Polar Record 39 (211): 339–346 (2003). Printed in the United Kingdom. DOI: 10.1017/S0032247403002997 339

Conducting environmental analyses at remote sites in cold climates

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Received July 2002

ABSTRACT. Clean-up sites in cold climates present unique challenges for the analytical chemist, primarily because of transportation constraints and limited infrastructure. Excavation of chemically contaminated soils and dumps requires a quick turnaround for analytical results. This is mainly due to the cost factors involved in having expensive heavy equipment idle and the short working seasons, but also because of melting of exposed permafrost during excavation. Three options are available for conducting analyses at remote polar sites. These are off-site determinations, the use of on-site test kits (or simple procedures), and the deployment of a mobile laboratory. This paper discusses these options and provides details of available on-site techniques as well as specific examples of their application in remote northern sites. The design and operation of a mobile laboratory at Resolution Island, Nunavut, is described, and available test kits are compiled and reviewed.

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Introduction

Chemical analyses are frequently performed to support environmental assessments and remediation projects. The six basic steps in the clean-up of a site are:

Phase 1: collection of site information;
Phase 2: reconnaissance testing program;
Phase 3: detailed testing program;
Phase 4: engineering design;
Phase 5: clean up;
Phase 6: confirmation testing and report.

In the first site visit, phase 2, samples are taken from potentially polluted areas, which are most likely to contain contaminated soil or water, and from drainage pathways in order to determine the nature of any chemical contamination that may exist. Other samples such as materials possibly containing asbestos, and paint chips are also collected. Samples are normally sent to a convenient accredited laboratory for wide spectrum analyses.

In phase 3, a more intensive sampling program is required in areas where contamination has been found in phase 2. Contaminated areas are gridded and sampled in order to determine the volumes and extent of the contamination problem; depth samples are also obtained at this point. Again, samples are generally sent to a convenient accredited laboratory for determination of analytes found to be present in phase 2 of the project. After the protocols to deal with the contamination problems have been worked out in phase 4, remediation activities are conducted in phase 5. The analytical requirements related to soil excavation are generally to test after excavation in order to determine whether clean-up criteria have been met. Because heavy equipment is usually involved, phase 6, confirmation testing, needs to be conducted quickly so as not to delay on-site activities. It is mostly for phases 5 and 6 that the efficacy of an on-site laboratory has to be weighed against the use of an off-site laboratory.

At remote polar sites, there are three options available for conducting analysis. These are off-site determinations, the use of on-site test kits or equivalent simple procedures, and the deployment of a mobile laboratory. This paper outlines the key issues that must be considered when deciding which option is appropriate. Specific examples of off-site analyses are then given for polychlorinated biphenyls (PCBs) and metals, which are the most common contaminants at abandoned military bases in the Arctic. Other contaminants are addressed by surveying available test kits and discussing their usefulness at polar sites.

Off-site versus on-site

The decision to use on-site analytical techniques and equipment as opposed to sending samples to the laboratory is a difficult one. The reasons that on-site analytical techniques and equipment are not often used are:

- Standard laboratory techniques need to be used to meet regulatory requirements.
- The methods employed in the analysis use complex equipment and often require trained laboratory personnel not available for an on-site team.

https://doi.org/10.1017/S0032247403002997 Published online by Cambridge University Press

- Maintaining complex equipment and carrying out repairs at remote sites can be difficult and expensive, and can cause major delays.
- Test kits or portable equipment cannot meet the required detection limits or are simply not available for the required parameters.
- No suitable buildings or appropriate infrastructure are available at the site to set up a laboratory area.
- It is not economically viable to set up a laboratory given the size of the clean-up project.
- Bad experiences with on-site analysis in the past influence the decision.

In cold climates other factors also need to be taken into account. The following factors often exist at remote Arctic and Antarctic sites and may make the use of test kits or an on-site mobile laboratory more attractive. These are discussed below.

- Transportation to an off-site laboratory may take several days and be unreliable.
- Weather delays may slow remediation work and increase time constraints, making quick turnaround of samples for analysis more critical.
- The short working season makes time more important.
- Polar bears in the Arctic pose a danger and can affect work schedules.
- Economic considerations may make on-site testing more attractive.
- Permafrost can affect remediation activities.

