



**A practicable and integrated
groundwater monitoring
programme proposed for the
Sellafield site**



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Executive Summary

Phase 1 of the Sellafield Contaminated Land Survey (SCLS) has recently been completed. One of the key objectives of the SCLS has been to construct a new borehole network to replace and complement the existing / historic network, a need which arose because the historic network includes boreholes that do not meet current minimum standards for groundwater sampling. A joint NII/EA (Nuclear Installations Inspectorate/Environment Agency) inspection of groundwater monitoring at Sellafield (NII/EA, 2003) recommended that a review of groundwater monitoring should be carried out.

To date, Westlakes Scientific Consulting (WSC) has provided independent reviews of both the perimeter groundwater monitoring programme and the contaminated land monitoring programme with respect to their corresponding objectives. These reviews have encompassed the evaluation of available groundwater analysis data from historic boreholes and from the newly constructed SCLS boreholes (69xx series). The reviews also considered recommendations received from the Regulators, and refers to EA guidance and both British and International Standards.

This report presents the outcome of combining the results of both reviews to design an integrated groundwater monitoring programme. This process has also involved discussions with representatives of British Nuclear Group who are responsible for the management of the groundwater monitoring programme to ensure that the programme is logistically feasible in terms of resources and laboratory capabilities. Consequently, the groundwater monitoring programme outlined herein is considered to be a practicable integrated monitoring programme for the Sellafield site that meets its stated objectives.

Non-radiological contamination is currently being evaluated as part of the application process for an IPPC (Integrated Pollution Prevention and Control) permit for the Sellafield site. This work will determine which sources of non-radiological contamination are significant enough to warrant investigation under the IPPC Site Protection and Monitoring Programme (SPMP). Consequently, the proposed groundwater monitoring programme is focused on radiological contamination.

A network of monitoring boreholes (Category A boreholes) is proposed, related to identified contaminant sources and potential contaminant migration pathways. New monitoring boreholes from the SCLS programme have been utilised wherever possible.

Additional boreholes (Category B boreholes) have been selected to supplement and validate the primary network. These are designed to provide additional information within the separation area (where the spatial variation in groundwater quality is inherently complex) and to maintain established monitoring of known contaminant plumes until it is possible to demonstrate that the new SCLS boreholes are providing representative detail of groundwater quality.

An analysis suite has been proposed for boreholes, based on their proximity to contaminant sources and historic monitoring data. The suites have been further refined to include, as a minimum, those contaminant species that, based on historic leak inventories, might leave the Sellafield site in groundwater at levels resulting in elevated doses to human or non-human biota.

The frequency at which the selected boreholes should be monitored is based on their proximity to known sources, their proximity to known contaminant plumes detected by historic groundwater monitoring and the mobility of contaminants in groundwater.

It is proposed that the supplementary (Category B) boreholes be monitored at a reduced frequency for a suite of nuclides that reflects the historic data. Until the Category A boreholes have been proved to be providing valuable and representative detail of groundwater quality, the Category B boreholes should continue to be monitored and no historic boreholes should be destroyed or otherwise decommissioned.

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1. Introduction

1.1 Background to work

Phase 1 of the Sellafield Contaminated Land Survey (SCLS) has recently been completed. One of the key objectives of the SCLS has been to construct a new borehole network to replace and complement elements of the existing/historic network, a need which arose because the historic network includes boreholes that do not meet the minimum standards for groundwater sampling. The joint NII/EA (Nuclear Installations Inspectorate/Environment Agency) inspection of groundwater monitoring at Sellafield (NII/EA, 2003), carried out as part of the requirements for compliance with the Nuclear Installation Act 1965 and Radioactive Substances Act 1993, produced a number of recommendations regarding the groundwater monitoring network. These include a recommendation that a review of the new borehole network should be carried out based on the results from the existing network, and that sampling methods should be adapted in order to meet the recommended standards presented in Best Practice documents. This best practice is summarised by Dearlove *et al.* (2004).

To date, Westlakes Scientific Consulting (WSC) has provided independent reviews of both the perimeter groundwater monitoring programme (Vickery *et al.*, 2005a) and the contaminated land monitoring programme (Vickery *et al.*, 2005b) with respect to their corresponding objectives. These reviews have encompassed the evaluation of available groundwater analysis data from historic boreholes and from the newly constructed SCLS boreholes (69xx series). The reviews also considered recommendations received from the Regulators, and refers to EA guidance and both British and International Standards.

More recently, attempts have been made to combine the results of both reviews to design an integrated groundwater monitoring programme. This process has also involved discussions with representatives of British Nuclear Group (BNG) who are responsible for the management of the groundwater monitoring programme to ensure that the programme is logistically feasible in terms of resources and laboratory capabilities. Consequently, the groundwater monitoring programme outlined herein is considered to be a practicable integrated monitoring programme for the Sellafield site that meets its stated objectives.

1.2 Objectives of the Groundwater Monitoring Programme

The integrated groundwater monitoring programme for the Sellafield site aims to assess both the current impact of operations on the Sellafield site and monitor the extent of contamination that already exists at the site. The corresponding objectives are outlined below.

1. To provide data to enable the current impact on humans and non-human species, of contaminants in groundwater, to be determined.
 - Determine the nature, scale and location of activity and other contaminants in the groundwater leaving the Sellafield site and / or available to human and non-human species.
2. Monitor changes in groundwater quality between the points that groundwater enters the Sellafield site to the points it leaves the site.
 - Determine the nature, scale and location of activity and other contaminants in the groundwater leaving the Sellafield site and / or available to human and non-human species.

- Determine the nature and scale of activity and other contaminants in the groundwater entering the Sellafield site.
3. To provide detail of groundwater quality across the Sellafield site.
 - Determine the nature, scale and extent of contamination in the groundwater beneath the Sellafield site
 4. Facilitate planning and prioritisation of remedial action.
 - Provide data to assess the direction and rate of migration of contamination entering groundwater from contaminated land and other sources.
 - Provide data (radionuclide concentrations, flows and directions) with which to assess the impact of contaminants in groundwater on actual or potential receptors including the sea or adjacent watercourses (the River Ehen and River Calder).
 - Provide data to demonstrate control and management of radioactive material accumulated in the ground.
 - Provide data to assess the rate of discharge to groundwater from contaminated land.
 - Provide data to assess the rate of generation of waste.
 5. Provide information to improve the conceptual hydrogeological model of the Sellafield site.
 - Monitor groundwater heads and hydraulic gradients across the site and provide information with which to improve the groundwater conceptual model.
 - Provide data to contribute to any routine water balance calculations for the site.

1.3 Scope of work

Development of a practicable integrated groundwater monitoring programme has involved referring to the reviews of both the perimeter groundwater monitoring programme (Vickery *et al.*, 2005a) and the contaminated land monitoring programme (Vickery *et al.*, 2005b). Both reviews, and therefore the development of the integrated monitoring programme, have involved the evaluation of:

- potential sources of radioactive and non-radioactive contamination relevant to current and historic operations on the Sellafield site;
- conceptual models of the site hydrogeology;
- groundwater samples acquired from the historic boreholes at the Sellafield site;
- groundwater samples acquired from the newly constructed SCLS boreholes (69xx series).

This information has then been used in conjunction with Best Practice guidance to determine the following criteria essential for a groundwater monitoring programme:

- borehole locations (selected from the complete network of boreholes that already exists at the Sellafield site);
- sampling and analysis suites; and,
- optimum sampling frequencies.

2. Potential sources of contamination

2.1 Sources of radiological contamination

The key sources of radiological contamination on the Sellafield site comprise installations located within the Separation Area (including the low-activity marine pipeline). The most up-to-date leak inventories for installations within the Separation Area have been used to characterise associated contamination. Leak inventories also exist for tritium mortuaries in North Group, the Calder Landfill and the South Landfill. All inventories were supplied by BNG on 21 October 2004.

In addition to the above, the SCLS team identified a number of potential sources of radiological contamination for which no leak inventories currently exist (Hunter 2004). These are the North Landfill, Calder Hall, the AGR (Advanced Gas-cooled Reactor) and other elements of North Group. Therefore, in summary, potential sources of radiological contamination include:

- A) Separation Area;
- B) North Group;
- C) Calder Landfill;
- D) South Landfill;
- E) North Landfill;
- F) Calder Hall;
- G) AGR.

Table 1 lists the radionuclides associated with each of the sources of radiological contamination on the Sellafield site, the locations of which are shown in Figure 1 (with an expanded view of the Separation Area shown in Figure 2).

2.2 Sources of non-radiological contamination

Details of non-radiological contamination sources have recently been compiled as part of the application process for an IPPC (Integrated Pollution Prevention and Control) permit for the Sellafield site. Further work is currently being undertaken to determine which of these sources are significant enough to warrant investigation under the IPPC Site Protection and Monitoring Programme (SPMP).

Consequently, at the time of writing, it is not possible to list Sellafield-specific non-radiological contaminants of concern. Therefore, industrial activities undertaken on the Sellafield site have been considered in the broadest sense in order to indicate the range of non-radiological contamination that may be expected. With reference to the Industry Profiles produced by the Department of the Environment, details of which are presented in Contaminated Land Report [CLR] 8 (Department for Environment Food and Rural Affairs and the Environment Agency, 2002), industrial activities considered pertinent to the Sellafield site (including the pre-nuclear history of the site) include the following.

- Chemical works: explosives, propellants and pyrotechnics manufacturing works.
- Chemical works: inorganic chemicals manufacturing works.
- Chemical works: organic chemicals manufacturing works.

- Engineering works: railway engineering works.
- Metal manufacturing, refining and finishing works: lead works.
- Power stations (excluding nuclear power stations).
- Railway land.
- Road vehicle servicing and repair: garages and filling stations.
- Road vehicle servicing and repair: transport and haulage centres.
- Sewage works and sewage farms.
- Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites.

Tables 2 and 3 list contaminant species (organic and inorganic respectively) associated with each of the activities that are considered to be “important” by DEFRA (Contaminated Land Report [CLR] 8, Department for Environment Food and Rural Affairs and the Environment Agency, 2002). These lists can be screened to reflect the practicability of laboratory analysis. In particular, whereas asbestos, dioxins and furans may well contaminate the soil at a relevant industrial site, they are unlikely to reside in the groundwater, unless there is a very high level of suspended particulate (AIControl Geochem and Scientific Analysis Laboratories Ltd *pers comm.*). Consequently, laboratories do not typically offer analysis of groundwater for these species and therefore we recommend that they be left out of the analysis suite unless more detailed assessments of non-radiological sources suggest that they are of particular concern.

2.3 Screening levels and limits of detection

For each of the contaminants (radiological and non-radiological) associated with potential sources on the Sellafield site, screening levels have been calculated. It is proposed that the screening levels represent the maximum (*i.e.* least sensitive) Limit of Detection (LoD) targets desirable for groundwater sample analyses.

The definition of contaminated land according to Part IIA of the Environmental Protection Act 1990 is any land that appears to be in such a condition, by reason of substances in, on or under the land that:

- significant harm (to the health of living organisms or their ecological systems) is being caused or there is a significant possibility of such harm being caused; or
- pollution of controlled waters is being, or is likely to be caused.

Therefore, as a primary guide for defining screening levels and thereby defining maximum LoD targets, the level of contamination considered capable of causing harm to both humans and non-human biota has been considered. Lower LoDs should be considered on a case by case basis if greater detail is required, for example to give early warning of migration or to provide supporting data for conceptual models.

2.3.1 Radiological

Screening levels for radioactivity in water have been derived by assessing doses to humans (Vickery *et al.*, 2005a) and doses to wildlife (Environment Agency approach defined by Copplestone, *et al.*, 2003). To be particularly conservative, when considering harm to humans, the LoD targets for radionuclides have been calculated based on individual radionuclide concentrations that may result in a 2 μ Sv dose to humans (as described in

Vickery *et al*, 2005a). These screening levels are presented in Table 4. It can be seen that the screening levels derived from assessing doses to humans are lower than those derived from assessing doses to wildlife. Therefore, it is proposed that the more sensitive levels associated with doses to humans should represent the maximum desirable LoD targets.

2.3.2 Non-radiological

Target Limits of Detection for non-radiological determinands have been calculated on the basis of advice given in Schedules 1, 4 and 5 of the Water Supply (Water Quality) Regulations 2000 (Drinking Water Inspectorate, 2000). These regulations give a permissible concentration in drinking water or value maximum for a substance and the recommended LoD as a percentage of the prescribed concentration or value maximum. These value maximums and LoDs are presented in Table 5.

3. Site hydrogeology and contaminant pathways

The Sellafield site is underlain by Triassic sandstone of the Sherwood Sandstone group, which forms a major regional aquifer. This is overlain by unconsolidated superficial deposits, largely of glacial origin, which are complex in nature, comprising mixed clays, sands and gravels. There is a major buried channel in the sandstone beneath the central part of the site, which is in-filled with unconsolidated glacial material (Dearlove, 1996a).

Regional groundwater flow in this area is generally towards the coast. However, a distinction may be made between the underlying sandstone aquifer and the superficial deposits, which are more heterogeneous hydrogeologically. The sandstone aquifer may be treated as a relatively constant system, whereas groundwater movement in the superficial deposits is likely to be more variable and dynamic (Dearlove, 1996b, Wagstaff, 1997).

Tidal influences and groundwater-surface water interactions may be important both with regard to the mass movement of water and in contaminant transport. Due to the complex nature of the superficial geology in this area, the potential for groundwater movement between rivers and streams may vary across the site, regardless of the position of the water table (Dearlove, 1996b, Wagstaff, 1997).

3.1 Contaminant pathways

Work conducted as part of the SCLS programme has resulted in the refinement of the hydrogeological conceptual model into eleven compartments comprising one “buried channel uncertainty zone” and ten contaminant pathways or migration routes (Hunter, 2004). The present report follows Hunter (2004) in the definition and geographical location of the pathways, with the addition of an eleventh pathway (Pathway 11) to encompass the only area of the Sellafield site not already compartmentalised in the SCLS conceptual model.

The refined model assumes that the pathways represent ‘corridors’ of migration of dissolved contaminants (radiological and non-radiological) discharged from clusters of sources located in close proximity to one another. A brief description of the pathways is given below, based on descriptions and assumptions presented by Hunter (2004), and shown in Figure 1 (in relation to sources of radiological contamination).

Buried Channel Uncertainty Zone (Labelled as Pathway 0 in this report for clarity)

The easternmost section of the in-filled sandstone channel (located beneath the separation area) is likely to form a crucial component in determining groundwater flow and contaminant

transport, and is also an area of significant hydrogeological uncertainty. It is therefore shown as a separate zone, and includes several source buildings.

Pathway 1

Pathway 1 connects to the southern side of the buried channel uncertainty zone, extending in a direction parallel to the regional groundwater gradient towards the beach. The up-gradient end lies within the Separation Area.

Pathway 2

Pathway 2 connects to the southern side of the buried channel uncertainty zone and extends in a direction parallel to the regional groundwater gradient towards the beach.

Pathway 3

Pathway 3 extends from the Calder Hall area (up-gradient end), southwards to the coast. The River Calder flows across the pathway at an oblique angle. Note that for the purposes of this study, Pathway 3 has been extended north-eastwards to encompass the site perimeter boundary.

Pathway 4

Connected to the western end of the buried channel uncertainty zone, with the up-gradient end located in the Separation Area.

Pathway 5

Pathway 5 is a small compartment enclosing the Southern Landfill and the mouth of the River Ehen.

