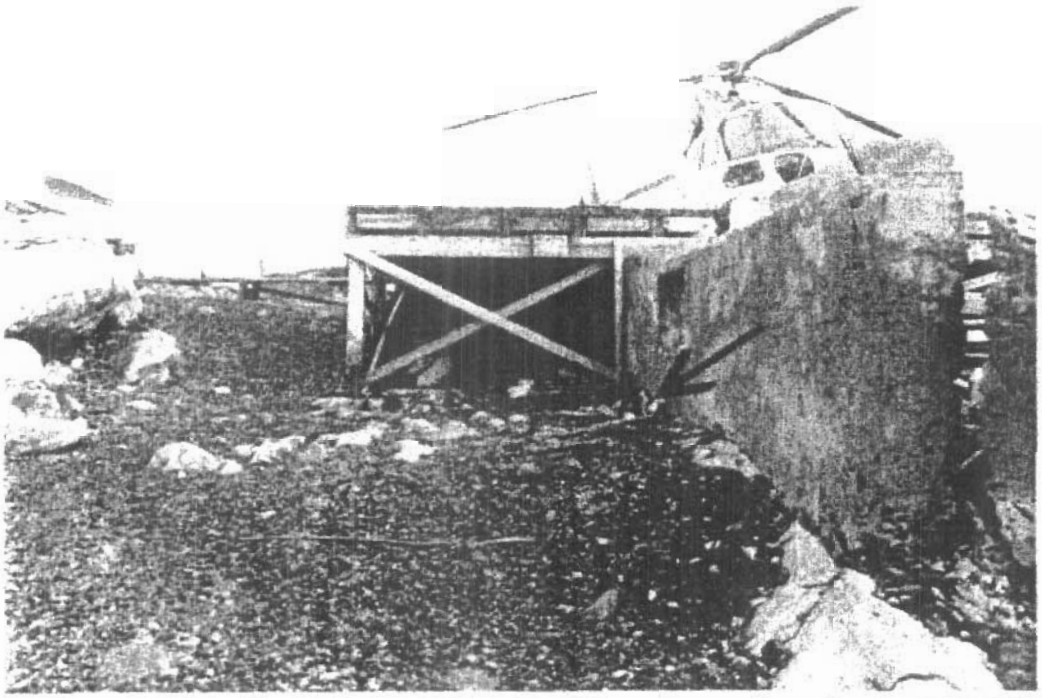
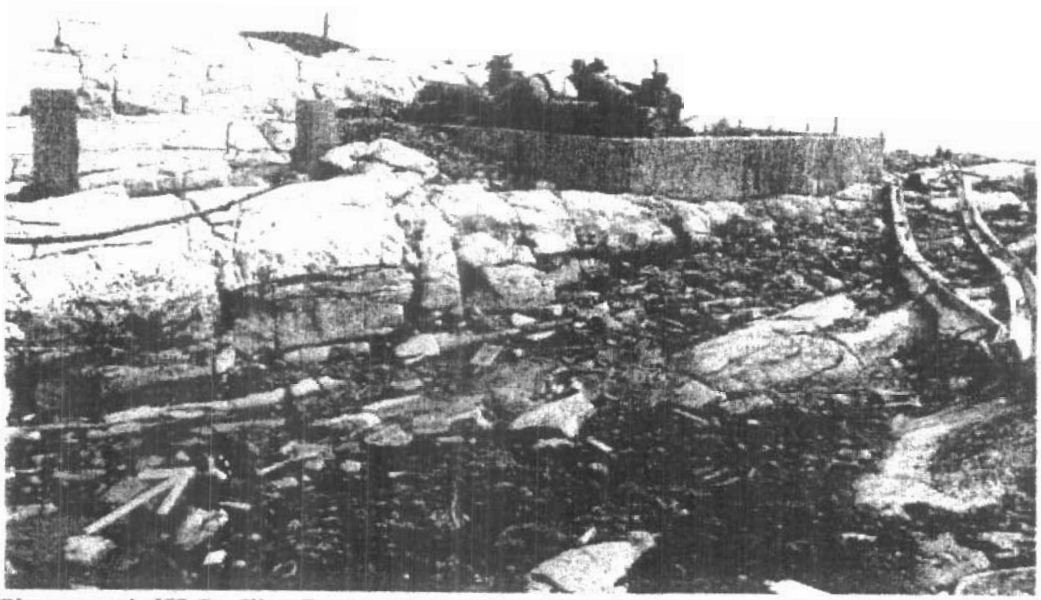
Photograph III-3: The Main House and Concrete Supports as seen from the north. Sampling locations 8411 and 8412 are indicated in the foreground.