Logistics are nearly always a major challenge when working in remote polar regions. Poor weather conditions such as fog, wind, and snow, in combination with cold temperatures, can severely disrupt transport operations. These conditions can slow down or even preclude work being conducted on particular days, putting more pressure on the analyst to obtain results quickly. At many sites there are frequently periods of several days during which no transportation can occur (Analytical Services Unit 1997, 1999). This translates to even longer times before an off-site laboratory receives the samples. The time constraints of the short field season, usually 2–3 months, exacerbate the problems caused by sample transport delays to an off-site laboratory. Alternatively, an on-site laboratory can process the samples in 24 hours.

Other factors that can slow down the work in the Arctic include polar bears, which are a safety problem when collecting samples. Frequently, a bear monitor is required to accompany scientists in the field. Soil excavation can be complicated by permafrost, which melts when the contaminated active layer is removed. This can result in very wet muddy conditions making work impossible. An additional concern in remote sites is that on-site buildings generally lack controlled heating and electrical power production is frequently by small generator. This can affect the operation and smooth running of analytical equipment.

It is sometimes desirable to attempt to carry out phase 2 and phase 3 together in one visit. This is because transport costs are very high and opportunities to visit sites are limited by the short season, poor weather, and restricted transportation options. The strategy is often to take as many samples as possible, analyze a small portion as per phase 2 and hope that one has sufficient samples to complete phase 3. The use of on-site test kits can greatly assist this strategy.

Economic considerations are always important when deciding on an analytical strategy. If the clean-up project is large and will take a number of seasons, the deployment of a mobile laboratory may be more economical than transportation of samples and resultant time delays. Generally all the factors mentioned above need to be taken into consideration when formulating an operational plan. The plan must also contain contingencies to deal with unexpected circumstances, which frequently arise when working in polar regions. The major costs in any remediation project are often incurred in mobilization and demobilization. The decision to use test kits, a mobile laboratory or off-site laboratory will be driven by economics, the type and amounts of contaminants present at the site, and the on-site conditions.

Off-site analysis

Many countries that are part of the polar regions or that have research stations in polar regions have analytical methodologies associated with their home country; alternatively, the methods of the US Environmental Protection Agency are frequently employed. The analytical methods to be used may be stipulated by environmental guidelines or by the environmental assessment approval process. If a suite of analyses is required to meet a legislated requirement and not all the analyses can be conducted on-site, then all the analyses are generally best conducted off-site. Results of analyses obtained off-site should never be less accurate or precise than results obtained from determinations conducted on-site. Accredited laboratories are often required for environmental remediation work and, as a result, only off-site laboratories can generally be used.

On-site test kits and procedures

There are many test kits or portable instruments available for the determination of various parameters in water and a lesser number for soil and petroleum products (United States Federal Remediation Technologies Roundtable 2001; Lopez-Avila and Hill 1997). Some of these, such as pH and conductivity meters, have been around for a long time and these parameters are often better recorded directly in the field. In subsequent sections, metals, with emphasis on the X-ray fluorescence (XRF) technique, and organic pollutants, with emphasis on PCBs are discussed. Table 1 lists some analyses that may be required, along with details regarding detection limits, the normal laboratory method, and potential field methods and their limitations.

https://doi.org/10.1017/S0032247403002997 Published online by Cambridge University Press

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Table 1. Summary table of field and laboratory analytical methods. Detection limits are those of the typical standard laboratory. General references to the analyses can be found at www.hach.com; www.chemetics.com; www.wilksir.com; www.dexsil.com; www.diagnostix.ca; www.envirologix.com; www.hannainst.com; www.sdix.com; www.coring.de; and at the following USEPA and related sites: www.epa.gov/superfund/programs/dfa/fldmeth.htm; www.epa.gov/region09/qa/mt-appendixa.pdf; www.frtr.gov/site/; and http://fate.clu-in.org/technologies.htm.