Pathway 6

Pathway 6 is up-gradient of the buried channel uncertainty zone, containing a narrow buried channel aligned parallel to the long axis, presumably a 'branch' of the larger buried channel comprising Pathway 0.

Pathway 7

Pathway 7 is a small compartment enclosing the northern pair of Calder cooling towers, and accommodating the local change in direction of the River Calder at this point, connecting the northern-most part of the Calder site to the buried channel uncertainty zone.

Pathway 8

Pathway 8 encloses the Calder landfill and the beachhead.

Pathway 9

Pathway 9 is up-gradient and connected to the buried channel uncertainty zone, and encloses the North Landfill.

Pathway 10

Pathway 10 encloses the large area to the west of the site, overlying the buried Ehen channel. While in close proximity to the buried channel uncertainty zone, it is assumed to have little connection.

Pathway 11

Pathway 11 encloses the area south-east of the Calder site and north of the Calder Landfill, enclosing the site perimeter.

3.2 Linkage between contaminant sources and pathways

Depending on the locations of the contaminant sources (described in Section 2), it is possible to predict which sources are the primary and secondary contributors of contamination transported along each pathway. The primary sources are those located within (or feeding directly in to) a specific pathway, whilst secondary sources are those located just outside the pathway and, depending on local groundwater flow conditions and/or contaminant dispersion characteristics, may provide some contribution of contamination. The adoption of this approach allows for uncertainty in the precise location of the groundwater compartments / pathways to be accounted for. This linkage between (radiological) sources and pathways is summarised in Table 6.

4. Proposed integrated groundwater monitoring network

Previous reviews conducted by WSC have identified boreholes suitable for monitoring the perimeter and the inner aspect of the Sellafield site (Vickery *et al.*, 2005a & b). Those boreholes selected to monitor the perimeter took account of comprehensive and explicit guidance provided by the EA on groundwater sampling programmes in relation to landfills (Environment Agency, 2003a). Other selection criteria for monitoring boreholes within and around the site are listed below.

- Areal distribution – it is necessary to ensure boreholes are distributed across the entire Sellafield site, paying particular attention to the presence of (or potential for) significant plumes.
- Quality of borehole construction – boreholes have been categorised by British Nuclear Group based on criteria such as screen length and depth, and quality of completion.
- Accessibility of boreholes.
- Screen positions – screens will ideally represent a single water-bearing unit. Each water-bearing unit (predominantly sandstone and drift) must be adequately represented.
- Proximity to contaminant sources – in order to adequately characterise contamination, boreholes are required both up and down hydraulic gradient of contaminant sources within the site boundary.
- Historic data – groundwater monitoring data collated to date are useful for determining the likely location and extent (both spatially and temporally) of contaminant plumes.

The boreholes have been categorised firstly according to those that will represent the key integrated monitoring programme (Category A) and those that will supplement the key programme, at least until it is possible to demonstrate that the new SCLS boreholes are providing valuable and representative detail of groundwater quality (Category B). The key distinction between the Category A and B boreholes relates to quality; at any particular location requiring monitoring, the highest quality boreholes available have been selected for Category A.

The borehole coverage of the Sellafield site is such that there are several cases where two or more boreholes that could be selected are in close proximity to one another. In order to minimise unnecessary replication of data (where neighbouring boreholes show similar trends), time series data from closely neighbouring boreholes have been compared. From this, the borehole that yields the most comprehensive and/or representative data (*e.g.* a borehole in a cluster which detects higher concentrations or a wider range of radionuclides) has been selected.

The Category A boreholes have been placed into one of six different groups based on their proximity to the contaminant sources and the site boundary, as described below.

- A1: Proximal Boreholes - boreholes close to contaminant sources (<50 m from a source).
- A2: Plume Monitoring Boreholes – boreholes located within contaminant migration pathways and also within known contaminant plumes.
- A3: Near-Field Boreholes - boreholes located within contaminant migration pathways between 50 m and 300m from a source.
- A4: Far-Field Boreholes - boreholes located within contaminant migration pathways greater than 300 m from a source.
- A5: Up-Flow Boreholes - boreholes up hydraulic gradient of contaminant sources.
- A6: Sentinel Boreholes – boreholes intended to monitor contaminant plumes moving off the site in groundwater, once such a plume has been detected at the site perimeter.

The boreholes selected for Category A are listed in Table 7 and the locations are shown in Figure 3.

Supplementary boreholes (Category B) have been selected to provide additional data both within and outside of the Separation Area, as described below.

- B1: Supplementary Separation Boreholes – boreholes within the separation area (for which the spatial variation in groundwater quality is inherently complex) that have a long record of monitoring data and positive detections.
- B2: Supplementary Non-Separation Boreholes – boreholes within the contaminant migration pathways that have a long record of monitoring contaminant plumes (radiological data only) over the past 5 years (and are therefore likely to be accessible and suitable for monitoring).

The selection of Category B boreholes was performed in conjunction with representatives of British Nuclear Group in order to gain from existing knowledge of the performance of the candidate boreholes.

The selection criteria for Category B boreholes includes:

- a long history of monitoring data above the analytical LoD (but not considered to be of sufficient quality to qualify as a Category A borehole);
- proximity to a Category A borehole (thus allowing comparison to ensure existing plumes are adequately monitored by the Category A boreholes);
- the number of piezometers (to characterise the widest range of lithologies and aquifers);
- broad coverage of the site and groundwater pathways.

The boreholes selected for Category B are listed in Table 8 and the locations are shown in Figure 4.

In the main, the borehole locations that have been proposed for the perimeter and contaminated land monitoring programmes (Vickery *et al.*, 2005a & b) have all been adopted for the integrated monitoring programme. Exceptions are discussed in Appendix A.

Wherever the piezometer positions allow, groundwater samples should be taken from both the drift aquifer and the sandstone aquifer at each selected borehole.

5. Radionuclides relevant to the integrated monitoring programme

The full suite of radionuclides associated with sources on the Sellafield site is considerable (see Table 1) and to analyse groundwater samples for this full suite would be impractical from both a technical and logistical point of view. Therefore, in order to identify those radionuclides most pertinent to the objectives of the groundwater monitoring programme, the full suite has been screened. The screening process leaves those radionuclides that, based on historic leak inventories, might contribute to activity in the groundwater leaving the Sellafield site at levels resulting in a dose of $2\mu\text{Sv yr}^{-1}$ to humans or $20\mu\text{Gy hr}^{-1}$ non-human biota (*i.e.* above the screening levels listed in Table 4). The calculations are described by Vickery *et al.* (2005a) and the results are shown in Table 9. In summary, the following list of radionuclides are considered significant to one or more of the contaminant migration pathways:

- H-3, C-14, Cl-36, Co-60, Sr-90, Tc-99, I-129, Ra-226, Np-237, total U, Am-241.

In addition to the above, it is considered prudent to include Pu-239, Ru-106 and Cs-137 in the list of significant radionuclides since they are likely to be present as a result of reprocessing activities on the Sellafield site (Jim Desmond [British Nuclear Group], *pers comm.*). These three radionuclides have also been a common feature of environmental monitoring programmes at the site for almost the entire duration of site operations because their individual contributions tend to dominate the critical group dose. Therefore, monitoring these radionuclides is likely to provide valuable information about groundwater quality across the site.

By combining the information contained in Tables 6 and 9 (radionuclides associated with contaminant sources; primary and secondary sources feeding each contaminant migration pathway) it is possible to determine which of the significant radionuclides listed above one might expect to encounter in each of the contaminant migration pathways. This information is summarised in Table 10.

6. Data analysis conducted to select analysis suite

It is proposed that the analysis suites be selected with respect to:

- proximity to sources, *i.e.* what one would expect to encounter in a borehole; and,
- historic data, *i.e.* what has been encountered in historic monitoring data that cannot be explained by known sources immediately up hydraulic gradient.

6.1 Radiological contamination expected at monitoring boreholes within and around the Sellafield site

Table 11 illustrates which are the primary and secondary contaminant transport pathways relevant to each selected borehole, *i.e.* a borehole will be located directly within a pathway (primary pathway) but, if it is located close to the nominal boundary of a pathway, may also record contamination in a neighbouring (secondary) pathway. This takes account of the uncertainty in the precise location of the groundwater compartments / pathways presented by Hunter (2004).

Table 10 illustrates which of the significant radionuclides listed in Section 5 one might expect to encounter in each of the contaminant migration pathways. By combining the detail of which primary and secondary contaminant transport pathways are relevant to each borehole with the detail of which of the significant radionuclides listed in Section 5 one might expect to encounter in each pathway, it is possible to determine which of the significant

radionuclides might, in theory, be detectable in each borehole. (Please note that if a radionuclide is secondary to a pathway [Table 10] and the pathway is only secondary for a borehole [Table 11] then it has been determined that the radionuclide is not expected in that borehole.) The results of this exercise are shown in Table 12.

6.2 Radiological contamination recorded at monitoring boreholes within and around the Sellafield site

In order to use the historic data to shape the integrated groundwater monitoring programme, it is recommended that they are analysed and interpreted to highlight every recorded contaminant plume. The analysis should focus particularly on those radionuclides that have been detected in areas where they are not expected (*i.e.* there is no known source up hydraulic gradient). As a first pass, WSC has reviewed the data recorded at the perimeter boreholes between July 2001 and August 2003 (Vickery *et al.*, 2005a) and has reviewed monitoring data acquired for key contaminants within the inner aspect of the Sellafield site (Vickery *et al.*, 2005b). However, it is recommended that these historic data be analysed in more detail to help refine the integrated groundwater monitoring programme into the future.

7. Proposed analysis suites

For each monitoring borehole, in line with Environment Agency guidance (Environment Agency, 2003a & b), two analysis suites have been established, namely: an indicator measurement suite and a characterisation measurement suite.

The parameters to be included in the indicator suite will incorporate anticipated contaminant indicators, as advised in the EA guidance (2003a). As far as reasonably practicable, the indicator suite will provide an indication of changes in concentrations of the key contaminants that are known to exist or are likely to exist in groundwater at the Sellafield site (listed in Section 5).

The characterisation suite will be used to define the “fingerprint” of contamination in each borehole and will be applied whenever a significant change in contamination is identified.

7.1 Defining significant changes in contamination (trigger events)

For all but the most comprehensive analysis suite there is the potential that variation in monitoring results might indicate a significant change in groundwater quality that prompts additional sampling and/or analysis. For example, “significant change” may be deemed to have occurred when:

- the concentration of one or more analytes in the indicator suite exceeds the specified LoD (discussed in Section 2.3) for the first time in a specific borehole; and/or,
- a change in equilibrium over a specified threshold occurs (*i.e.* a deviation from the established fingerprint for each contaminant in a specific borehole).

The change in equilibrium and threshold values should be determined against a suitable reference, for example by the use of combined Shewart-CUSUM control charts (Gibbons, 1994), with outliers first identified using Grubb’s test (Gibbons, 1994). This methodology is currently employed in the analysis of groundwater monitoring data from the Sellafield Site from non-SCLS boreholes and can be applied to the SCLS data.

It should be noted that in order to carry out a statistically valid Shewart-CUSUM test at least eight historical independent samples should be analysed in order to provide reliable estimates of the mean and standard deviation of radionuclide concentrations at each borehole.

7.2 Radiological indicator suite

A basic radiological indicator suite has been defined in order to respond as far as reasonably practical, to changes in concentrations of all radionuclides with the potential to exist at the site perimeter. This has been achieved by dividing the full list of key radionuclides (Section 5) into groups of alpha-emitters, beta-emitters, gamma emitters and weak beta-emitters (with respect to their detection by standard BNG analyses), as outlined below.

Alpha-emitters: Pu alpha, U alpha, Ra-226, Np-237 and Am-241

Beta emitters: Co-60, Sr-90, Ru-106 and Cs-137

Gamma-emitters: Co-60, Ru-106 and Cs-137

Weak beta-emitters: H-3, C-14, Cl-36, Tc-99 and I-129

Inherently, measurements of total alpha, total beta and a gamma scan are indicators of alpha-emitters, beta-emitters and gamma-emitters respectively. In terms of the weak beta-emitters, the contaminated land review suggested that H-3, C-14, Cl-36, Tc-99 and I-129 should all be included within the indicator suite because they are not detected by analysis of total alpha or total beta, and are not picked up on a gamma scan (Vickery *et al.*, 2005b). However, on examination of the existing leak inventories, British Nuclear Group hypothesises that Cl-36, Tc-99 and I-129 are unlikely to occur in isolation, without H-3 or Tc-99. Furthermore, because H-3 and Tc-99 are more mobile than the other weak beta-emitters (as discussed in Section 8.1.1), they will reach monitoring boreholes before other radionuclides. This hypothesis is supported by the leak inventory database, which indicates that I-129, C-14 and Cl-36 have not occurred to date without H-3 or Tc-99 being present. Therefore, if neither H-3 nor Tc-99 is detected within a groundwater sample it is unlikely that analysing for the presence of I-129, C-14 or Cl-36 will yield a positive result. Consequently, it is proposed that H-3 and Tc-99 form part of the indicator suite, whilst I-129, C-14 and Cl-36 form part of the characterisation suite, as described in Section 7.3 below. It is suggested that this hypothesis be examined further as part of the on-going review process.

In summary:

- total alpha is an indicator for Pu alpha, U alpha, Ra-226, Np-237 and Am-241;
- total beta is an indicator for Co-60, Sr-90, Ru-106 and Cs-137;
- gamma scan detects Co-60, Ru-106 and Cs-137;
- H-3 and Tc-99 are being used as screens for I-129, C-14 and Cl-36.

7.3 Radiological characterisation suites

As defined in Section 5, it is proposed that an analysis suite be defined for each selected borehole based on the proximity of the borehole to sources and what has been encountered in historic monitoring data. Therefore, by examining the location of the selected boreholes with respect to groundwater pathways (Table 11) and comparing this with the list of contaminants that one would expect to encounter in a pathway (Table 10), it is possible to define an analysis suite for each selected borehole apart from the Up-Flow boreholes. Clearly, the presence of contaminants in boreholes up-hydraulic gradient of contaminant sources is not

expected, but, as it is necessary to determine the baseline contamination, the Up-Flow Boreholes should be analysed for all key potential contaminants listed in Section 5.

Rather than monitoring each of the boreholes to be characterised for every single significant radionuclide considered likely to be in the groundwater at that point, it is proposed that the groundwater be analysed first according to the indicator suite. The results of the indicator suite will then allow a targeted approach to characterisation and prevent unnecessary analysis (*e.g.* if the result for total alpha is below LoD then there is no point in conducting radionuclide specific analysis for alpha-emitting radionuclides). To this end, LoDs for all elements of both the indicator and characterisation suites need to be defined appropriately.

In practice, a positive measurement of gamma activity will not prompt radionuclide specific analysis because the scan already affords this information. Similarly, a positive measurement of beta activity will either be explained by the presence of beta/gamma emitters picked up on the gamma scan (Co-60, Ru-106 and Cs-137) or will prompt the analysis of Sr-90 (see flow diagram in Figure 5). However, detecting the presence of either alpha-emitters or weak beta emitters would require the analysis of a number of radionuclides, which would require significant resource. Therefore, it is proposed that samples are analysed for alpha-emitting and weak beta emitting radionuclides in priority order, based on the likelihood of a radionuclide being present at the Sellafield site. This priority order has been defined after analysis of the leak inventories, *i.e.* in order to determine the key alpha-emitting and weak beta emitting radionuclides likely to be present on the Sellafield site, the radionuclides associated with the leak inventories have been ranked according to:

- the level of activity that each radionuclide contributed to each leak; and,
- the number of leaks in which the radionuclide forms part of the inventory.