Photograph III-4: The Helipad as seen from the northeast. Sampling location 8441 is indicated by the arrow. The Main House can be seen to the east.

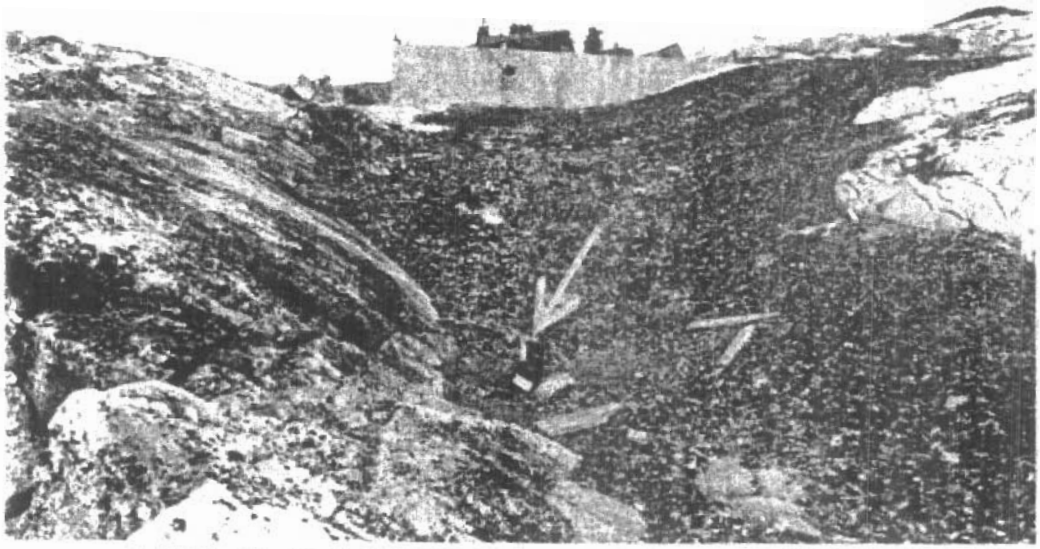
Photograph III-5: The Helipad as seen from the north. Sampling location 8442 is indicated by the arrow. The Winch Shed can be seen to the east.

Photograph III-6: A Small Dump Area located to the northeast of the Main House. Sampling location 8417 is indicated by the arrow.



Photograph III-7: The Generator Building Foundation as seen from the northwest. Sampling location 8460 is indicated in the foreground.

Photograph III-8: The Generator Building Foundation as seen from the southeast. Sampling location 8453 is indicated in the foreground.



Photograph III-9: The Generator Building Foundation as seen from the southeast. Sampling location 8463 is indicated in the foreground.

Photograph III-10: The remains of a structure at the Beach Area. Sampling locations 8427 and 8428 are indicated by the arrows.

IV. RECOMMENDATIONS

A. General

Chemical contamination at Radio Island is extensive and is limited mainly to the inorganic elements copper, lead and zinc. Copper contamination is most likely due to the use of copper pipes, and zinc contamination the result of oxidation from the large amount of metal debris found at the site. The lead contamination can be attributed to the combination of three factors: fuel spills and the use of leaded gasoline; high lead concentrations in paint; and the numerous old and decaying batteries found at the site.

The DEW Line Cleanup Protocol has been used to develop the recommendations presented below. Details of the protocol are presented in Chapter II, Annex C. The main points of the protocol are:

- non-hazardous debris should be placed in an engineered landfill along with any soil that contains inorganic elements in excess of DCC Tier I.

- soil containing contaminants in excess of DCC Tier II should be removed from contact with the ecosystem.

