergy2	22	25	0	0	0	1	0
	2017	Synergy2	22	16	0	0	0	0	0
	2018	Synergy2	21	12	0	0	0	0	0
Braystones	2007	Evolution	19	1	0	4	0	0	0
	2008	Evolution	19	0	0	3	0	0	0
	2009	Evolution	21	2	0	2	0	0	0
	2009	Synergy	15	25	0	2	0	0	0
	2010	Synergy	64	131	0	11	0	2	0
	2011	Synergy	45	46	0	3	0	0	0
	2012	Synergy	42	38	0	4	0	1	0
	2013	Synergy	36	51	0	3	0	1	0
	2014	Synergy	12	8	0	2	0	0	0

Beach	Year	System	Area (ha)	Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	Cobalt rich particle	Cobalt rich larger object
Braystones	2014	Synergy2	17	48	0	0	0	0	0
	2015	Synergy2	21	21	0	1	0	0	0
	2016	Synergy2	25	26	0	0	0	0	0
	2017	Synergy2	22	27	0	0	0	0	0
	2018	Synergy2	23	10	0	1	0	0	0
Sellafield	2006	Evolution	5	0	0	2	7	0	0
	2007	Evolution	35	19	1	52	162	1	1
	2008	Evolution	114	17	1	67	192	3	0
	2009	Evolution	42	9	1	31	44	2	1
	2009	Synergy	14	31	1	3	8	0	0
	2010	Synergy	51	141	2	17	41	0	0
	2011	Synergy	43	118	0	15	20	0	0
	2012	Synergy	37	77	0	16	16	1	0
	2013	Synergy	44	101	0	15	13	1	0
	2014	Synergy	13	6	0	2	5	0	0
	2014	Synergy2	27	150	0	27	36	0	0
	2015	Synergy2	80	198	0	22	38	0	0
	2016	Synergy2	82	117	0	19	67	0	0
	2017	Synergy2	80	114	0	24	34	0	0
	2018	Synergy2	81	88	0	6	17	0	0
Seascale	2007	Evolution	24	0	0	6	0	0	1
	2008	Evolution	53	3	0	5	3	0	0
	2009	Evolution	50	1	0	6	0	0	0
	2009	Synergy	20	2	0	3	0	0	0
	2010	Synergy	33	14	0	0	0	0	0

Beach	Year	System	Area (ha)	Alpha rich particle	Alpha rich larger object	Beta rich particle	Beta rich larger object	Cobalt rich particle	Cobalt rich larger object
Seascale	2011	Synergy	36	3	0	0	0	0	0
	2012	Synergy	15	6	0	0	0	0	0
	2013	Synergy	13	6	0	1	0	0	0
	2014	Synergy	9	4	0	0	0	0	0
	2014	Synergy2	31	14	0	2	0	0	0
	2015	Synergy2	16	7	0	0	0	0	0
	2016	Synergy2	28	1	0	0	0	0	0
	2017	Synergy2	22	7	0	0	0	0	0
	2018	Synergy2	22	9	0	0	0	0	0
Drigg	2007	Evolution	19	2	0	1	1	0	1
	2008	Evolution	34	1	0	1	0	0	0
	2010	Synergy	50	10	0	0	0	0	0
	2011	Synergy	5	1	0	0	0	0	0
	2012	Synergy	15	2	0	0	0	0	0
	2013	Synergy	5	0	0	0	0	0	0
	2014	Synergy	4	0	0	0	0	0	0
	2014	Synergy2	5	4	0	0	0	0	0
	2015	Synergy2	3	1	0	0	0	0	0
	2016	Synergy2	1	2	0	0	0	0	0
	2017	Synergy2	1	2	0	0	0	0	0
	2018	Synergy2	3	1	0	0	0	0	0
Seabed	2012	Seabed	Grab sampling	1	0	0	0	0	0