These two rankings have been combined to give an overall ranking for both alpha-emitting and weak beta-emitting radionuclides. The outcome of this ranking exercise is shown in Table 13, which lists the radionuclides in priority order.

In summary, characterisation of groundwater at a borehole will reflect the results of the indicator suite analysis as outlined below.

- Positive total alpha leads to the analysis of the alpha-emitting radionuclides expected at that location in priority order according to likelihood of occurrence, *i.e.* initially Pu alpha then, if Pu alpha does not account for the positive alpha, Am-241, then U alpha, then Np-237 and finally Ra-226. This procedure is presented in a flow diagram (Figure 6).
- Positive total beta leads to analysis of Sr-90 if it cannot be accounted for by those beta/gamma emitters identified from the Gamma scan.
- Gamma scan already characterises Co-60, Ru-106 and Cs-137
- Positive H-3 or Tc-99 leads to analysis of I-129 then Cl-36 and finally C-14 if they are expected at that location.

8. Proposed monitoring frequencies

8.1 Calculation of theoretical monitoring frequencies

As a result of reviewing both the perimeter and contaminated land monitoring programmes, it is proposed that the frequency at which contaminants should be monitored within particular boreholes depends on the following criteria:

- proximity to sources;
- proximity to known contaminant plumes detected by the historic groundwater monitoring programme; and,
- mobility of contaminants in groundwater.

The British and International Standard BS ISO 5667-18:2001 suggests the use of a nomogram method to calculate the sampling frequency for a particular monitoring point located a specific distance from a known pollution source. This methodology requires hydrogeological data on:

- hydraulic conductivity;
- effective porosity;
- hydraulic gradient between source and borehole;
- distance along flowpath between source and borehole.

Using the equation:

$$F = (D \cdot N / 86,400 \cdot K \cdot i)^{-0.1} (D \cdot N / 86,400 \cdot K \cdot i)$$

where:

F= sampling frequency (in days);

D= Distance along flowpath (m);

N = Effective porosity;

K = Hydraulic conductivity (m s^{-1});

i = hydraulic gradient (m m^{-1}).

Effective porosity and hydraulic conductivity data were obtained from recent groundwater modelling work conducted by WSC (Coleman, 2003) and represent reasonable, physically-based average values (collated from a wide range of site specific studies) for drift and bedrock encountered at the Sellafield site. Parameters for a combination of sand and gravel have been applied to the drift in order to achieve conservative results.

A site-average groundwater gradient was used for each flow path. This represents a conservatively high value, lying at the upper end of the range of gradients that have been used in previous hydrogeological assessments of the site. Coleman (2005) provides further discussion of hydrogeological parameters. If sensitivity analysis of the nomogram calculations were to be carried out, the results would most likely highlight these conservative estimates.

The nomogram methodology outlined above can take account of the first two criteria to be considered in determining monitoring frequency (proximity to sources and plumes) but does not consider the mobility of contaminants. Therefore, WSC has adapted the above methodology to incorporate contaminant retardation (Coleman, 2005). This is summarised below for radiological contaminants.

8.1.1 Proposed monitoring frequency for radiological contaminants

Contaminant migration rates for the significant radionuclides listed in Section 5 (based on groundwater flow rates selected for drift deposits and bedrock at the Sellafield site) are shown in Figure 7. Based on this information, the radionuclides have been divided into four broad categories, as outlined below:

Very mobile: H-3;

Mobile: Tc-99, Cl-36, I-129, Co-60, Ra-226;

Retarded: C-14, U-232-238, Sr-90, Np-237, Ru-106;

Very retarded: Cs-137, Am-241 and Pu-239.

These migration rates have been incorporated into the nomogram outlined above to calculate theoretical sampling frequencies for each of the significant radionuclides. (Please note that even though specific monitoring frequencies have been allocated to specific radionuclides, in practice, radionuclides such as Co-60, Ru-106 and Cs-137 will be detected on the gamma scan, which will form part of the analysis suite for every sample.)

The first four groups of boreholes in Category A (thereby excluding the Up-Flow Boreholes [Group A5] and the Off-site Sentinel Boreholes [Group A6]) have been allocated a nominal distance from the source or known plume as follows:

A1: Proximal Boreholes <50 m from a source = average of 25 m from source;

A2: Plume Monitoring Boreholes within known contaminant plumes = average 50 m from plume centre;

A3: Near-Field Boreholes between 50 m and 300m from a source = average of 175 m from source;

A4: Far-Field Boreholes between 300 m and 700 m from a source = average of 500 m from source.

These nominal distances and the radionuclide retardation factors have been used in the nomogram to calculate theoretical monitoring frequencies for each group of boreholes. These frequencies are shown in Table 14. Although the theoretical monitoring frequencies indicate that some radionuclides need only be monitored once in every ten, hundred or a thousand years, it is recognised that, in reality, reviewing site contamination at those frequencies would be unacceptable. Therefore, a decision was made that the maximum period between monitoring should be one year to feed into an annual review.

It is not sensible to calculate the monitoring frequencies for the Up-Flow Boreholes (Category A, Group 5) because the distance between the boreholes and any source that is up-hydraulic gradient (off site) is unknown. Therefore, in order to ensure adequate updating of the background contamination, it is proposed that the monitoring frequency replicates that determined for the Group 3 (Near-Field) boreholes.

It is proposed that the Sentinel Boreholes (Category A, Group 6) be monitored at the same frequency as the Group 4 (Far-Field) Boreholes because they are typically at a similar or greater distance from contaminant sources as the Far-Field Boreholes.

It should be noted that in all cases, the monitoring frequency at any borehole can be increased as a result of a trigger event (Section 8.2.3).

8.2 Proposed monitoring frequencies for radionuclides in Category A boreholes

Taking account of Environment Agency guidance (Environment Agency, 2003a), it is proposed that there will be:

- initial characterisation monitoring of groundwater flowing onto the site;
- initial characterisation of contaminated groundwater;

- routine monitoring;
- assessment monitoring in response to a trigger event; and,
- ongoing characterisation measurements.

8.2.1 Initial characterisation of radionuclides in groundwater

Initial characterisation monitoring will be conducted to define a baseline and normal range of variation for both:

- the natural groundwater entering the Sellafield site (Up-Flow Boreholes); and,
- the current contamination status of groundwater down hydraulic gradient of contaminant sources on the Sellafield site.

The Environment Agency guidance for characterising groundwater (Environment Agency, 2003a) states that:

- initial characterisation should be undertaken for at least one year;
- the monitoring period should be sufficient to characterise seasonal variations (normally quarterly);
- at least 16 sets of data should be obtained per uniform water body (in order to enable robust statistical analysis); and,
- where water characteristics are uniform in a water body, samples could reasonably be obtained from a combination of several monitoring points.

Ideally, the fingerprint of groundwater in each uniform water body (*i.e.* both the drift and sandstone aquifer in each contaminant migration pathway) would be established at the start of any groundwater monitoring programme. However, as a result of the prohibitive cost of such a programme and recognising the value of historic data collected to date, it is proposed that this fingerprinting takes place in a staged process. To this end, it is proposed that the fingerprint is set first for those boreholes most likely to encounter contamination (Proximal Boreholes [A1] and Plume Monitoring Boreholes [A2]) as well as the Up-Flow Boreholes (A5), *i.e.* starting (but not necessarily finishing) in the first year of monitoring.

As outlined in Section 7.3, it is proposed that the initial characterisation process start with analysing for and then evaluating the results of the indicator suite. Therefore, the monitoring frequency that is proposed for the elements of the indicator suite during routine monitoring (Section 8.2.2) is also relevant here. If the indicator suite prompts radionuclide specific analysis then, between the relevant boreholes monitoring a particular uniform water body, these radionuclides should be analysed at the frequency indicated in Table 14 until at least 16 measurements are available for that water body and equilibrium is established. If there are too few boreholes monitoring a uniform water body that requires monitoring for a specific radionuclide then the monitoring frequencies could be increased (compared to those presented in Table 14) in order to obtain at least 16 data that characterise seasonal variations.

It should be noted that whilst characterising the Up-Flow Boreholes and those boreholes most likely to encounter contamination, the remaining boreholes will not only be analysed according to the indicator suite but will also be characterised if the analysis results from the indicator suite cannot be explained. In particular, if any of the distal boreholes show results in the indicator suite that cannot be explained by the results of analysis in boreholes immediately up-flow then the groundwater in the borehole will also be characterised.

In order to provide an indication of how the full monitoring programme might look in the initial stages, British Nuclear Group has assessed historic data as if they were the results of the indicator suite. From this assessment, it has been possible to determine which radionuclides should be analysed in specific boreholes (both Category A and B) to define the current status of each uniform water body. The programme also includes additional Sr-90 measurements to take account of regulatory concern and historic data. This programme is presented in Appendix B and is derived entirely from information provided by BNG (Jim Desmond [British Nuclear Group], *pers comm.*).

8.2.2 *Monitoring frequency for routine monitoring of radionuclides*

Table 15 indicates the proposed frequency for monitoring each group of boreholes for analysis of each element of the indicator suite. It should be noted that the proposed frequencies for the key elements of the indicator suite (total alpha, total beta, gamma scan, H-3 and Tc-99) are more conservative than those required according to the theoretical monitoring frequencies calculated using the nomogram method. This will assist the investigation of seasonal variations and, perhaps more importantly, reassure stakeholders that best endeavours are being made to continually update the understanding of groundwater quality at the Sellafield site.

8.2.3 *Identifying and responding to significant changes in contamination (defining trigger events)*

Following a trigger event (Section 7.1), an investigation into the cause of the exceedance or change in equilibrium shall be instigated. The investigation comprises a chain of response tasks, and the investigation can be halted at any point in the chain once the cause of the trigger event has been established. This chain of tasks is described below.

1. Repeat analysis of the trigger sample will be conducted to confirm the result.
2. If the result is confirmed, a second sample will be taken and analysed.
3. If this sample also indicates a significant change, then the sample will be characterised, analysing for specific radionuclides in priority order (defined in Section 7.3 and shown in Figures 5 and 6) to “fingerprint” the contamination.
4. If the results for the existing characterisation suite do not explain the increase in activity observed then a desk study would be performed. The desk study will aim to determine whether new information on sources exists and will examine monitoring data from neighbouring and up-gradient boreholes. This might result in changes to the routine monitoring suites.
5. Once the cause of the significant change has been confirmed, enhanced attention will be applied to any neighbouring boreholes (particularly those that are down hydraulic gradient) to provide further information on the extent of the contamination event.

For Step 5, the frequency of monitoring for the indicator suite at the triggered borehole and any key boreholes associated with the significant change will be increased by a step change, *e.g.* from six-monthly to quarterly, or quarterly to monthly. The radionuclide specific analysis will be carried out at least at the frequency indicated in Table 14.

Routine monitoring frequencies and analysis suites would be reinstated once a new equilibrium (*i.e.* new borehole fingerprint) has been established.

8.2.4 *Monitoring frequency for ongoing characterisation measurements*

EA guidance (Environment Agency, 2003a) states that ongoing characterisation measurements (of leachate) should be a periodic repeat of the same measurements that were undertaken during the initial characterisation monitoring programme, but at a lower frequency. Therefore, once the initial characterisation of each group of boreholes has taken place, it is proposed that responding to a trigger event with analysis of specific radionuclides in priority order be continued indefinitely.

8.3 Proposed monitoring frequencies for radionuclides in Category B boreholes

It is proposed that the monitoring frequency assigned to Category B boreholes follows the logic defined for Category A boreholes (Section 8.2) except that the analysis of the indicator suite (as part of both the characterisation and routine monitoring) be conducted at a reduced frequency. The frequency of analysing for the indicator suite will be reduced by a step change, *e.g.* from quarterly to biannually, or monthly to quarterly, as shown in Table 15. However, if analysis results of the indicator suite prompt radionuclide specific analysis, then the frequency of monitoring for the specific radionuclides will still mirror those frequencies listed in Table 14.

9. Water level monitoring

Groundwater head levels should be monitored in all selected boreholes whenever they are sampled, in addition to any measurements for other purposes. Additional water level monitoring may be required to assist in improving the conceptual hydrogeological model of the Sellafield site.

10. Summary

This report presents the outcome of combining the results of reviewing both the perimeter groundwater monitoring programme and the contaminated land monitoring programme with respect to their corresponding objectives (Vickery *et al*, 2005a & b), to produce an integrated monitoring programme for the Sellafield site. This process has also involved discussions with representatives of British Nuclear Group who are responsible for the management of the groundwater monitoring programme to ensure that the programme is logistically feasible in terms of resources and laboratory capabilities.

Defining the integrated monitoring programme has involved:

- combining the boreholes proposed for the perimeter and contaminated land monitoring networks, removing duplications where appropriate;
- including additional historic boreholes as Supplementary Boreholes (Category B) to reflect the value of data recorded to date;
- defining a systematic approach for the prioritisation of radionuclide analysis; and,
- consideration of radionuclide mobility in calculating monitoring frequencies at all boreholes.

The objectives of the integrated monitoring programme are to:

- provide data to enable the current impact on humans and non-human species of contaminants in groundwater to be determined;

- monitor changes in groundwater quality between the points that groundwater enters the Sellafield site to the points it leaves the site;
- provide detail of groundwater quality across the Sellafield site;
- facilitate planning and prioritisation of remedial action;
- provide information to improve the conceptual hydrogeological model of the Sellafield site.

In order to achieve this, the proposed monitoring network of boreholes (Category A boreholes) comprises:

- A1: Proximal Boreholes - boreholes close to contaminant sources (<50 m from a source);
- A2: Plume Monitoring Boreholes – boreholes located within contaminant migration pathways and also within known contaminant plumes;
- A3: Near-Field Boreholes - boreholes located within contaminant migration pathways between 50 m and 300m from a source;
- A4: Far-Field Boreholes - boreholes located within contaminant migration pathways greater than 300 m from a source;
- A5: Up-Flow Boreholes - boreholes up hydraulic gradient of contaminant sources;
- A6: Sentinel Boreholes – boreholes intended to monitor contaminant plumes moving off the site in groundwater, once such a plume has been detected at the site perimeter.

In addition to the above boreholes, additional boreholes have been selected to supplement and validate the key programme, at least until it is possible to demonstrate that the new SCLS boreholes are providing valuable and representative detail of groundwater quality. These supplementary (Category B) boreholes comprise:

- B1: Supplementary Separation Boreholes – boreholes within the separation area (for which the spatial variation in groundwater quality is inherently complex) that have a long record of monitoring data and positive detections;
- B2: Supplementary Non-Separation Boreholes – boreholes within the contaminant migration pathways that have a long record of monitoring contaminant plumes (radiological data only).

Analysis suites have been proposed for boreholes based on the proximity of the borehole to sources and what has been encountered in historic monitoring data. The suites have been further refined to include as a minimum those contaminant species that, based on historic leak inventories, might leave the Sellafield site in groundwater at levels resulting in elevated doses to human or non-human biota.

The frequency at which the selected boreholes should be monitored depends on the following criteria:

- proximity to sources;
- proximity to known contaminant plumes detected by the historic groundwater monitoring programme; and,
- mobility of contaminants in groundwater.

Until the Category A (SCLS) boreholes have been proved to be providing valuable and representative detail of groundwater quality, the Category B boreholes should continue to be monitored and no historic boreholes should be destroyed or otherwise decommissioned.

The integrated monitoring programme proposed herein should be reviewed regularly to ensure that it continues to meet the monitoring objectives.