In total it is estimated that there are 310 m^3 of soil to be treated as Tier II. It is also estimated that there is an additional 20 m^3 of soil to be treated as hazardous or special waste.

The terrain at Radio Island is mostly bedrock with a very small amount of soil. Moss covers most of the drainage pathways. There are no gravel sources on the island. It is therefore recommended that all nonhazardous debris be shipped to Resolution Island (BAF-5), or elsewhere, for placement in an engineered landfill.

B. Main Site

The contaminants of concern in this area were inorganic elements, specifically copper, nickel, cobalt, cadmium, lead, zinc and arsenic. Thirty soil sampling locations contained some or all of these elements at concentrations in excess of the DCC. The samples collected in the drainage courses from the main site did contain high concentrations of these elements, indicating that the contamination is migrating. However, sampling locations near the ocean did not contain high levels of these elements,

indicating that the contamination is not yet reaching the ocean. One soil sampling point at the main site contained leachable lead in excess of both the Ontario and the British Columbia Leachate Criteria for lead.

Cleanup requirements for the main site therefore involve the excavation of soil around the buildings, foundation and drainage courses, and the cleanup of debris, hazardous and nonhazardous. The estimated volume of DCC II soil is 230 m^3. The estimated volume of leachate toxic soil is 10 m^3.

C. Generator Building Foundation

The contaminants of concern in this area were inorganic elements, specifically copper, nickel, cadmium, lead, and zinc. Ten soil sampling locations contained these elements at concentrations in excess of the DCC. The samples collected in the drainage to the north of the foundation did not contain high concentrations of these elements, indicating that the contamination is not migrating to the north of the foundation and ultimately the ocean. However, samples collected in the drainage to the south of the foundation did contain high concentrations of these elements, indicating that the contamination is migrating to the south and interior of the island. Two soil sampling locations contained leachable lead in excess of both the Ontario and the British Columbia Leachate Criteria for lead.

Cleanup requirements for the generator building foundation therefore involve the excavation of soil from around the foundation, and the cleanup of debris, hazardous and nonhazardous. The estimated volume of DCC II soil is 70 m^3. The estimated volume of leachate toxic soil is 10 m^3.

D. Beach Area

The contaminants of concern in this area were inorganic elements, specifically cadmium, lead and zinc. Two soil sampling locations contained these elements at concentrations exceeding the DCC. In both cases nearby samples from drainage courses were compared, and did not contain high concentrations of these elements, indicating that the contamination is relatively localized and is not migrating. Therefore, cleanup

requirements for the beach area involve the excavation of soil from the two locations, and the cleanup of debris, hazardous and nonhazardous. The estimated volume of DCC II soil is 10 m^3.

Table IV-1: Summary of Cleanup Actions for Radio Island

Area	Non-Hazardous Materials	Hazardous or Potentially Hazardous Materials	DCC Tier II Contaminated Soil
Main Site	-remains of buildings -empty barrels (70) -metal debris -coal	-Leachate Toxic Soil ($10m^3$) -batteries -panel containing asbestos	-Main House and Winch Shed ($80 m^3$) -Helipad ($150 m^3$)
Generator Building Foundation	-empty barrels (30) -metal debris -coal	-Leachate Toxic Soil ($10m^3$) -batteries	-Foundation ($70 m^3$)
Beach Area	-empty barrels (35) -metal debris -coal	-batteries	-8427 and 8428 ($10 m^3$)

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VI. APPENDICES

Appendix A: Methods

Appendix B: Quality Assurance/ Quality Control

Appendix C: Site Descriptions

Appendix D: Data Tables

APPENDIX A: METHODS

A. Sampling

1. Approach

When there are localized areas of contamination at a large site such as Radio Island, the geostatistical, or random field approach to collecting samples, which involves sampling at the randomly chosen coordinates of a gridded area, may not be the most effective technique since it generates a very large number of samples. An alternative technique, the deterministic random approach, concentrates on areas likely to be contaminated: samples are collected near the contamination sources and in drainage pathways leading away from them. At Radio Island this latter approach was used to obtain samples from the site as a whole.