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

Beach	Year	System	Alpha rich particles (per ha)	Beta rich particles (per ha)	Beta rich larger objects (per ha)
Allonby	2008	Evolution	0	<0.1	0
	2010	Synergy	0	0	0
	2011	Synergy	IA	0	0
	2012	Synergy	<1	0	0
	2013	Synergy	IA	0	0
	2014	Synergy	IA	0	0
	2014	Synergy2	<1	<0.1	0
	2015	Synergy2	0	0	0
	2016	Synergy2	0	0	0
	2017	Synergy2	IA	0	IA
	2018	Synergy2	<1	0	0
St Bees	2007	Evolution	<0.1	<1	0
	2008	Evolution	<0.1	<0.1	0
	2009	Evolution	<0.1	<0.1	0
	2009	Synergy	0	0	0
	2010	Synergy	1	<0.1	0
	2011	Synergy	1	<0.1	0
	2012	Synergy	<1	<0.1	0
	2013	Synergy	<1	0	0
	2014	Synergy	<1	0	0
	2014	Synergy2	1	<0.1	0
	2015	Synergy2	1	<0.1	0
	2016	Synergy2	1	0	0
	2017	Synergy2	<1	0	0
	2018	Synergy2	<1	0	0
Braystones	2007	Evolution	<0.1	<1	0
	2008	Evolution	0	<1	0
	2009	Evolution	<0.1	<0.1	0
	2009	Synergy	2	<1	0
	2010	Synergy	2	<1	0
	2011	Synergy	1	<0.1	0
	2012	Synergy	<1	<0.1	0
	2013	Synergy	1	<0.1	0
	2014	Synergy	<1	<1	0
	2014	Synergy2	3	0	0
	2015	Synergy2	1	<0.1	0
	2016	Synergy2	1	0	0
	2017	Synergy2	1	0	0
	2018	Synergy2	<1	<0.1	0
Sellafield	2006	Evolution	0	IA	IA
	2007	Evolution	<1	1	5
	2008	Evolution	<1	<1	2
	2009	Evolution	<1	<1	1
	2009	Synergy	2	<1	<1

Beach	Year	System	Alpha rich particles (per ha)	Beta rich particles (per ha)	Beta rich larger objects (per ha)
Sellafield	2010	Synergy	3	<1	<1
	2011	Synergy	3	<1	<1
	2012	Synergy	2	<1	<1
	2013	Synergy	2	<1	<1
	2014	Synergy	<1	<1	<1
	2014	Synergy2	6	<1	1
	2015	Synergy2	2	<1	<1
	2016	Synergy2	1	<1	<1
	2017	Synergy2	1	<1	<1
	2018	Synergy2	1	<0.1	<1
Seascale	2007	Evolution	0	<1	0
	2008	Evolution	<0.1	<0.1	<0.1
	2009	Evolution	<0.1	<1	0
	2009	Synergy	<0.1	<1	0
	2010	Synergy	<1	0	0
	2011	Synergy	<0.1	0	0
	2012	Synergy	<1	0	0
	2013	Synergy	<1	<0.1	0
	2014	Synergy	IA	0	0
	2014	Synergy2	<1	<0.1	0
	2015	Synergy2	<1	0	0
	2016	Synergy2	<0.1	0	0
	2017	Synergy2	<1	0	0
	2018	Synergy2	<1	0	0
Drigg	2007	Evolution	<1	<0.1	<0.1
	2008	Evolution	<0.1	<0.1	0
	2009	Evolution	0	0	0
	2009	Synergy	0	0	0
	2010	Synergy	<1	0	0
	2011	Synergy	IA	0	0
	2012	Synergy	<1	0	0
	2013	Synergy	0	0	0
	2014	Synergy	0	0	0
	2014	Synergy2	IA	0	0
	2015	Synergy2	IA	0	0
	2016	Synergy2	IA	0	0
	2017	Synergy2	IA	0	0
	2018	Synergy2	IA	0	0

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.

This page is intentionally blank

Sellafield Ltd

Sellafield Site

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