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12. Tables

Table 1: Full list of radionuclides associated with sources of radiological contamination on the Sellafield site

	Separation Area	North Group	Calder Landfill	South Landfill	North Landfill	Calder Hall	AGR
Radionuclide	A	B	C	D	E	F	G
H-3	1	1/2	1	1	5	6	6
C-14	1	3					
Cl-36	1						
Mn-54		3					
Fe-55	1	3					
Co-60	1	3					
Zn-65		3					
Se-79	1						
Sr-89	1						
Sr-90	1		1	1	5	7	7
Nb-94	1						
Nb-95	1						
Zr-95	1						
Tc-99	1						
Ru-103	1						
Ru-106	1		1	1	5		
Sb-125	1						
Sn-126	1						
I-129	1						
I-131	1						
Cs-134	1						
Cs-135	1						
Cs-137	1		1	1	5	7	7
Ce-144	1		1	1	5		
Pm-147	1						
Eu-152	1						
Eu-154	1						
Eu-155	1						
Pb-210	1						
Po-210	1	4					
Ra-226	1						
Ac-227	1						
Ra-228	1						
Th-228	1						
Th-229	1						
Th-230	1						
Pa-231	1						
Th-232	1						
U-232	1						
U-233	1						

	Separation Area	North Group	Calder Landfill	South Landfill	North Landfill	Calder Hall	AGR
Radionuclide	A	B	C	D	E	F	G
U-234	1						
U-235	1						
U-236	1						
Np-237	1		1	1	5		
Pu-238	1	3/4	1	1	5	8	
U-238	1						
Pu-239	1	3/4	1	1	5	8	
Pu-240	1	3/4	1	1	5		
Pu-241	1	3/4	1	1	5	8	
Am-241	1		1	1	5		
Pu-242	1	3/4					
Cm-242	1		1	1	5		
Am-243	1						
Cm-243	1						
Cm-244	1						
Cm-245	1						

Key:

1. Leak inventories
2. Tritium associated with B124, B136 & B138 (George Towler (SCLS) *pers comm.*)
3. Activation products associated with B136 (George Towler (SCLS) *pers comm.*)
4. Spillage from Plutonium finishing operations (Andrew Smith (WSC) *pers comm.*)
5. Potential for contaminated soil being tipped in unlicensed landfill resulting in similar inventory to that identified for Calder and South Landfills.
6. Potential tritium in cooling condensate (John Hunter (SCLS) *pers comm.*)
7. Potential moisture-induced corrosion of dry-stored, failed fuel elements left in basement mortuaries (John Hunter (SCLS) *pers comm.*)
8. Potential contamination to ground from aerial release from cooling towers in 1961 (Andrew Smith (WSC) *pers comm.*)

Table 2: Important organic chemicals associated with industrial activities relevant to the Sellafield site (from CLR 8)

Industry	Organic chemicals													
	Volatile/ Semi-Volatile Organic Compounds (VOCs/ SVOCs)													
	Oil/fuel hydrocarbons	PAHs	PCBs	Phenol	Acetone	Aromatic hydrocarbons	Chlorinated aliphatic hydrocarbons	Chlorinated aromatic hydrocarbons	Organolead compounds	Dioxins and furans	Chlorophenols	a, β and ? hexachlorocyclohexane	Dieldrin	Organotin compounds
Chemical works: explosives, propellants and pyrotechnics manufacturing works	X		X	X	X	X	X							
Chemical works: inorganic chemicals manufacturing works		X												
Chemical works: organic chemicals manufacturing works				X	X	X		X						
Engineering works: railway engineering works		X	X			X	X							
Metal manufacturing, refining and finishing works: lead works	X	X	X											
Power stations (excluding nuclear power stations)	X	X	X				X							
Railway land		X	X				X							
Road vehicle servicing and repair: garages and filling stations	X	X				X	X		X					
Road vehicle servicing and repair: transport and haulage centres		X			X	X	X		X					
Sewage works and sewage farms	X		X				X	X		X				
Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites	X	X	X				X	X		X				

Table 3: Important metals, semi-metals, non-metals and inorganic chemicals associated with industrial activities relevant to the Sellafield site (from CLR 8)

Industry	Metals										Semi-metals & non-metals				Inorganic chemicals					Other	
	List I*		List II*								List II*										
	Cd	Hg	Ba	Be	Cr	Cu	Pb	Ni	V	Zn	As	B	Se	S ₀	Complex CN ⁻	Free CN ⁻	NO ₃ ⁻	SO ₄ ²⁻	S ²⁻	Asbestos	pH
Chemical works: explosives, propellants and pyrotechnics manufacturing works		X	X		X	X	X	X		X	X						X	X		X	X
Chemical works: inorganic chemicals manufacturing works	X	X	X		X	X	X	X	X	X	X	X			X	X	X	X	X	X	X
Chemical works: organic chemicals manufacturing works					X	X	X	X	X	X					X		X			X	X
Engineering works: railway engineering works	X				X	X	X	X		X			X						X	X	X
Metal manufacturing, refining and finishing works: lead works	X				X	X	X	X		X							X	X	X	X	X
Power stations (excluding nuclear power stations)	X	X	X	X	X	X	X	X	X	X		X					X	X	X	X	X
Railway land	X				X	X	X	X	X								X			X	
Road vehicle servicing and repair: garages and filling stations					X	X	X			X										X	X
Road vehicle servicing and repair: transport and haulage centres					X	X	X		X	X			X							X	X
Sewage works and sewage farms	X	X			X	X	X	X		X					X	X	X	X	X	X	X
Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites	X				X	X	X	X		X									X	X	X

Table 4: Screening levels for radionuclides in water

Radionuclide	Screening level for humans (Bq m ⁻³) ¹	Screening level for non-human biota (Bq m ⁻³) ²
Total alpha ³	6.65E+01	3.5E+02
Total beta ⁴	5.95E+02	2.5E+06
H-3	1.85E+05	4E+10
C-14	5.75E+03	2E+06
Cl-36	3.58E+03	-
Mn-54	4.69E+03	-
Fe-55	1.01E+04	-
Co-60	9.80E+02	1E+05
Zn-65	8.55E+02	-
Se-79	1.15E+03	-
Kr-85	N/A	-
Sr-89	1.28E+03	-
Sr-90	1.19E+02	5E+05
Y-91	1.39E+03	-
Nb-94	1.96E+03	-
Nb-95	5.75E+03	-
Zr-95	3.51E+03	-
Tc-99	5.21E+03	5E+06
Ru-103	4.57E+03	-
Ru-106	4.76E+02	5E+04
Ag-110	1.19E+03	-
Sb-125	3.03E+03	-
Sn-126	7.09E+02	-
I-129	3.03E+01	1E+07
I-131	1.52E+02	5E+06
Cs-134	1.75E+02	-
Cs-135	1.67E+03	-
Cs-137	2.56E+02	2E+05
Ce-144	6.41E+02	-
Pm-147	1.28E+04	-
Eu-152	2.38E+03	-
Eu-154	1.67E+03	-
Eu-155	1.04E+04	-
Pb-210	4.83E+00	-
Po-210	2.78E+00	6E+01
Ra-226	1.19E+01	-
Ac-227	3.03E+00	-
Ra-228	4.83E+00	-
Th-228	4.63E+01	-
Th-229	6.80E+00	-
Th-230	1.59E+01	-
Pa-231	4.69E+00	-
Th-232	1.45E+01	-
U-232	1.01E+01	-
U-233	6.54E+01	-
U-234	6.80E+01	-
U-235	7.09E+01	-
U-236	7.09E+01	-
Pu-236	3.83E+01	-
Np-237	3.03E+01	-
Pu-237	3.33E+04	-
U-238	7.41E+01	6E+02
Pu-238	1.45E+01	-

Radionuclide	Screening level for humans (Bq m⁻³)¹	Screening level for non-human biota (Bq m⁻³)²
Pu-239	1.33E+01	7E+01
Pu-240	1.33E+01	-
Pu-241	6.94E+02	-
Am-241	1.67E+01	2E+02
Pu-242	1.39E+01	-
Cm-242	2.78E+02	-
Am-243	1.67E+01	
Cm-243	2.22E+01	
Cm-244	2.78E+01	
Cm-245	1.59E+01	

1. Based on concentration required to produce an annual dose of 2 µSv to an adult drinking 0.6 m³ yr⁻¹ of groundwater.
2. Based on Environment Agency habitat assessments (Coplestone *et al.*, 2003)
3. Screening level set to five times that of Pu-239, which is used as an indicator for total alpha because it is a common radionuclide in release inventories with a high ingestion dose factor. (Less common alpha-emitting radionuclides with higher ingestion dose factors are not selected because of their relative scarcity in typical source inventories.) Multiplying the screening level for Pu-239 by five takes account of the number of radionuclides likely to contribute to measurements of total alpha.
4. Screening level set to five times that of Sr-90, which is used as an indicator for total beta because it is a common radionuclide in release inventories with a high ingestion dose factor. Multiplying the screening level for Sr-90 by five takes account of the number of radionuclides likely to contribute to measurements of total beta.

Table 5: Target Limits of Detection for non-radiological species based on drinking water standards

Determinand	Units	Concentration or value maximum	LoD % of prescribed concentration/value	LoD ¹
acetone*	-	-	-	-
alkalinity ²	mg HCO ₃ /l	30		
aluminium	µg/l	200	10	20
ammoniacal nitrogen ⁵	mg/l	0.3		
ammonium	mg/l	0.5	10	0.05
antimony	µg/l	5	25	1.25
aromatic hydrocarbons*	-	-	-	-
arsenic*	µg/l	10	10	1.0
asbestos*	-	-	-	-
barium* ²	µg/l	-	-	-
benzene	µg/l	1	25	0.25
benzo(a)pyrene	µg/l	0.01	25	0.0025
benzo 3,4 pyrene ²	ng/l	10	-	-
beryllium*	-	-	-	-
biochemical oxygen demand ⁵	mg/l	2.5	-	-
boron*	mg/l	1	10	0.1
bromate	µg/l	10	25	2.5
cadmium*	µg/l	5	10	0.5
calcium ²	mg/l	250	-	-
chemical oxygen demand ⁵	mg/l	30	-	-
chloride	mg/l	250	10	25
chlorinated aliphatic hydrocarbons*	-	-	-	-
chlorinated aromatic hydrocarbons*	-	-	-	-
chromium*	µg/l	50	10	5
colour	mg/l Pt/Co	20	10	2
conductivity	µS/cm @ 20°C	2500	10	250
copper*	mg/l	2	10	0.2
cyanide*	µg/l	50	10	5
1,2-dichloroethane	µg/l	3	10	0.3
dioxins & furans*	-	-	-	-
dissolved oxygen ⁵	mg/l	5	-	-
diuron (C ₉ H ₁₀ C ₁₂ N ₂ O) ⁵	µg/l	-	-	0.1 ⁶
fluoride	mg/l	1.5	10	0.15
glyphosate (C ₃ H ₈ NO ₅ P) ⁵	µg/l	-	-	0.1 ⁶
iron	µg/l	200	10	20
lead ³ *	µg/l	25	10	2.5
	µg/l	10	10	1
magnesium ²	mg/l	50	-	-
manganese	µg/l	50	10	5
mercury*	µg/l	1	20	0.2
nickel*	µg/l	20	10	2
nitrate*	mg/l	50	10	5
nitrite	mg/l	0.5	10	0.05
Kjeldahl nitrogen ²	mg/l	1	-	-
oil/fuel hydrocarbons*	-	-	-	-
organochlorine pesticides ⁵	µg/l	-	-	0.5 ⁶

Determinand	Units	Concentration or value maximum	LoD % of prescribed concentration/value	LoD ¹
organolead compounds*	-	-	-	-
oxidizability ²	mg/O ₂ /l	5	-	-
pentachlorophenol ³	µg/l	-	-	0.1 ⁶
pesticides (total)	µg/l	0.5	25	0.125
pH* ²	pH value	9.5 (max)	-	-
		5.5 (min)	-	-
phenol* ²	µg/l	0.5	-	-
phosphorous ²	µg/l	2200	-	-
polychlorinated biphenyls*	-	-	-	-
polycyclic aromatic hydrocarbons ^{4*}	µg/l	0.1	25	0.025
potassium ²	mg/l	12	-	-
redox potential R _H ⁵	mV	-	-	-
selenium*	µg/l	10	10	1
silver	µg/l	10	-	-
sodium	mg/l	200	10	20
sulphate*	mg/l	250	10	25
sulphide*	-	-	-	-
sulphur*	-	-	-	-
surfactants ²	µg/l	200	-	-
vanadium*	-	-	-	-
volatile fatty acids ⁵	-	-	-	-
temperature ²	°C	25	-	-
tetrachloroethene	µg/l	10	10	1
tetrachloromethane	µg/l	3	20	0.6
total hardness ²	mg Ca/l	60	-	-
total organic carbon ²	mg/l	no significant increase	-	0.5 ⁷
total oxidised nitrogen ⁵	mg/l	3	-	-
total speciated hydrocarbons ⁵	µg/l	-	-	10 ⁶
trichloroethene	µg/l	10	10	1
trihalomethanes	µg/l	100	10	10
turbidity	NTU	4	10	0.4
vanadium*	-	-	-	-
zinc* ²	µg/l	5000	-	30 ⁶

Notes:

* listed in relevant industry profile (CEAR 8)

1. based on Water Supply (Water Quality) Regulations 2000 (as amended) unless otherwise stated

2. based on Water Supply (Water Quality) Regulations 1989 (as amended)

3. 1 after 25/12/13

4. benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene

5. included on recommendation by British Nuclear Group

6. recommended by British Nuclear Group (ideally LoDs should be an order of magnitude lower)

7. from Guidance on the Water Supply (Water Quality) Regulations 2000 (England) and the Water Supply (Water Quality) Regulations 2001 (Wales), 2005

Note: where LoDs have been suggested by both Water Supply Regulations and British Nuclear Group, the Water Supply value has been taken as LoD

Table 6: Primary (P) and secondary (s) contaminant sources relevant to contaminant transport pathways

	Separation Area	North Group	Calder Landfill	South Landfill	North Landfill	Calder Hall	AGR
	A	B	C	D	E	F	G
Pathway 0	P	P			P	P	
Pathway 1	P	P			P	P	
Pathway 2	P	P			P	P	
Pathway 3	s	s			s	P	
Pathway 4	P	P			P	P	s
Pathway 5	s	s		P		P	
Pathway 6		P			s		
Pathway 7					P	P	
Pathway 8			P			s	
Pathway 9		s			P		
Pathway 10	s	s			s		P
Pathway 11						s	

Table 7: Boreholes selected to represent the integrated monitoring programme (Category A)