This approach was designed to obtain samples that would:

- be representative of the status of the site - samples were obtained from all areas of the site;
- determine the nature and distribution of the main chemical contaminants - samples were collected from both stained and unstained soils; and
- indicate any contaminant migration within the ecosystem - soil samples from drainage courses and plant samples (to indicate uptake into the food chain) were collected.

The number of samples collected from each area was dependent on the topography and the extent of dump and spill activity. Background samples were obtained from locations remote from the sites and free of any local inputs.

The sampling approach was also guided by results obtained in previous investigations at military sites (ESG, 1991, 1992, 1993a and 1993b, 1994); the analytical data indicated a common waste disposal pattern at these sites.

2. General Soil and Water

On arrival at the site, the team members familiarized themselves with the area and selected sampling locations. Two types of soil samples were collected at most locations. The one designated for inorganic analyses was obtained using a plastic scoop and stored in a Whirl Pak™ bag. The other, for organic analyses, was collected using a stainless steel scoop (which had been pre-washed, baked and stored in baked aluminum foil to preclude organic contamination) and placed in a 1 litre amber jar fitted with a Teflon-lined lid. These jars were obtained commercially (I-CHEM Ltd.) and were certified free of organic materials. Soil samples were generally restricted to the upper 10 cm of the substrate and care was taken to obtain representative material.

Soil samples were kept at ambient temperatures. The samples were shipped by guaranteed air freight to labs in Victoria, British Columbia where the samples were frozen pending analysis for organic compounds, and in Kingston, Ontario at Queen's University, where the samples were kept cold while awaiting analysis for inorganic elements.

Water samples were collected in 1 litre Teflon bottles for PCB analysis, and in polyethylene bottles for inorganic element analysis. Upon receipt in the laboratory, they were stored at 4°C until analysis.

Each sample collection was witnessed by at least two team members and in all cases a photographic record was made. The sample location and description were independently recorded by at least two team members.

3. Plant Samples

i. Collection of Vegetation

Plants were collected from the same locations as soil samples wherever sufficient material could be obtained. These plants, which included shrubs, grasses and sedges, provided a representative cross-section of the vegetation potentially grazed by herbivores. The plants were collected within a one metre square area surrounding the soil sample location and included leaves, stems and root tissue (where possible). A sufficient quantity was collected both for chemical analysis and for later identification and/or verification. All plant samples were placed in air-tight Ziploc bags and stored until they could be processed.

ii. Processing and Identification of Plants

Samples were rinsed in tap water from Iqaluit NWT and patted dry with analytical grade paper towels before packaging. One representative sample of each plant species collected at a site was subdivided into root and shoot sub-samples (where possible). All processed samples were divided into two homogeneous sub-samples for inorganic and organic analysis. Samples designated for inorganic element analysis were placed in plastic Ziploc bags which were sealed with tape. Samples for organic analysis were wrapped in aluminum foil and placed in Ziploc bags. After processing, all samples were frozen for later chemical analysis.

Samples for identification/verification were pressed (preserved) on-site for future reference. Following preliminary field identification, rigorous identification of species was conducted in Kingston and follows the taxonomy of Scoggan (1978).

4. Potentially Asbestos-Containing Materials

One sample of insulation material was collected from a chimney located at the main site and one sample of floor tile was collected from the main building (building #1). The samples were stored in polyethylene bags which were sealed, labeled and shipped to the laboratory for asbestos analysis.

5. Paint Samples

Paint samples were collected from any remaining buildings and surfaces. Samples were collected using a stainless steel scoop (which had been pre-washed, baked and stored in baked aluminum foil to preclude organic contamination) which acted as a paint scraper and was used to remove the paint from the structure. The samples were stored in polyethylene bags which were sealed, labeled and shipped to the laboratory for analysis.

6. Chain of Custody

A rigorous chain-of-custody was maintained for sample control. Chain of custody forms were filled out and checked for each sample before shipment from the North, and the contents of shipments were verified upon receipt in the laboratory. The relevant documentation is available on request.

7. Quality Assurance/Quality Control (QA/QC)

Field duplicate soil samples were collected with approximately every tenth sample. The soil sample was homogenized in the field and split into two containers which were labeled with consecutive numbers.

The analytical work was conducted by carefully selected analytical laboratories. QA/QC procedures were carried out by means of the standard techniques of blind replicates and spiked samples. A detailed discussion is given in Appendix B.