Analyte (matrix)	Detection limit	Laboratory standard method	Comments on field methods
General parameters			
pH, turbidity conductivity, colour, temperature	Various	Various specific meters	Standard laboratory method instruments and probes relatively portable and robust.
Total dissolved solids – TDS (water)	1 mg l^{-1}	Filter/dry/weigh	Field TDS meters commercially available. TDS estimated from conductivity measurements.
Total suspended solids – TSS (water)	1 mg l^{-1}	Filter/weigh	Turbidity meters can provide immediate estimate of the TSS concentration. Nonlinear response at higher TSS concentrations.
Biological oxygen demand – BOD (water)	3 mg l^{-1}	Dissolved oxygen meter	Portable benchtop dissolved oxygen meters readily available. Laboratory method adaptable to field conditions but requires laboratory apparatus and an incubator.
Chemical oxygen demand – COD (water)	3 mg l^{-1}	Digestion/colorimetry	The USEPA approved method uses mercuric sulphate to eliminate chloride interferences; more readily disposable kit also available when chloride interference not a concern. Require digester blocks as well as the standard colorimeter and therefore not very suitable for field application.
Alkalinity (water)	–	Titration	Laboratory standard method could be used.
Total organic carbon – TOC (water)	2.0 mg l^{-1}	Oxidation/CO_2 detection	Colorimetric test kits.
Inorganic parameters			
Inorganic elements (soil)	1–100 ug g^{-1}	Acid digestion/ICP	XRF as per discussion in text.
Inorganic elements (water)	ug l^{-1} levels	ICP or acid digestion/ICP	Colorimetric test kits available for individual metals. However, for environmental samples, interferences often present and the required detection limits cannot always be achieved.
Chromium (VI) (soil and water)	2.0 ug g^{-1} and 0.1 mg l^{-1}	Extraction/colorimetry and colorimetry	Field colorimetric methods exist for measurement of Cr (VI) in water and waste water. Laboratory methods similar but with a scanning spectrometer can identify and correct for interferences.
Phosphorus, ammonia (water)	0.01 mg l^{-1}	Autoanalyzer	Colorimetric test kits.
Anions (water)	0.1–0.05 mg l^{-1}	Ion chromatography	Colorimetric test kits.
Fluoride (water)	0.1 mg l^{-1}	Ion specific electrode	Colorimetric test kits: laboratory standard method could be used.
Cyanide (water)	0.1 mg l^{-1}	Autoanalyzer or ion specific electrode	Colorimetric or titrimetric test kits.
Organic parameters			
Acid/base/neutral priority Pollutants – ABNs (soil and water)	ug g^{-1} and ug l^{-1} levels	Solvent extraction/GC/MS	No general field method for ABNs, but some components can be analysed for individual compounds or groups of compounds by immunoassay test kit.

https://doi.org/10.1017/S0032247403002997 Published online by Cambridge University Press