Primary Pathway	Borehole Group					
	A1	A2	A3	A4	A5	A6
0	719p1, 743p1, 767p1, 767p2, 767p3, 770p2, 770p3, 2410p1, 2410p2					
1	744p1, 4041p1, 4041p2, 4041p3, 4082p1, 4082p2, 4363p1, 4539p1, 4539p2, 4539p3, <i>6902p1, 6902p1,</i> <i>6902p2, 6910p1, 6910p2</i>	4382p1, 4382p2, 4382p3, 6226p1, 6226p2, 6227p1, 6227p2, 6228p1, 6228p2, 6229p1, <i>6914p1, 6914p2,</i> <i>6915p1, 6915p2</i>				<i>6973p1, 6973p2, 6974p1,</i> <i>6974p2</i>
2	755p1, 3005p1, 3005p2, 4542p1, 4542p2, <i>6903p1,</i> <i>6903p2</i>	<i>6904p1, 6905p1, 6905p2,</i> <i>6917p1, 6917p2, 6918p1,</i> <i>6919p1, 6920p1, 6920p2,</i> <i>6926p1, 6926p2</i>				<i>6978p1</i>
3	<i>6923p1, 6923p2</i>	2744p1, 4991p1, 4996p1, 4996p2, <i>6921p1, 6927p1,</i> <i>6928p1, 6929p1, 6929p1,</i> <i>6929p2, 6948p1</i>	<i>6951p1, 6952p1, 6953p1,</i> <i>6954p1</i>	4688p1	<i>6957p1, 6957p2, 6967p1</i>	<i>6977p1, 6977p2</i>
4	708p1, <i>6908p1, 6908p2</i>	<i>6909p1, 6909p2</i>				<i>6969p1, 6969p2, 6972p1,</i> <i>6972p2</i>
5	<i>6979p1, 6979p2</i>					
6	782Ap1		<i>6938p1, 6940p1</i>		<i>6964p1</i>	
7					<i>6945p1</i>	
8	<i>6925p1, 6980p1, 6981p1,</i> <i>6981p2</i>					
9	781p1, 781p2, 781p3, 6942p1, <i>6942p2, 6984p1,</i> <i>6984p2</i>		<i>6941p1</i>			
10		<i>739p1, 6907p1, 6936p1,</i> <i>6936p2</i>	<i>6935p1, 6935p2</i>		<i>6959p1, 6961p1, 6962p1</i>	
11				<i>6947p1, 6949p1</i>	<i>6965p1, 6966p1</i>	

Note: SCLS boreholes shown in italics

Table 8: Boreholes selected to represent the integrated monitoring programme (Category B)

Primary Pathway	Borehole Group	
	B1	B2
0	4681p1, 4682p1, 6985p1, 6985p2, 720p1, 769p1, 769p2, 771p1, 783p1, 783p2, 783p3, 784p1, 790p1, 790p2, 790p3	
1	1901p1, 2463p1, 4081p1, 4081p2, 4540p1, 4540p2, 4541Pp1, 4541Pp2, 4691p1, 4691p2, 754p1, 785p1, 785p2, 785p3, 785p4, 787p1, BHP142, BHP142p1, BHP149p1, BHP149p2	4025p1, 6113p1, 6113p2, 6118p1, 6118p2, 6911p1, 6911p2, 6912p1, 6912p2, 6913p1, 6913p2, 6986p1, 6986p2
2	2794p1, 3006p1, 794Ap1, 794Ap2, 804p1, 804p2, 804p3	4023Bp1, 4538Pp1, 4538Pp2, 4538Pp3, 711p1, 740p1, 801p1
3	5767p1	1239p1, 1241p1, 2028Pp1, 2564p1, 2796p1, 2796p2, 4027Bp1, 4683p1, 4684p1, 4994p1, 4994p2, 793p1, 793p2, 793p3
4	4690p1	6975p1, 6975p2
5		
6		5080p1, 748p1
7		
8		1248Pp1
9		733p1
10		5688p1, 5688p2, 5688p3, 738p1
11		

Table 9: Radionuclides (associated with contaminant sources) capable of reaching the site perimeter (per pathway in hydrogeological contact with the site perimeter) at a detectable level (above screening level) before 2220.

Radionuclide	Pathway 1	Pathway 2	Pathway 3	Pathway 4	Pathway 5	Pathway 8	Pathway 9	Pathway 10	Pathway 11
H-3	Y	Y	Y	Y	Y	Y	Y	Y	Y
C-14	Y	Y		Y				Y	
Cl-36	Y	Y	Y	Y	Y			Y	
Mn-54									
Fe-55									
Co-60	Y			Y				Y	
Zn-65									
Se-79									
Sr-89									
Sr-90	Y				Y	Y	Y		
Nb-94									
Nb-95									
Zr-95									
Tc-99	Y	Y	Y	Y	Y			Y	
Ru-103									
Ru-106									
Sb-125									
Sn-126									
I-129	Y	Y	Y	Y	Y			Y	
I-131									
Cs-134									

Radionuclide	Pathway 1	Pathway 2	Pathway 3	Pathway 4	Pathway 5	Pathway 8	Pathway 9	Pathway 10	Pathway 11
Cs-135									
Cs-137									
Ce-144									
Pm-147									
Eu-152									
Eu-154									
Eu-155									
Pb-210									
Po-210									
Ra-226	Y	Y	Y	Y	Y			Y	
Ac-227									
Ra-228									
Th-228									
Th-229									
Th-230									
Pa-231									
Th-232									
U-232									
U-233									
U-234	Y			Y				Y	
U-235	Y			Y				Y	
U-236	Y			Y				Y	
Np-237					Y	Y			
Pu-238									
U-238	Y			Y				Y	
Pu-239									
Pu-240									
Pu-241									
Am-241						Y			
Pu-242									
Cm-242									
Am-243									
Cm-243									
Cm-244									
Cm-245									

Table 10: Significant radionuclides that have the potential to occur as a Primary (P) or Secondary (s) contaminant in each migration pathway

Radio-nuclide	Path 0	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	Path 7	Path 8	Path 9	Path 10	Path 11
H-3	P	P	P	P	P	P	P	P	P	P	P	s
C-14	P	P	P	s	P	s	P			s	s	
Cl-36	P	P	P	s	P	s					s	
Co-60	P	P	P	s	P	s	P			s	s	
Sr-90	P	P	P	P	P	P	s	P	P	P	P	s
Tc-99	P	P	P	s	P	s					s	
Ru-106	P	P	P	s	P	P	s	P	P	P	s	
I-129	P	P	P	s	P	s					s	
Cs-137	P	P	P	P	P	P	s	P	P	P	P	s
Ra-226	P	P	P	s	P	s					s	
U-232	P	P	P	s	P	s					s	
Np-237	P	P	P	s	P	P	s	P	P	P	s	
Pu-239	P	P	P	P	P	P	P	P	P	P	s	s
Am-241	P	P	P	s	P	P	s	P	P	P	s	

Table 11: Primary and secondary pathways relevant to each borehole within the integrated groundwater monitoring network

Primary Pathway	Secondary Pathway	Borehole(s)
0	-	<i>720, 769, 771, 783, 4682, 6985</i>
0	1	767 , <i>790, 2410, 4681</i>
0	2	719, 770
0	4	743 , <i>784</i>
1	-	<i>BHP149, 1901, 2429, 2463, 4025, 4041, 4081, 4082, 4363, 4691, 6113, 6118, 6910, 6913, 6914, 6915, 6973, 6986</i>
1	2	<i>754, 787, 4539P, 4540, 4541P, 6226-6229, 6902, 6911, 6912</i>
1	4	<i>BHP142, 744, 785, 4382, 6974</i>
2	-	<i>794A, 3005, 3006, 4023B, 4538P, 6903, 6904, 6905, 6917, 6920</i>
2	1	<i>711, 6978, 755, 801, 804, 4542P</i>
2	3	<i>2794, 6918, 6919, 6926</i>
3	-	<i>793, 1239, 1241, 2028P, 2564, 2744P, 2796, 4027B, 4683, 4684, 4688, 4991, 4994, 6921, 6927, 6928, 6929, 6948, 6951, 6954, 6957, 6967, 6977</i>
3	2	<i>4996, 5767</i>
3	5	6923
3	11	6952 , 6953
4	-	6908 , 6972
4	1	708 , <i>4690, 6909, 6975</i>
4	10	6969
5	-	6979
6	-	782 , <i>5080, 6940, 6964</i>
6	9	<i>748, 6938</i>
7	-	6945
8	-	6925 , 6980
8	5	6981
9	-	6941
9	7	<i>733, 6942, 6984</i>
9	6	781
10	-	<i>739, 740, 5688, 6935, 6959, 6961, 6962</i>
10	4	<i>738, 6907</i>
10	6	6936
11	-	6947 , 6949 , 6965
11	3	<i>1248P, 6966</i>

Key: Category A boreholes in **BOLD**; Category B boreholes in *italics*

Table 12: Nuclides expected to be associated with boreholes at the Sellafield site

Borehole location		Analyte															
Primary pathway	Secondary pathway	Alpha	Beta	H-3	C-14	Cl-36	Co-60	Sr-90	Tc-99	Ru-106	I-129	Cs-137	Ra-226	Np-237	Total U	Pu-239	Am-241
0	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
0	1			X	X	X	X	X	X	X	X	X	X	X	X	X	X
0	2			X	X	X	X	X	X	X	X	X	X	X	X	X	X
0	4			X	X	X	X	X	X	X	X	X	X	X	X	X	X
1	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
1	2			X	X	X	X	X	X	X	X	X	X	X	X	X	X
1	4			X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	1			X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	3			X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	2			X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	5			X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	7			X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	11			X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	1			X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	10			X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
6	-			X	X		X	X		X		X		X		X	X
6	9			X	X		X	X		X		X		X		X	X
6	10			X	X		X	X		X		X		X		X	X
7	-			X				X		X		X		X		X	X
7	3			X				X		X		X		X		X	X
7	9			X				X		X		X		X		X	X
8	-			X				X		X		X		X		X	X
8	5			X				X		X		X		X		X	X
9	-			X	X		X	X		X		X		X		X	X

Borehole location		Analyte															
Primary pathway	Secondary pathway	Alpha	Beta	H-3	C-14	Cl-36	Co-60	Sr-90	Tc-99	Ru-106	I-129	Cs-137	Ra-226	Np-237	Total U	Pu-239	Am-241
9	6			X	X		X	X		X		X		X		X	X
9	7			X	X		X	X		X		X		X		X	X
10	-			X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	0			X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	4			X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	6			X	X	X	X	X	X	X	X	X	X	X	X	X	X
11	-			X				X				X				X	
11	3			X				X				X				X	
Up-flow																	

Table 13: Priority order of radionuclides listed in the leak inventories for Sellafield site (ranking based on frequency of inclusion within leak inventories and the relative level of associated activity).

Alpha-emitting nuclides	Weak beta-emitting nuclides
Pu Alpha	Tc-99
Am Alpha	H-3
U Alpha	I-129
Np-237	Cl-36
<i>Cm Alpha*</i>	C-14
Ra-226	
<i>Pa-231*</i>	
<i>Po-210*</i>	
<i>Th Alpha*</i>	

* Radionuclides unlikely to reach the site perimeter at levels resulting in a dose of 2µSv to human or non-human biota.

Table 14: Theoretical monitoring frequencies

Radionuclide	Category A Group 1 (25 m)		Category A Group 2 (50 m)		Category A Groups 3 & 5 (175 m)		Category A Groups 4 & 6 (500 m)	
	Time between sampling (years)	Equivalent monitoring frequency	Time between sampling (years)	Equivalent monitoring frequency	Time between sampling (years)	Equivalent monitoring frequency	Time between sampling (years)	Equivalent monitoring frequency
H-3	0.12	Monthly	0.23	Quarterly	0.81	Biannually	2.30	Annually
Tc-99	0.41	Biannually	0.81	Annually	2.85	Annually	8.13	Annually
Cl-36	0.47	Biannually	0.93	Annually	3.26	Annually	9.30	Annually
I-129	0.47	Biannually	0.93	Annually	3.26	Annually	9.30	Annually
Co-60	0.70	Biannually	1.40	Annually	4.89	Annually	13.97	Annually
Ra-226	0.70	Biannually	1.40	Annually	4.89	Annually	13.97	Annually
C-14	1.28	Annually	2.56	Annually	8.97	Annually	25.63	Annually
U alpha	3.61	Annually	7.23	Annually	25.30	Annually	72.29	Annually
Sr-90	5.95	Annually	11.89	Annually	41.63	Annually	118.95	Annually
Np-237	11.78	Annually	23.56	Annually	82.46	Annually	235.59	Annually
Ru-106	35.11	Annually	70.22	Annually	245.76	Annually	702.17	Annually
Am-241	116.76	Annually	233.52	Annually	817.32	Annually	2335.20	Annually
Pu-239	291.73	Annually	583.45	Annually	2042.09	Annually	5834.54	Annually
Cs-137	1399.85	Annually	2799.70	Annually	9798.97	Annually	27997.05	Annually
Total alpha (as for Ra-226*)		Biannually		Annually		Annually		Annually
Total beta (as for Sr-90@)		Annually		Annually		Annually		Annually
Gamma scan (as for Co-60#)		Biannually		Annually		Annually		Annually

* Fastest radionuclide in suite being indicated by total alpha)

@ Fastest radionuclide in suite being indicated by total beta

Fastest radionuclide in suite being indicated by gamma activity

Table 15: Proposed monitoring frequency for elements of the indicator suite

	Total alpha	Total beta	Gamma scan	H-3	Tc-99
A1	Quarterly	Quarterly	Quarterly	Monthly	Quarterly
A2	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
A3	Biannually	Biannually	Biannually	Biannually	Biannually
A4	Annually	Annually	Annually	Annually	Annually
A5	Biannually	Biannually	Biannually	Biannually	Biannually
A6	Annually	Annually	Annually	Annually	Annually
B1	Biannually	Biannually	Biannually	Quarterly	Biannually
B2	Biannually	Biannually	Biannually	Biannually	Biannually

13. Figures

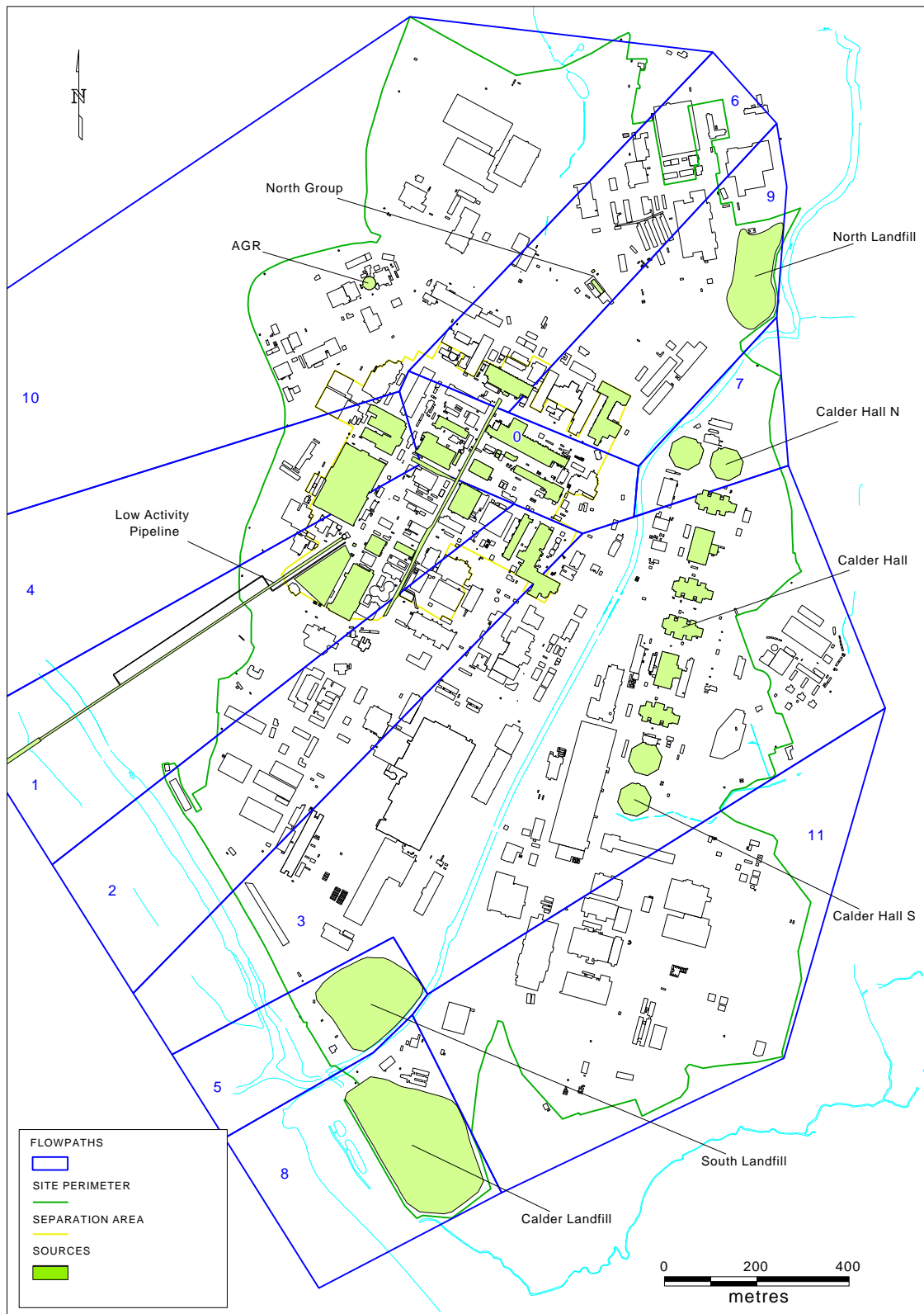


Figure 1: Sources of radiological contamination considered during review of contaminated land monitoring network