B. Analysis of Inorganic Elements

1. Method for Soil Samples

Samples were analyzed by the Analytical Services Unit of Queen's University. The concentrations of arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) were measured.

The analyses were carried out using the following procedure. Samples were air-dried and ground to a fine powder with a mortar and pestle; large stones were removed as they would not be expected to contain any anthropogenic environmental contaminants. Approximately 0.5 g of this dried material was heated with 2 mL HNO_3 and 6 mL HCl overnight so that the volume was reduced to 1-2 mL. This solution was then made up to 25 mL with distilled, deionized water and analyzed by atomic absorption spectrophotometry (AAS). While it is recognized that the digestion procedure used may not bring all metals into solution (some metals may be locked into silicate minerals), it was felt that the metals released into solution are of greater environmental significance than absolute total metals. Analyses were done in batches of ≤ 36, which comprised ≤ 28 samples, 2 blanks, 4 duplicates and 2 samples of reference material (NRC MESS-1).

2. Method for Plant and Tissue Samples

Plant or tissue samples were dried in an oven overnight at 70°C and ground in a mill to pass through a 1 mm sieve. Approximately 1.0 g of dried sample was then weighed into a 100 mL beaker; 20 mL of nitric acid was added, and the mixture was

heated for 1 hour. Perchloric acid (10 mL) was added and heating continued until the volume was reduced to about 1-2 mL. The digest was then made up to 25 mL and analyzed by AAS as for soils.

3. Method for Water Samples

A water sample (400 mL) was placed in a beaker on a hot plate together with 3 mL of nitric acid and slowly boiled to dryness. Twenty millilitres of 2% nitric acid was then added, the samples heated to boiling, cooled, and made up to 25 mL. The resulting solutions were then analyzed for the selected eight elements by AAS.

C. Analysis of Polychlorinated Biphenyls (PCBs) and Pesticides in Sediment/Soil and Plants

1. Summary

Analysis for PCBs and pesticides were conducted by Axys Analytical Services Ltd. of Sidney, BC Each sample was clearly labeled and locked in a secure frozen storage area until retrieved by the analyst.

All samples for PCB and/or pesticide analysis were spiked with an aliquot of surrogate standard (2,4,5,6-tetrachloro-m-xylene, PCB 209 and d_4-alpha endosulphan) prior to analysis by gas chromatography with electron capture detection (GC/ECD); for gas chromatography with mass spectrometry (GC/MS), the samples were spiked with aliquots of ^{13}C labeled surrogate standard (PCB 101, PCB 180, PCB 209, gamma-BHC, Mirex, p,p'-DDE, p,p'-DDT and d_4-alpha endosulphan). Sediments were extracted with a solvent on a shaker table. Tissues were ground with sodium sulphate, packed in a glass chromatographic column and eluted with solvent. Water was liquid/liquid extracted with dichloromethane. Sample extracts were separated into three fractions on a Florisil column. The first fraction was also analyzed for PCBs as Aroclors, PCB congeners and chlorinated pesticides by GC/ECD or GC/MS. The second and third fractions were analyzed for chlorinated pesticides by GC/ECD.

2. *Extraction Methods*

i. Soils/Sediments

The sediment sample was thoroughly homogenized and a subsample taken for the determination of wet weight/dry weight ratio.

Wet sediment (10 - 15 g), to which an aliquot of surrogate standard had been added, was extracted once with 80 mL of 1:1 dichloromethane/methanol by shaking on a shaker table for 30 minutes. The extraction procedure was repeated using 80 mL of dichloromethane. The extracts were combined, washed with solvent-extracted water, dried over anhydrous sodium sulphate and concentrated by Kuderna-Danish techniques. After the addition of activated copper to remove sulphur, the extract was separated on a Florisil column.

ii. Tissues

The wet tissue was homogenized and a subsample was dried for moisture determination.

Homogenized wet tissue (5 - 10 g), anhydrous sodium sulphate and an aliquot of surrogate standard were ground with a glass mortar and pestle to a free-flowing powder. This powder was transferred to a glass chromatographic column containing 1:1 dichloromethane/hexane and eluted with additional solvent at 3 - 5 mL/min. The eluent was concentrated and subsampled for gravimetric lipid analysis.