Table 1. Continued

Analyte (matrix)	Detection limit	Laboratory standard method	Comments on field methods
Benzene, toluene, ethyl benzene, xylenes – BTEX (soil and water)	100 ng g^{-1} and 2 ug l^{-1}	Purge and trap/GC/MS	Immunoassay test kits can be used to give the total BTEX concentration, but will not give concentrations for individual components; these test kits are optimized on one specific compound. Typically, detection limits of 1–5 ppm in soil and down to 10–500 ppb in water are possible. More recently, portable ultraviolet fluorescence meters proposed for determining total BTEX concentrations. Portable GC/FID units also available. These are less portable than test kits, expensive, and require a significant level of operator training.
Ethylene glycol (water)	5 mg l^{-1}	GC/FID	Fourier transform infrared spectroscopy (FTIR) can detect ethylene glycol in water in the field at low percent level. Instruments not portable, but transportable. Portable colorimetric test kits can be used to detect low levels of glycols in potable water samples, but are susceptible to interferences.
Oil & grease (soil and water)	0.01% and 1.0 mg l^{-1}	Extraction/ gravimetry	Field test kits are available that utilize infrared spectroscopy for the measurement in water and soil. The gravimetric method is normally used in the laboratory and has replaced the infrared method due to the variable response of the C-H stretch to different organic compounds.
Polyaromatic hydrocarbons – PAHs (soil and water)	0.05 ug g^{-1} and 1.0 ug l^{-1}	Solvent extraction/GC/MS	Immunoassay test kits are typically used for field analysis of PAHs. Results reflect total PAH concentration with varying responses for individual PAHs. Some test kits measure a range of concentrations from 1–25 ppm in soil. Test kits for determining PAHs in water recently available for field use with detection limits of about 1 ppb.
PCBs (soil and water)	0.5 ug g^{-1} and 3.0 ug l^{-1}	Solvent extraction/GC/ECD	Immunoassay test kits; see discussion in text.
PCBs (oil)	2.0 ug g^{-1}	Clean-up/GC/ECD	Clor-n-oil test kit (50 ppm level).
Pesticides (soil and water)	ng g^{-1} and ug l^{-1} levels	Solvent extraction/GC/ MS or ECD	Immunoassay test kits for chlorinated pesticides available for field use. These are normally specific for only one particular pesticide, such as atrazine or DDT; sub-ppb detection limits often achievable. Test kits designed for specific pesticides or herbicides may, however, also respond to compounds in the same family, such as triazines or carbamates, and to metabolites of the parent pesticide. Test kits available for soil and water.
Total petroleum hydrocarbon – TPH (soil and water)	40 g^{-1} and 1 mg l^{-1}	Solvent extraction/GC/FID	Soil test kits available that use technology based on a Friedel-Crafts chemical reaction. Detection limits vary and the test is not specific. Immunoassay test kits can be used for the analysis of TPH in both water and soil. Detection limits vary depending on the composition of the hydrocarbon contaminant, but the normal detection range is 0.1–1 ppm for water.
Volatile organic compounds – VOCs (soil)	20–100 ng g^{-1}	Purge & trap/GC/MS	Organic vapour analyzers with PID detectors or industrial hygiene monitors such as combustible gas indicator monitors (CGI) can be used to determine VOC concentrations in air or VOCs emanating from water or soil. These instruments are for screening only and are normally used to determine conditions that are hazardous to personnel, especially during confined space entry. Portable GC instruments can be used but generally for screening purposes.



Fig. 1. The mobile laboratory at Resolution Island, Nunavut, Canada.

On-site mobile laboratory

A mobile laboratory, rather than a makeshift area in which to conduct analysis using test kits or simple procedures, is needed when the analytical method requires such facilities as a fume hood or controlled environment, or services such as water supply and gases. A mobile laboratory is also a cleaner and more convenient place to work than, for instance, a garage or warehouse. In making the choice to establish a mobile laboratory at a site, one must weigh the potential problems related to equipment breakdown, repair, or maintenance against convenience and analysis turnaround times as well as economic considerations. Generally a mobile laboratory will contain complex electronic equipment that may require a supplier's technician to repair in the case of breakdown.

A mobile laboratory (44 × 10 ft (13.4 × 3.0 m)) was designed and constructed for use at the Resolution Island remediation clean-up site in Nunavut, Canada, and has been in operation for two years (Analytical Services Unit 2001, 2002). The laboratory, as shown in Figure 1, was constructed with three separate areas. The utilities area contains cold-water storage, water pump, hot-water tank, and electrical panel. Gases required to operate the gas chromatograph are normally supplied by cylinders of helium, nitrogen, hydrogen, and air. In the mobile laboratory, these cylinders have been replaced by a separate hydrogen generator and air and nitrogen systems that are jointly connected to an air compressor. Hydrogen is used in place of the helium. Electrical power has been provided by the camp generator but could be supplied by a separate unit. The electrical generator should be separate from the laboratory and at least 50 m away in order to reduce the noise. The middle section of the laboratory contains benches, a sink, and an emergency shower, and is used for activities relating to sampling. Sampling supplies and containers for soil, water, air, and oils are stored in the area, as well as equipment for the measurement of air quality, radioactivity, dust, etc.

The final section of the laboratory is primarily devoted to the equipment needed for the analysis of PCBs in soil. The gas chromatograph with electron capture detection (GC/ECD) is also equipped with a flame ionization detector (FID) for the identification of organic compounds such as petroleum products. The analysis of soils by GC/ECD also requires a flask shaker unit, drying oven, rotary evaporator, and sets of glassware. The rotary evaporator uses cold water supplied and recirculated by a refrigerator unit, and vacuum is provided by a Buchi 502 controller unit. This section also houses a large fume hood, as the analysis requires the use of organic solvents such as dichloromethane, hexane, and acetone. The rate of extraction of air through the fume hood requires adjustment through a variable electrical switch to alter the flow of air into the laboratory.