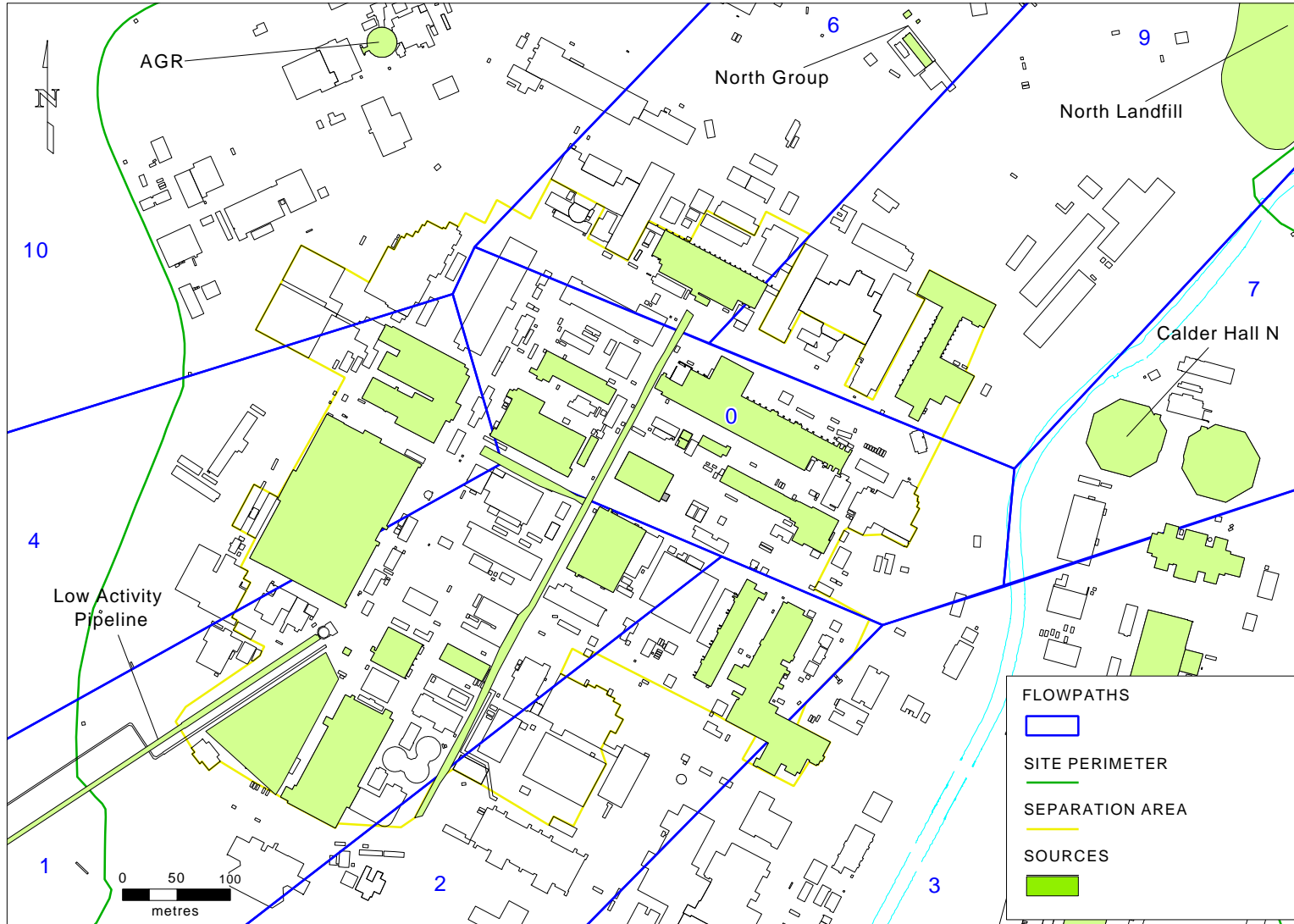


Figure 2: Detail of radiological sources in the Separation Area.