The remaining extract was placed on a calibrated Biobead SX-3 gel permeation column and eluted with 1:1 dichloromethane/hexane. The 150 - 300 mL fraction was collected, evaporated to a small volume, and fractionated on a Florisil column.

iii. Water

A 1 litre sample was placed in a separatory funnel and spiked with aliquots of surrogate standard solution and methanol. The sample was extracted with three 100 mL portions of dichloromethane. The combined portions were dried over anhydrous sodium sulphate, spiked with hexane, reduced by rotary evaporation, and fractionated on a Florisil column.

3. Sample Cleanup and Separation

i. Cleanup for GC/ECD

The extract was quantitatively transferred to a Florisil column and eluted with three solvent systems consisting of hexane (Fraction-1), 85:15 dichloromethane/hexane (Fraction-2) and 50:50 dichloromethane/hexane (Fraction-3).

An aliquot of surrogate standard was added to each Fraction-2 to allow quantification, since the surrogate standard added at the beginning of the procedure eluted into Fraction-1 and Fraction-3. Each fraction was concentrated, transferred to a microvial, and an aliquot of recovery standard (4,4'-dibromooctafluorobiphenyl and PCB 204 to Fraction-1 and Fraction-2 and ^{13}C-PCB 153 to Fraction-3) was added prior to analysis by GC/ECD.

Fraction-1 was analyzed by GC/ECD for PCBs as Aroclors, PCB congeners, and mildly polar chlorinated pesticides.

Fraction-2 was analyzed by GC/ECD for moderately polar chlorinated pesticides.

Fraction-3 was analyzed by GC/ECD for the most polar chlorinated pesticides.

ii. Cleanup for GC/MS

The extract was quantitatively transferred to a Florisil column. The column was eluted with hexane followed by 85:15 dichloromethane/hexane. The eluates were combined (Fraction-1). The column was eluted with 50:50 dichloromethane/hexane (Fraction-2).

Each fraction was concentrated, transferred to a microvial and spiked with an aliquot of recovery standard (^{13}C-PCB 153) prior to instrumental analysis.

Fraction-1 was analyzed by GC/MS for PCBs as Aroclors, PCB congeners, and non-polar and moderately polar chlorinated pesticides.

Fraction-2 was analyzed by GC/ECD for the most polar chlorinated pesticides.

4. *Instrumental Analysis*

i. GC/ECD Analysis

Each fraction was analyzed for pesticides by using an HP 5830A gas chromatograph equipped with a ^{63}Ni electron capture detector (GC/ECD), a 60 m DB-5 column (0.25 mm i.d. x 0.1 μm film thickness) and HP 3392 integrator. Fraction-1 was simultaneously analyzed for PCBs as Aroclors and PCB congeners. Chromatographic conditions were as follows - Initial temp: 100 °C; Injection: splitless, 1 min; Initial time: 2 min; Ramp: 10°C/min to 150°C, 3 °C/min to 300 °C; Final time: 5 min. Column conditions were: Carrier gas, helium; Pressure, 21 psi; Flow rate, 60 mL/min; and Split ratio, 15:1.

The instrument was calibrated daily using a solvent blank and standards of Aroclor 1242, Aroclor 1254 and Aroclor 1260. For each Aroclor, the sum of the areas of three characteristic peaks was used to calculate its response factor against the internal standard. The area of the same three peaks was used to determine the concentration of each Aroclor in the sample.

All values reported in the data tables in Appendix D are in ppb (ng/g) on a dry weight basis for soil samples and on a wet weight basis for plant samples. Procedural blank information is given in the QA/QC discussion, Appendix B.