Only the hydrogen generator is taken from the Arctic at the end of the season. All other equipment is left in the trailer. Before closing for the nine months of winter, water lines are drained and all equipment is appropriately shut down and covered with a layer of polythene. Metal shutters are placed over the windows to prevent damage by polar bears. The rationale for this is that more damage may result from transport of the equipment to and from the site than by leaving it in an unheated environment for nine months. On arrival on site, the laboratory is heated for at least one day with all the polythene removed to make sure that any moisture is removed from electronic components in the equipment before they are turned on.

Metal analysis

General

There are four methods for determining metals in complex environmental samples. These are atomic absorption analysis (AAS), X-ray fluorescence spectroscopy (XRF),

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Table 2. Method detection limits (ppm) for the Spectrace 9000 XRF instrument and Canadian Arctic guidelines.

Element	Detection limit count time A	Detection limit count time B	DEW Line clean-up criteria (Environmental Sciences Group 1991)
Arsenic	88	37	30
Cadmium	234	322	5
Chromium	512	231	250
Cobalt	807	615	50
Copper	113	41	100
Lead	29	48	500
Nickel	359	182	100
Zinc	55	41	500

inductively coupled plasma optical emission spectroscopy (ICP), and neutron activation analysis (NAA). Various electrochemical methods can be used for specific elements, because others, such as colorimetric test kits, lack sensitivity and specificity. Mercury is generally determined separately from other metals using a dedicated mercury analyzer.

NAA is unsuitable for fieldwork since the neutron flux required to obtain the required detection limits is generally only obtainable from a nuclear reactor. ICP equipment is fragile and complex and therefore unsuitable for fieldwork. AAS employs robust equipment and could be established in an on-site laboratory equipped with compressed gases, a ventilation system to remove hot gases away from the burner head, and a fume hood for the acid digestion. Most XRF spectrometers are not suitable for on-site work because they are either too large and complex or they require good matrix matching of standards and samples. Environmental samples often do not have the same matrix — for example, soil can range from high organic content to sand.

X-ray fluorescence spectroscopy (XRF)

XRF instruments that contain algorithms to correct for matrix interference have now been available for more than 10 years. Spectrace 9000 portable instruments have been used in the Canadian Arctic by the Analytical Services Unit for almost 10 years to determine copper, lead, and zinc contamination levels in soil. There are now at least two other companies from which this type of instrument is available (Niton Corporation and Philips Analytical).

A Spectrace 9000 field-portable X-ray fluorescence analyzer was used for the inorganic element analysis described in this paper (Potts and others 1995). This XRF is equipped with a high-resolution solid-state (mercuric iodide) detector and fundamental-parameters-quantitative-analysis software. Fundamental-parameters quantitative analysis involves measuring major elements present and compensating for the effects of the interferences by computer calculations. This allows for a good estimate of inorganic element concentrations for all soil matrix types without the use of several standard samples having the same general concentrations and matrix. The XRF employs three radioactive sources for X-ray generation. The sources and acquisition times used for analysis were: count time A: Fe-66, 100 seconds; Cd-109, 300 seconds; and Am-241, 50 seconds, and count time B: Fe-66, 200 seconds; Cd-109, 1000 seconds; and Am-241, 50 seconds.

The operation of the instrument was monitored periodically with pure element and Teflon standards during analyses as well as commercially available reference materials. Results were obtained for arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and zinc. In Canada, the remediation guidelines (Canadian Council of Ministers of the Environment 1989, 1999; Environmental Sciences Group 1991) for these eight elements in soil for Arctic work dictate the sensitivity required. Table 2 lists the method detection limit and the Canadian remediation guidelines. Detection limits were generated by repeat (8) analysis of a soil sample spiked with levels of the eight elements at approximately 10 times their detection limits. Detection limits (95% probability) were calculated using the standard laboratory practice of multiplying the standard deviation by 2 and then by the appropriate t-statistic.