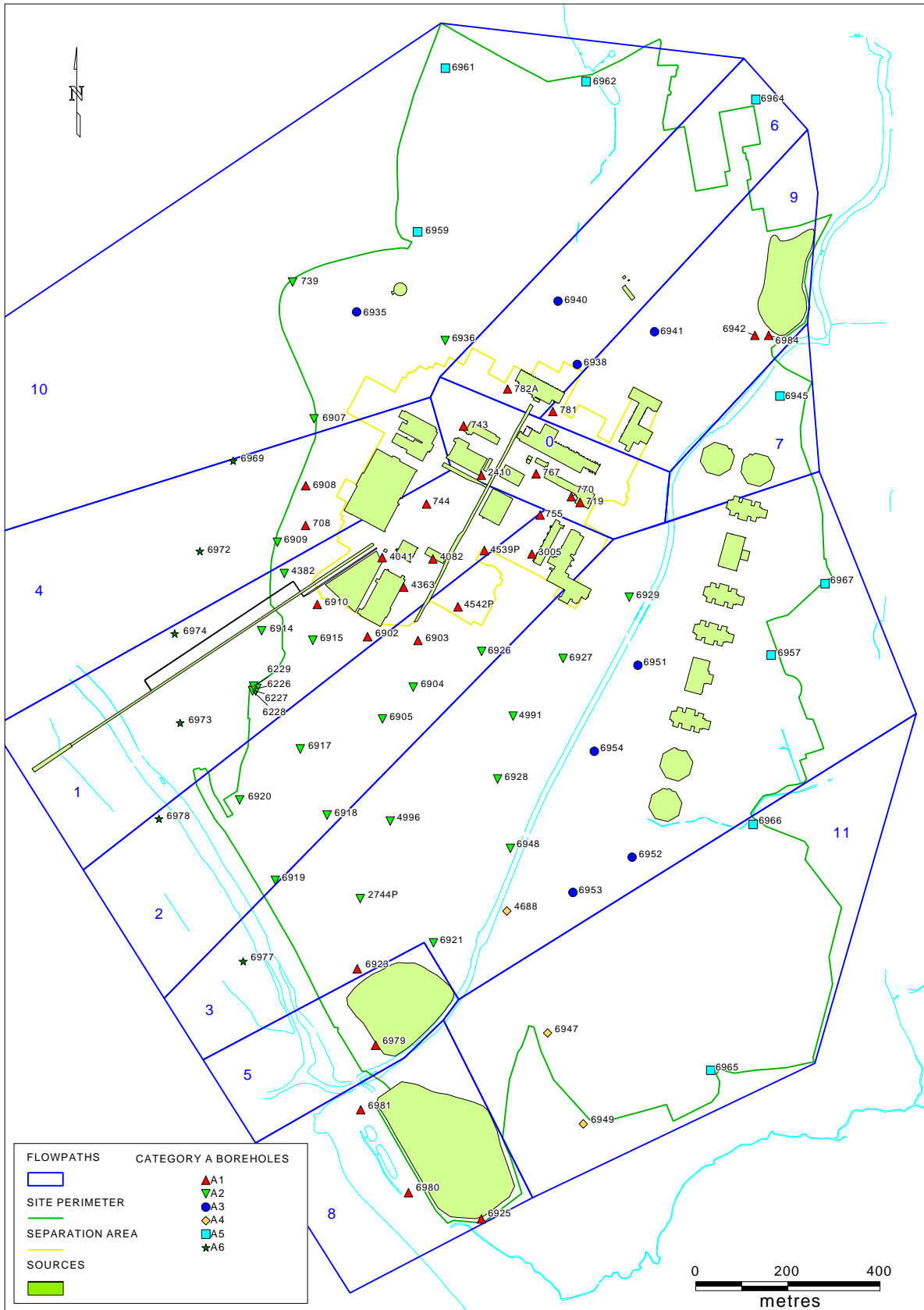


Figure 3: Location of Category A boreholes

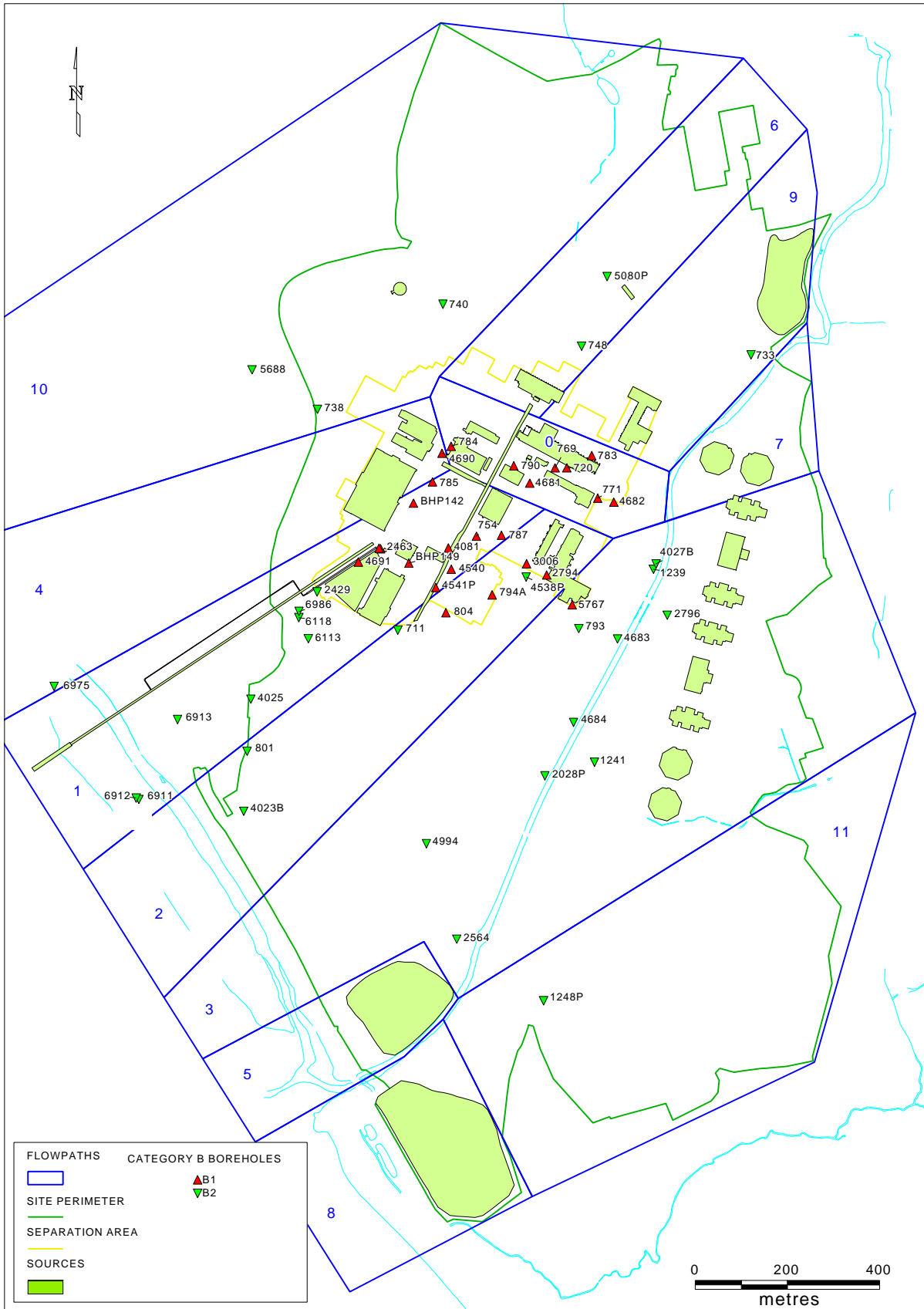


Figure 4: Location of Category B boreholes

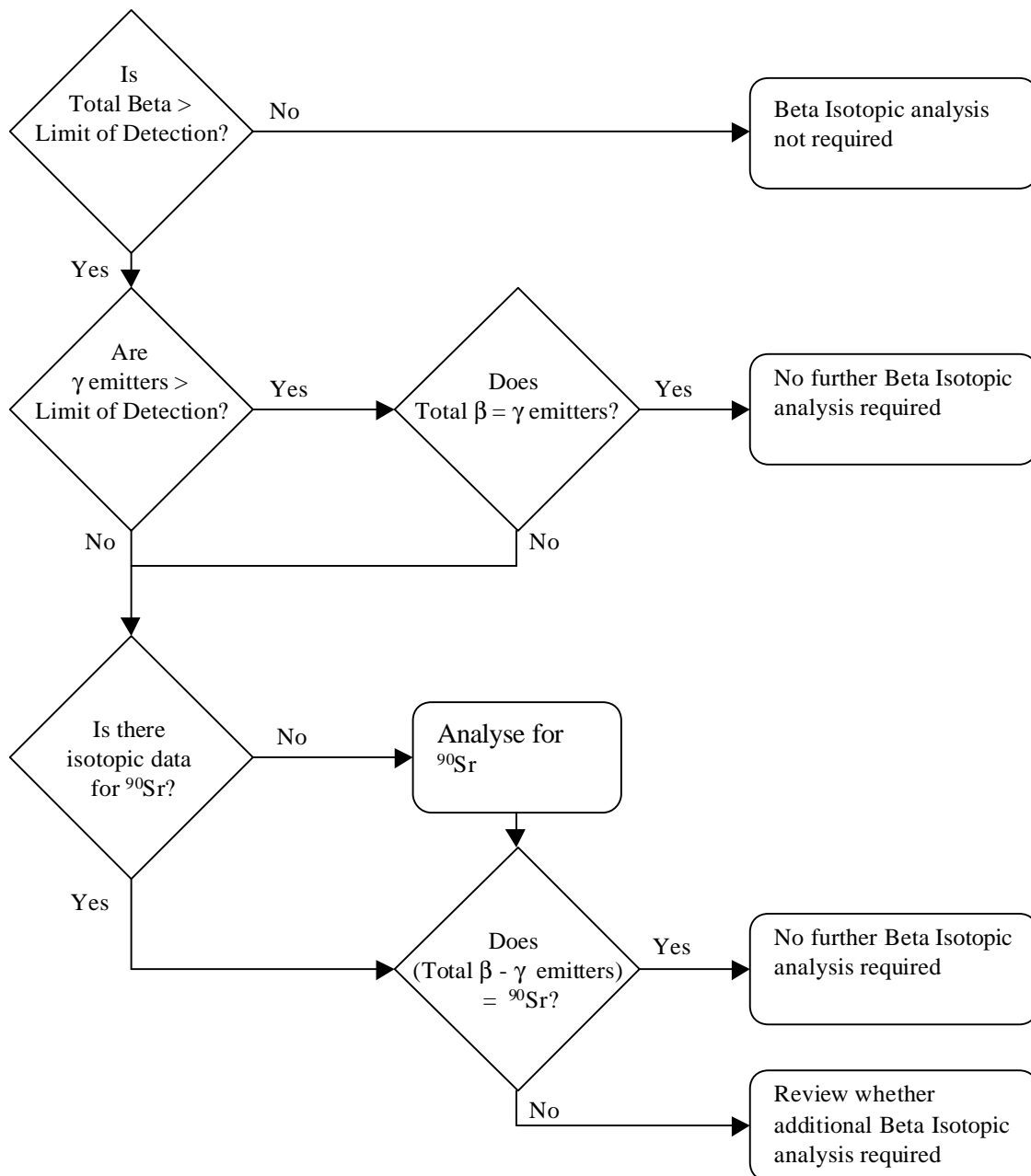


Figure 5: Flow of radionuclide specific analysis for beta-emitting nuclides

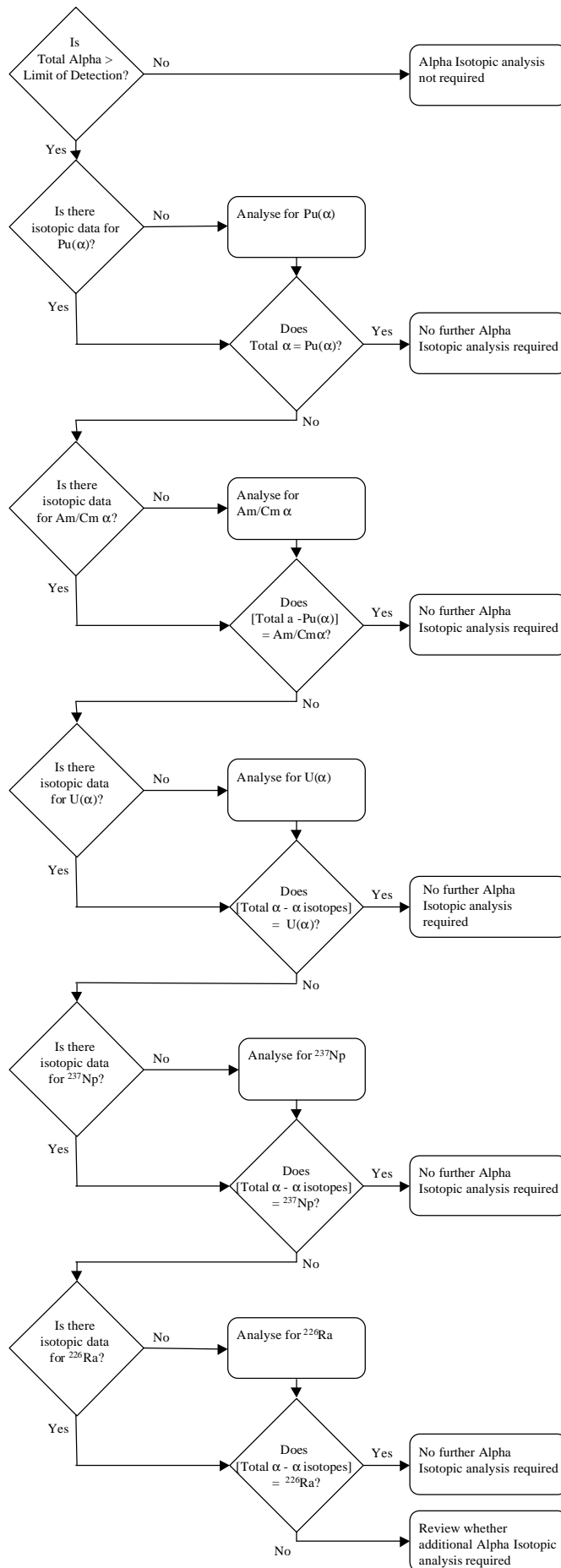


Figure 6: Flow of nuclide specific analysis for alpha-emitting nuclides

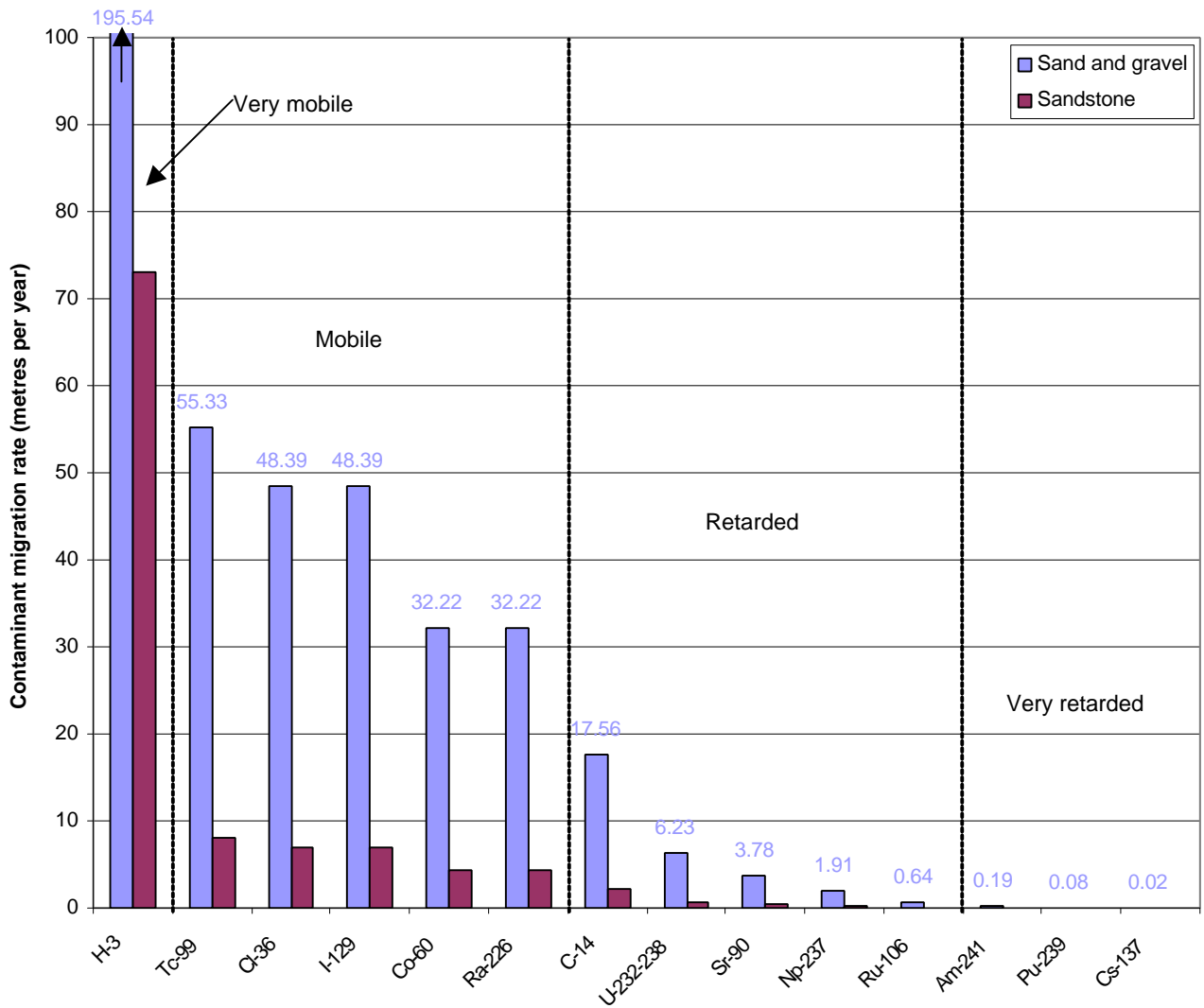


Figure 7: Contaminant migration rate based on groundwater flow rate in drift (sand and gravel) and bedrock (sandstone)

Appendix A: Selecting boreholes for the integrated monitoring programme

In combining the boreholes selected for the perimeter and contaminated land monitoring programmes, a review was carried out to ensure that:

- the integrated programme could meet all of its stated objectives;
- any newly-drilled SCLS boreholes could be included;
- boreholes with a long history of monitoring data could be added;
- boreholes were still accessible.

Consequently, in defining the borehole network suitable for the integrated monitoring programme, some boreholes have been removed and some added, as outlined below.

Table A1: Additions to borehole programme of Vickery *et al.* (2005 a & b)

Category	Pathway	Borehole	Historic Name	REASON - Historic data as detailed plus
A1 Proximal	9	6942p1		New borehole, close to 733 / BHP33
A1 Proximal	9	6942p2		New borehole, close to 733 / BHP33
Non-Separation		2429	BHP9a	
Non-Separation	1	4025p1	BHP139	Curr. CEAR perim. b E+02, Sr-90 E+02, H-3 E+06, Tc-99 E+02, I-129 E+02
Non-Separation	1	6911p1		New borehole, Ehen Spit
Non-Separation	1	6911p2		New borehole, Ehen Spit
Non-Separation	1	6912p1		New borehole, Ehen Spit
Non-Separation	1	6912p2		New borehole, Ehen Spit
Non-Separation	1	6913p1		New borehole, Off site, adjacent to 6973
Non-Separation	1	6913p2		New borehole, Off site, adjacent to 6974
Non-Separation	2	801p1	BHP101	Current CEAR perimeter H-3 E+05, Tc-99 E+03 E+04
Non-Separation	3	1239p1	BHP34	Current CEAR perimeter a E+02, b E+03, Sr-90 E+03, Tc-99 E+02
Non-Separation	3	2028Pp1	BHP35	Current CEAR perimeter b E+02, Sr-90 E+02
Non-Separation	3	2564p1	BHP36A	Current CEAR perimeter b E+02 - E+03, Sr-90 E+02
Non-Separation	3	2744Pp1	BHP137	Current CEAR perimeter b E+02, Sr-90 E+02 (?)
Non-Separation	3	4683p1	BHP49A	Current CEAR perimeter
Non-Separation	3	4684p1	BHP50A	Current CEAR perimeter b E+02, Sr-90 E+02 (?)
Non-Separation	3	4688p1	BHP113A	Current CEAR perimeter b E+02, Sr-90 E+02 (?)
Non-Separation	4	6975p1		New borehole, Ehen Spit
Non-Separation	4	6975p2		New borehole, Ehen Spit H-3 E+05
Non-Separation	4	6986p1		New borehole, Refurbished BHP 103 / 803p1 Current CEAR perimeter
Non-Separation	4	6986p2		New borehole, Refurbished BHP 103 / 803p1 Current CEAR perimeter
Non-Separation	9	733p1	BHP33	Current CEAR perimeter b E+02 - E+03, Sr-90 E+02 - E+03, Tc-99 E+03
Non-Separation	10	5688p1	BHP159P1	Off site, Sellafield Tarn
Non-Separation	10	5688p2	BHP159P2	Off site, Sellafield Tarn
Non-Separation	10	5688p3	BHP159P3	Off site, Sellafield Tarn
Separation	0	6985p1		New borehole, B38 compound
Separation	0	6985p2		New borehole, B38 compound
Separation	0	714p1	BHP14	a E+02, b E+05, Sr-90 E+05 (No recent data)
Separation	0	720p1	BHP20	b E+06, Sr-90 E+05, Cs-137 E+02 -E+04, H-3 E+06 (No recent data)
Separation	1	1901p1	BHP119	b E+03, Sr-90 E+02 - E+03, H-3 E+06 (No recent data)
Separation	1	2463p1	BHP121	b E+04, Sr-90 E+04, Cs-137 E+03, H-3 E+06 (No recent data)
Separation	1	4081p1	BHP144P1	b E+03, Sr-90 E+03, H-3 E+05
Separation	1	4081p2	BHP144P2	b E+02 - E+03, Sr-90 E+02 - E+03
Separation	1	4540p1	BHP154P1	b E+02 - E+04
Separation	1	4540p2	BHP154P2	b E+02 - E+03, Sr-90 E+02 - E+03
Separation	1	4691p1	BHP141	b E+04, Sr-90 E+03 - E+04, H-3 E+06 (No recent data)
Separation	1	4691p2	BHP141P1	Included because of p1
Separation	1	BHP142	BHP142	a LOD - E+03, b E+04, Sr-90 E+04
Separation	1	BHP142p1	BHP142p1	b E+04 - E+05, Sr-90 E+04
Separation	1	BHP149p1	BHP149p1	b E+03, Sr-90 E+02, Cs-137 E+02
Separation	1	BHP149p2	BHP149p2	a E+03, b E+05, Sr-90 E+05, Cs-137 E+03

Table A2: Deletions from borehole programme of Vickery *et al.* (2005 a & b)

Category	Borehole	Historic Name	REASON
A1 Proximal	4363p2	BHP148P2	Borehole blocked.
A1 Proximal	4363p3	BHP148P3	2.5cm tube. Only suitable for dipping
A1 Proximal	713p1	BHP13	Inaccessible. No data since 1995
A6 Sentinel	6944		Borehole not completed.
B2	704	BHP4	Under condemned building
Non-Separation	2744Pp1	BHP137	Duplicate entry.
Non-Separation	4688p1	BHP113A	Duplicate entry.
Separation	714p1	BHP14	Borehole is dry. No data since 1994
Separation	717p1	BHP17	Borehole destroyed.

Note: Information in Tables A1 and A2 supplied by British Nuclear Group (Jim Desmond [British Nuclear Group], *pers comm.*).