PCBs were also quantified as individual congeners by calibrating the GC/ECD response with four well-characterized mixtures of 51 congeners (total) obtained from the National Research Council (NRC), Halifax, NS. Aroclor mixtures of known composition were used for some congeners not present in the NRC mixtures.

ii. Low Resolution GC/MS

Fraction-1 was analyzed for PCB congeners, Aroclors and non-polar and moderately polar chlorinated pesticides using a Finnigan INCOS 50 mass spectrometer equipped with a Varian 3400 GC, a CTC autosampler and a DG 10 data system running INCOS 50 (Rev 9) software. Chromatographic separation of pesticides was achieved with a 60 m DB-5 column (0.25 mm i.d. and 0.10 μm film thickness). The mass spectrometer was operated in the electron impact (EI) mode at unit mass resolution in the multiple ion detection (MID) mode acquiring two characteristic ions for each target analyte and surrogate standard.

iii. High Resolution GC/MS

For high resolution GC/MS analysis, a VG 70 SE mass spectrometer, equipped with a Hewlett Packard 5890 GC, a 60 m DB-5 chromatographic column (0.25 mm i.d. and 0.10 µm film thickness) and a CTC autosampler were used. Data was acquired in the MID mode to enhance sensitivity. Two characteristic ions for each target analyte and surrogate standard were monitored.

D. Analysis of Polycyclic Aromatic Hydrocarbons (PAHs)

1. Summary

Analyses were conducted by the Environmental Sciences Group Analytical Laboratory at Royal Military College in Kingston, Ontario. Each sample was in an appropriate container, clearly labeled and stored at low temperatures in a secured area before and after analysis.

Samples were spiked with a Surrogate standard (a mixture of the deuterated PAHs: naphthalene, phenanthrene, anthracene, and benzo(a)anthracene) prior to extraction and analysis by gas chromatography (GC) with mass selective detection (MS). Soil and sediment samples were extracted with dichloromethane using an ultra-sonic bath. Extracts were concentrated using the EPA recommended Kuderna-Danish method and the solvent was exchanged prior to cleanup through a laboratory prepared silica-gel column.

2. Extraction Method

Samples were thoroughly homogenized before analysis. Soil and sediment samples were subsampled for determination of the wet/dry weight ratio.

Accurately weighed wet soil (12 g), to which the surrogate standard (1 mL), sodium sulphate (40 g) and Ottawa sand (20 g) were added, were extracted by ultrasound using three separate portions of 75 mL of dichloromethane for 10 minutes each. The extract, including the solvent used for rinsing (totaling 250 mL) was collected in the Kuderna-Danish apparatus. The volume was then reduced to near 1 mL and exchanged

with 2 mL of cyclohexane. This was then applied to a laboratory-prepared activated silica-gel (Grade 923, 100-200 mesh) column for cleanup. The column was rinsed with hexanes (7 mL) and this portion of the eluant was discarded before collecting the dichloromethane fraction (25 mL). In some cases extracts were applied to an LC-Si - Supelco column containing silica gel for cleanup and diluted to 10 mL. In either case a GC vial (2 mL) was filled by measuring 960 µL of the sample solution and 40 µL of an internal standard and submitted for analysis by GC/MS.

3. Instrumental Analysis

Each sample was analyzed using an HP 5890 Series II Plus - GC equipped with an HP 5972 Mass selective detector, a PTE™ - 5 fused silica capillary column (30 m, 0.25 mm ID x 0.25 µm film thickness) and the HPChem station software. The chromatographic conditions were as follows: Sample volume 1 µL, splitless injection, initial temperature - 70°C for 5 min; ramp 12°C/min to 130 °C, 5°C/min to 260°C, final time 27 min. The carrier gas used was high purity helium with a column flow rate of 1 mL/min. The mass selective detector was used in the selective ion monitor mode for the following ions: Mass/Charge ratio (m/z) 128, 136, 152, 166, 172, 178, 188, 202, 228, 240, 252, 276, 278, representing each of the 16 PAHs, 4 surrogates and the internal standard used in the analysis.

For each set of samples analyzed, a six point calibration curve (0, 20, 50, 100, 250, and 500 ppb) was prepared for EACH of the 16 PAHs analyzed. Concentrations of PAHs in samples were determined by comparing sample responses with calibration curves. The surrogate and internal standards were used to account for the efficiency of extraction and analysis.

E. Analysis of Total Petroleum Hydrocarbons (TPH) in Soils

1. Summary

The above analyses were conducted by the Analytical Services Unit, Queen's University, Kingston, Ontario. Each sample was contained in an appropriate container,