The method works well for copper, lead, and zinc, but the detection limits are too high with respect to the guidelines for the other five elements. For copper, lead, and zinc, which represent most of the metal contamination found in the environmental assessments of former military bases in the Canadian Arctic, results were obtained by both AAS and XRF for a large number of samples.

Actual field soil samples were prepared for XRF by air-drying. Large pebbles and stones were removed and the remaining soil ground with a pestle and mortar. The fraction less than 1 mm in size was then used. The AAS method involved digestion in aqua regia overnight. Because the aqua regia may not dissolve all of the metals completely, one might expect the AAS results to be lower than the XRF determinations. From the environmental point of view, if a fraction of each of the metals does not dissolve in aqua regia then that fraction is generally considered not to be environmentally important.

Zinc and lead results obtained by XRF correlated well with those obtained by AAS ($r = 0.96$; $n = 89$) and ($r =$

https://doi.org/10.1017/S0032247403002997 Published online by Cambridge University Press

0.95; n = 90), respectively. Using count time A, the detection limit of the method for both these elements is well below their environmental criteria, so results of analysis of a single sample can be obtained in less than 10 minutes. For copper, the correlation between XRF and AAS results are good (r = 0.87; n = 39); however, to obtain the required detection limit, count time B is required. Copper analyses therefore take approximately 25 minutes per sample.

Once samples have been dried overnight, 24 samples can be analyzed for copper or 60 samples for lead and zinc in a 10-hour working day on site. The sample throughput is similar to AAS, but the AAS method requires overnight digestion of the dried samples, increasing turnaround time by 24 hours.

Organic priority pollutants by test kits

General

Several immunoassay test kits are now available for the analysis of organic contaminants such as petroleum hydrocarbons, BTEX, PAHs, pesticides, and PCBs. Various test kits have been evaluated (United States Environmental Protection Agency 1996). Field test-kit analysis for PCBs has been used extensively in Arctic remediation. The application and evaluation of PCB immunoassay test kits under site conditions are discussed below.

Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a common contaminant in the soil at former military bases in the Arctic (Analytical Services Unit 1995, 1996; Environmental Sciences Group 1991; Poland and others 2001). Electrical equipment and paint additives are two common sources of PCBs at these bases. The standard laboratory method for analysis of PCBs in soil is solvent extraction followed by gas chromatography, with electron capture detection. Soxhlet, shaker flasks, and accelerated solvent extraction are used to extract PCBs from soil. In all cases an internal standard is used; the efficiency of extraction may vary depending on soil type and extraction technique. Clean-up using commercially available Florisil columns or equivalent is followed by gas chromatography (GC) and electron capture (ECD) or mass spectrometric (MS) detection. Results are reported as Aroclors, which are the commercial mixtures manufactured by Monsanto, or as congeners, which are the individual isomers.

Immunoassay PCB test kits became commercially available in the early 1990s, and tests kits using colorimetric and electrometric end points were available prior to that. In electrometric test kits (Finch and others 1990), the PCBs are extracted from the soil using a solvent and the extract is reacted with sodium. A chloride specific electrode is then used to measure the amount of chloride produced. Both colorimetric and electrometric test kits are not specific and will give positive results for any chlorinated organic compounds present in the soil. At military bases in the Canadian Arctic, other organic contaminants, including chlorinated solvents, are found in the soil and, thus, the specificity of the immunoassay test kits was required (Analytical Services Unit and Environmental Sciences Group 1993).

Analysis of oil samples for PCBs was also required in the Canadian Arctic. Test kits that use a colorimetric end point are available for PCBs in oil (Clor-N-Oil). A sodium reagent is used and the chloride ions are reacted with mercury and diphenylcarbazone to form a purple colour. These test kits were used during excavation of a dump, which contained many barrels of waste oil and various mixtures of petroleum products and solvents (Analytical Services Unit 1999). Some of these barrels contained low levels of PCBs and needed to be processed separately to those containing only petroleum products. The kits were very useful as an immediate screening tool, which could be used during the excavation; several false positive results were obtained. At the Resolution Island on-site laboratory, gas chromatography analysis was performed on the barrel contents, which tested positive to the test kits. This combination of on-site laboratory and test kits allowed the excavation of the dump to proceed with minimal delays due to analysis.