Appendix B: Initial groundwater monitoring programme proposed by British Nuclear Group

Category	Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
A1 Proximal	A1	0	2410p1	BHP118	Q	Q	M		Q	Q		A	b	A	Q	b	Q
A1 Proximal	A1	0	2410p2	BHP118P1	Q	Q	M		Q	Q		A	b	A	Q	b	Q
A1 Proximal	A1	0	719p1	BHP19	Q	Q	M		A	Q							Q
A1 Proximal	A1	0	743p1	BHP43	Q	Q	M		A	Q		Q	Q	Q	Q	Q	Q
A1 Proximal	A1	0	767p1	BHP67P1	Q	Q	M		A	Q							Q
A1 Proximal	A1	0	767p2	BHP67P2	Q	Q	M		A	Q							Q
A1 Proximal	A1	0	767p3	BHP67P3	Q	Q	M		A	Q							Q
A1 Proximal	A1	0	770p2	BHP70P1	Q	Q	M	A	b	Q	Q	b					Q
A1 Proximal	A1	0	770p3	BHP70	Q	Q	M	A	b	Q	Q	b					Q
A1 Proximal	A1	1	4041p1	BHP120	Q	Q	M	A	b	A	Q	b					Q
A1 Proximal	A1	1	4041p2	BHP120P1	Q	Q	M	A	b	A	Q	b					Q
A1 Proximal	A1	1	4041p3	BHP120P2	Q	Q	M	A	b	A	Q	b					Q
A1 Proximal	A1	1	4082p1	BHP145P1	Q	Q	M		A	Q							Q
A1 Proximal	A1	1	4082p2	BHP145P2	Q	Q	M		A	Q							Q
A1 Proximal	A1	1	4363p1	BHP148P1	Q	Q	M	A	b	A	Q	b					Q
A1 Proximal	A1	1	4539p1	BHP153P1	Q	Q	M		A	Q							Q
A1 Proximal	A1	1	4539p2	BHP153P2	Q	Q	M		b	Q							Q
A1 Proximal	A1	1	4539p3	BHP153P3	Q	Q	M		b	Q							Q
A1 Proximal	A1	1	6902p1		Q	Q	M		A	Q							Q
A1 Proximal	A1	1	6902p2		Q	Q	M		A	Q							Q
A1 Proximal	A1	1	6910p1		Q	Q	M		A	Q							Q
A1 Proximal	A1	1	6910p2		Q	Q	M			Q							Q
A1 Proximal	A1	1	744p1	BHP44	Q	Q	M		A	Q							Q
A1 Proximal	A1	2	3005p1	BHP15	Q	Q	M		Q	Q							Q
A1 Proximal	A1	2	3005p2	BHP15P1	Q	Q	M		Q	Q							Q
A1 Proximal	A1	2	4542p1	BHP156P1	Q	Q	M		A	Q							Q
A1 Proximal	A1	2	4542p2	BHP156P2	Q	Q	M		A	Q							Q
A1 Proximal	A1	2	6903p1		Q	Q	M	A	b	A	Q	b					Q
A1 Proximal	A1	2	6903p2		Q	Q	M	A	b	A	Q	b					Q
A1 Proximal	A1	2	755p1	BHP55	Q	Q	M	A	b	A	Q	b					Q

Category		Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
A1 Proximal	A1	3	6923p1		Q	Q	M	A	b		Q	b						Q
A1 Proximal	A1	3	6923p2		Q	Q	M	A	b		Q	b						Q
A1 Proximal	A1	4	6908p1		Q	Q	M	A	b	A	Q	b						Q
A1 Proximal	A1	4	6908p2		Q	Q	M	A	b		Q	b						Q
A1 Proximal	A1	4	708p1	BHP8	Q	Q	M			A	Q							Q
A1 Proximal	A1	5	6979p1		Q	Q	M	A	b	A	Q	b						Q
A1 Proximal	A1	5	6979p2		Q	Q	M	A	b	A	Q	b						Q
A1 Proximal	A1	6	782Ap1	BHP82	Q	Q	M	A	b	A	Q	b						Q
A1 Proximal	A1	8	6925p1		Q	Q	M				Q							Q
A1 Proximal	A1	8	6980p1		Q	Q	M	A	b		Q	b						Q
A1 Proximal	A1	8	6981p1		Q	Q	M			A	Q							Q
A1 Proximal	A1	8	6981p2		Q	Q	M			A	Q							Q
A1 Proximal	A1	9	6942p1		Q	Q	M			Q	Q							Q
A1 Proximal	A1	9	6942p2		Q	Q	M			Q	Q							Q
A1 Proximal	A1	9	6984p1		Q	Q	M			Q	Q							Q
A1 Proximal	A1	9	6984p2		Q	Q	M			Q	Q							Q
A1 Proximal	A1	9	781p1	BHP81P1	Q	Q	M	A	b		Q	b						Q
A1 Proximal	A1	9	781p2	BHP81	Q	Q	M	A	b	A	Q	b						Q
A1 Proximal	A1	9	781p3	BHP81P2	Q	Q	M	A	b		Q	b						Q
A2 Plume	A2	1	4382p1	BHP146P1	Q	Q	Q			A	Q							Q
A2 Plume	A2	1	4382p2	BHP146P2	Q	Q	Q			A	Q							Q
A2 Plume	A2	1	4382p3	BHP146P3	Q	Q	Q			A	Q							Q
A2 Plume	A2	1	6226p1		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6226p2		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6227p1		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6227p2		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6228p1		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6228p2		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6229p1		Q	Q	Q				Q	b						Q
A2 Plume	A2	1	6914p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	1	6914p2		Q	Q	Q			A	Q							Q
A2 Plume	A2	1	6915p1		Q	Q	Q			b	Q	b						Q
A2 Plume	A2	1	6915p2		Q	Q	Q				Q	b						Q

Category		Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
A2 Plume	A2	2	6904p1		Q	Q	Q				Q							Q
A2 Plume	A2	2	6905p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	2	6905p2		Q	Q	Q			A	Q							Q
A2 Plume	A2	2	6917p1		Q	Q	Q				Q							Q
A2 Plume	A2	2	6917p2		Q	Q	Q				Q							Q
A2 Plume	A2	2	6918p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	2	6919p1		Q	Q	Q				Q							Q
A2 Plume	A2	2	6920p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	2	6920p2		Q	Q	Q				Q							Q
A2 Plume	A2	2	6926p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	2	6926p2		Q	Q	Q			A	Q							Q
A2 Plume	A2	3	2744p1	BHP137	Q	Q	Q				Q							Q
A2 Plume	A2	3	4991p1	BHP130	Q	Q	Q			A	Q							Q
A2 Plume	A2	3	4996p1	BHP151P1	Q	Q	Q				Q							Q
A2 Plume	A2	3	4996p2	BHP151P2	Q	Q	Q				Q							Q
A2 Plume	A2	3	6921p1		Q	Q	Q				Q							Q
A2 Plume	A2	3	6927p1		Q	Q	Q				Q							Q
A2 Plume	A2	3	6928p1		Q	Q	Q				Q							Q
A2 Plume	A2	3	6929p1		Q	Q	Q				Q							Q
A2 Plume	A2	3	6929p2		Q	Q	Q				Q							Q
A2 Plume	A2	3	6948p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	4	6909p1		Q	Q	Q			A	Q							Q
A2 Plume	A2	4	6909p2		Q	Q	Q				Q							Q
A2 Plume	A2	10	6907p1		Q	Q	Q	A	b		Q	b						Q
A2 Plume	A2	10	6936p1		Q	Q	Q				Q							Q
A2 Plume	A2	10	6936p2		Q	Q	Q				Q							Q
A2 Plume	A2	10	739p1	BHP39	Q	Q	Q			A	Q							Q
A3 Near field	A3	3	6951p1		b	b	b			A	b							b
A3 Near field	A3	3	6952p1		b	b	b				b							b
A3 Near field	A3	3	6953p1		b	b	b				b							b
A3 Near field	A3	3	6954p1		b	b	b			A	b							b
A3 Near field	A3	6	6938p1		b	b	b			A	b							b
A3 Near field	A3	6	6940p1		b	b	b				b							b

Category	Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
A3 Near field	A3	9	6941p1		b	b	b			b							b
A3 Near field	A3	10	6935p1		b	b	b		A	b							b
A3 Near field	A3	10	6935p2		b	b	b		A	b							b
A4 Far field	A4	3	4688p1	BHP113A	A	A	A		A	A							A
A4 Far field	A4	11	6947p1		A	A	A			A							A
A4 Far field	A4	11	6949p1		A	A	A			A							A
A5 Up flow	A5	3	6957p1		b	b	b	A	A	A	b	A					b
A5 Up flow	A5	3	6957p2		b	b	b	A	A	A	b	A					b
A5 Up flow	A5	3	6967p1		b	b	b				b						b
A5 Up flow	A5	6	6964p1		b	b	b	A	A	A	b	A					b
A5 Up flow	A5	7	6945p1		b	b	b	A	A	A	b	A					b
A5 Up flow	A5	10	6959p1		b	b	b				b						b
A5 Up flow	A5	10	6961p1		b	b	b				b						b
A5 Up flow	A5	10	6962p1		b	b	b	A	A	A	b	A					b
A5 Up flow	A5	11	6965p1		b	b	b	A	A	A	b	A					b
A5 Up flow	A5	11	6966p1		b	b	b				b						b
A6 Sentinel	A6	1	6973p1		A	A	A				A	A					A
A6 Sentinel	A6	1	6973p2		A	A	A				A	A					A
A6 Sentinel	A6	1	6974p1		A	A	A				A						A
A6 Sentinel	A6	1	6974p2		A	A	A		A	A							A
A6 Sentinel	A6	2	6978p1		A	A	A		A	A							A
A6 Sentinel	A6	3	6977p1		A	A	A				A						A
A6 Sentinel	A6	3	6977p2		A	A	A				A						A
A6 Sentinel	A6	4	6969p1		A	A	A				A						A
A6 Sentinel	A6	4	6969p2		A	A	A				A						A
A6 Sentinel	A6	4	6972p1		A	A	A				A						A
A6 Sentinel	A6	4	6972p2		A	A	A				A						A
Non-Separation		1	4025p1	BHP139	Q	Q	Q		A	Q							Q
Non-Separation		1	6113p1		Q	Q	Q		Q	Q	Q						Q
Non-Separation		1	6113p2		Q	Q	Q		A	Q	Q						Q
Non-Separation		1	6118p1		Q	Q	Q		A	Q	Q						Q
Non-Separation		1	6118p2		Q	Q	Q		A	Q	Q						Q
Non-Separation		1	6911p1				Q			Q							

Category	Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
Non-Separation	1	6911p2				Q				Q							
Non-Separation	1	6912p1				Q				Q							
Non-Separation	1	6912p2				Q				Q							
Non-Separation	1	6913p1		A	A	Q				A	A						A
Non-Separation	1	6913p2		A	A	Q				A	A						A
Non-Separation	1	6986p1		Q	Q	M			A	Q	b						Q
Non-Separation	1	6986p2		Q	Q	M			A	Q	b						Q
Non-Separation	2	4023Bp1	BHP138	b	b	Q			A								b
Non-Separation	2	4538Pp1	BHP152p1	b	b	Q			A								b
Non-Separation	2	4538Pp2	BHP152p2	b	b	Q			A								b
Non-Separation	2	4538Pp3	BHP152p3	b	b	Q			A								b
Non-Separation	2	711p1	BHP11	b	b	Q			A								b
Non-Separation	2	740p1	BHP40	b	b	Q			A								b
Non-Separation	2	801p1	BHP101	Q	Q	Q				Q							
Non-Separation	3	1239p1	BHP34	b	b	Q			A								
Non-Separation	3	1241p1	BHP108	b	b	Q			A								
Non-Separation	3	2028Pp1	BHP35	b	b	Q			A								
Non-Separation	3	2564p1	BHP36A	b	b	Q			A								
Non-Separation	3	2796p1	BHP98P1	b	b	Q											
Non-Separation	3	2796p2	BHP98P2	b	b	Q											
Non-Separation	3	4027Bp1	BHP140	b	b	Q			A								b
Non-Separation	3	4683p1	BHP49A	b	b	Q			A								
Non-Separation	3	4684p1	BHP50A	b	b	Q			A								
Non-Separation	3	4994p1	BHP133P1	b	b	Q			A								b
Non-Separation	3	4994p2	BHP133P2	b	b	Q			A								b
Non-Separation	3	793p1	BHP93P1	b	b	Q			A								b
Non-Separation	3	793p2	BHP93P2	b	b	Q			A								b
Non-Separation	3	793p3	BHP93P3	b	b	Q			A								b
Non-Separation	4	6975p1				Q				Q							
Non-Separation	4	6975p2				Q				Q							
Non-Separation	6	5080p1	BHP162P1	b	b	Q			A								b
Non-Separation	6	748p1	BHP48	b	b	Q			A								b
Non-Separation	8	1248Pp1	BHP115	b	b	Q			A								

Category	Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
Non-Separation	9	733p1	BHP33	b	b	Q			A								
Non-Separation	10	5688p1	BHP159P1			Q											
Non-Separation	10	5688p2	BHP159P2			Q											
Non-Separation	10	5688p3	BHP159P3			Q											
Non-Separation	10	738p1	BHP38	Q	Q	Q			A	Q							
Separation	0	4681p1	BHP12A	Q	Q	Q			b						b	A	A
Separation	0	4682p1	BHP30A	Q	Q	Q			A								Q
Separation	0	6985p1		Q	Q	M			Q	Q							Q
Separation	0	6985p2		Q	Q	M			Q	Q							Q
Separation	0	720p1	BHP20	Q	Q	Q			Q								Q
Separation	0	769p1	BHP69P1	Q	Q	Q			Q						Q	b	Q
Separation	0	769p2	BHP69	Q	Q	Q			Q								Q
Separation	0	771p2	BHP71	Q	Q	Q			A								A
Separation	0	783p1	BHP83P1	Q	Q	Q											Q
Separation	0	783p2	BHP83P2	Q	Q	Q			b								A
Separation	0	783p3	BHP83P3	Q	Q	Q											A
Separation	0	784p1	BHP84	Q	Q	Q			b			Q	Q	Q	Q	Q	A
Separation	0	790p1	BHP90	Q	Q	Q			A								A
Separation	0	790p2	BHP90P1	Q	Q	Q			b								A
Separation	0	790p3	BHP90P2	Q	Q	Q			b						Q	b	A
Separation	1	1901p1	BHP119	Q	Q	Q			A								A
Separation	1	2463p1	BHP121	Q	Q	Q			b								Q
Separation	1	4081p1	BHP144P1	Q	Q	Q			A								A
Separation	1	4081p2	BHP144P1	Q	Q	Q			A								A
Separation	1	4540p1	BHP154P1	Q	Q	Q			A								Q
Separation	1	4540p2	BHP154P2	Q	Q	Q			A								Q
Separation	1	4541Pp1	BHP155P1	Q	Q	Q			A								A
Separation	1	4541Pp2	BHP155P2	Q	Q	Q			A								A
Separation	1	4691p1	BHP141	Q	Q	Q			b								Q
Separation	1	4691p2	BHP141P1	Q	Q	Q			b								Q
Separation	1	754p1	BHP54	Q	Q	Q			Q						Q	b	Q
Separation	1	785p1	BHP85P1	Q	Q	Q			b						Q	b	A
Separation	1	785p2	BHP85P2	Q	Q	Q			b						Q	b	A

Category	Path	Borehole	Historic	Alpha	Beta	H-3	C-14	Cl-36	Sr-90	Tc-99	I-129	Ra-226	Np-237	Total U	Pu-239	Am-241	g-Scan
Separation	1	785p3	BHP85P3	Q	Q	Q			b						b	A	A
Separation	1	785p4	BHP85P4	Q	Q	Q			b						Q	b	A
Separation	1	787p1	BHP87	Q	Q	Q			Q								A
Separation	1	BHP142	BHP142	Q	Q	Q			b						Q	b	A
Separation	1	BHP142p1	BHP142p1	Q	Q	Q			b								A
Separation	1	BHP149p1	BHP149p1	Q	Q	Q			A						b	A	Q
Separation	1	BHP149p2	BHP149p2	Q	Q	Q			Q			b	Q	b	Q	Q	Q
Separation	2	2794p1	BHP126	Q	Q	Q			Q			A	b	A	Q	b	Q
Separation	2	3006p1	BHP16	Q	Q	Q			Q			b	Q	b	Q	Q	Q
Separation	2	794Ap1	BHP94	Q	Q	Q			A								Q
Separation	2	794Ap2	BHP94p1	Q	Q	Q			A								Q
Separation	2	804p1	BHP104P1	Q	Q	Q			A								A
Separation	2	804p2	BHP104P2	Q	Q	Q			A								A
Separation	2	804p3	BHP104P3	Q	Q	Q			A								A
Separation	3	5767p1	BHP127	Q	Q	Q			A								A
Separation	4	4690p1	BHP128	Q	Q	Q			A								A

Note: Information supplied by British Nuclear Group (Jim Desmond [British Nuclear Group], *pers comm.*) and has not been checked by WSC.