Immunoassay test kits use specific antibodies that will bind to the antigen or target contaminant. The steps involved in the immunoassay are normally extraction into a suitable solvent, addition of conjugate and the extract to the tubes lined with antibodies, rinsing of the tubes, addition of a substrate that will react with the conjugate antibody complex to produce colour, and addition of a stop solution to produce a colour the intensity of which is read on a spectrophotometer.

The immunoassay was generally carried out according to the manufacturer's instructions with a few minor modifications. Samples were well mixed and a sub-sample was laid out to air-dry overnight. A 5 g portion was weighed and extracted with methanol. The soil–methanol mixture was filtered and an aliquot (5–25 μl) of the extract used for subsequent analysis as described above. The appropriate Aroclor standards were purchased and diluted to prepare calibration standards. The extraction efficiency of the test-kit method is lower than the standard laboratory method and has no correction for incomplete extraction by the use of an internal standard. Results obtained by the test kits are therefore treated conservatively when comparing them to environmental criteria.

The test kits were initially assessed using soils from eight different sites across the Arctic, with a wide variety of soil types (Analytical Services Unit and Environmental Sciences Group 1993). The initial 83 test-kit results correlated satisfactorily with the GC/ECD results (r = 0.80, n = 60). The results were compared to the DEW Line clean-up criterion (Environmental Sciences Group 1991), which defines different levels in Arctic soils and depending on the concentration of the contaminant lead to various remediation protocols. The initial priority of the clean-up was the soils containing PCBs at concentrations above 5 ppm, and the test kits were used successfully to delineate according to this criterion. The initial

https://doi.org/10.1017/S0032247403002997 Published online by Cambridge University Press

assessment included one very organic soil that did not yield reliable results by test kit. Subsequent assessment of the test kits at individual sites has confirmed that soils with high organic content may yield false positives using immunoassay test kits. Analysis of wood samples was also not possible by test kit.

Application of any test kit to a particular site requires an evaluation of the performance of the test-kit performance using soil samples from characteristic areas of the site. At least 10% of samples should be checked by the standard GC/ECD method. At the S1/S4 beach area of Resolution Island, Nunavut, the organic content of the soil is higher and soils are contaminated with petroleum products. Soil samples were analyzed for total petroleum hydrocarbons, and results ranged from 60 to 28,000 ppm. The poor correlation ($r = 0.15$, $n = 12$) for samples with TPH values greater than 100 ppm clearly indicated that the test kits could not be used in this area (Analytical Services Unit 1995). At the S1/S4 valley the correlation coefficient is 0.80 and test kits were used successfully. Delineation of areas with soils greater than 2000 ppm PCBs was also required. Excavated soils with >50 ppm PCBs were screened to 2 inches to reduce volume, but soils that contained >2000 ppm PCBs were not screened. The immunoassay test kits were adapted to delineate at this high concentration by extraction of less soil (0.5 g) and dilution of the methanol extract. GC/ECD analysis of a subset of the samples confirmed that the test kits could successfully be used to analyze samples in this high-concentration range.

Test-kit analysis of PCBs is much quicker than GC/ECD analysis. Once dried, analysis of 10 samples could be completed by one technician in two hours as compared to 24 hours, which would be required to report results from approximately 10 samples using one GC/ECD and one technician for eight hours.

Conclusions

The decision as to whether an off-site laboratory, test kits, or on-site laboratory should be used to perform chemical analysis can dramatically affect the success and economics of a remediation project in the polar regions. Test kits and portable equipment, as demonstrated with the examples of XRF for copper, lead, and zinc and immunoassay test kits for PCBs, can be exceedingly useful for many clean-ups. However for Resolution Island, Nunavut, the use of an on-site laboratory with the capacity to analyze PCBs in soil by GC/ECD was found to be the optimal solution. Clean-up work in the polar regions presents unique challenges. The appropriate option for chemical analysis will depend on the accessibility and conditions at the site, and the nature and scale of the contaminants present.

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https://doi.org/10.1017/S0032247403002997 Published online by Cambridge University Press